

Visual extinction and cortical connectivity in human vision

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Abstract

Visual extinction is a common, poorly understood, consequence of unilateral cerebral damage, where a patient fails to detect one of two simultaneously presented stimuli (the one more contralateral to the lesion), despite the fact that each stimulus is correctly detected when presented in isolation. The phenomenon implies a failure of shifting attention from an attended object to an unattended one[7, 8, 16]. We show here that pair detection is improved in conditions where the two stimuli presented to the two halves of the visual field are proximal, co-oriented and co-axial. It is further shown that stimulus properties producing reduced extinction correlate with the selectivity pattern of spatial lateral interactions observed in the primary visual cortex[3, 6, 12, 13, 14, 9]. We suggest that neuronal activity in early stages of cortical visual processing encodes, using long-range lateral interactions, an image description in which visual objects are already segmented and marked. Segmentation seems to function properly even in the presence of significant destruction of the parietal cortex leading to extinction.

Five first-episode stroke patients with unilateral cerebral damage and contra-lateral extinction participated in the study. Patients¹ were tested with briefly (160 msec) presented stimuli (Figure 1) containing one or two targets,

¹All five patients had extensive middle-cerebral artery infarctions (D.H., B.G., E.A. and S.S. - on the right hemisphere; and U.L. - on the left), affecting parts of the frontal, temporal and parietal lobes in all patients, save S.S. with a lesion confined to the parietal lobe and external capsule. The occipital lobes and the geniculo-striate pathways were preserved in all patients save U.L. (in whom the lateral occipital gyri, but not the primary visual cortex, were also involved). Patients had normal visual fields except for the occurrence of extinction of the contralesional stimulus upon bilateral simultaneous stimulation (again, U.L. was exceptional in showing a right-upper-quadrant scotoma in perimetric examination, but no effect within the eccentricity range of testing in the present study). Soon after onset, all patients manifested contralesional neglect in activities of daily living and performed abnormally the standardized "Behavioral Inattention Test" for visual neglect.

each being a horizontal or vertical Gabor signal, to which they had to verbally respond with the perceived number of targets (0, 1 or 2). Extinction is demonstrated by the frequent failures to perceive two targets, despite successful detections of single targets at the same locations. In Figure 2 we present separately data from trials with iso-oriented targets and from trials with targets of different orientations. Detection scores are presented as a function of target eccentricity (during bilateral simultaneous stimulation, both targets were equidistant from the mid-sagittal plane so that inter-target separation was twice the eccentricity value). For patients D.H. and B.G. detection in the right hemifield was superior to that in the left hemifield, while for U.L. detection in the left hemifield was superior to that in the right hemifield, in consistence with the presence of contralateral visual neglect. Detection rates for two targets showed a significant advantage of the iso-oriented pairs at eccentricities up to 4° for D.H., 3° for B.G. and 2° for U.L., indicating orientation selective spatial interactions within an average range of 6 degrees of visual angle. Within this range, extinction was observed mostly with pairs of different orientations, while at larger separations extinction did not depend on orientation similarity. The measured range of interactions differs between patients but correlates with the amount of practice the patients had with our experiments: D.H. with 2591 trials reached 8° , B.G. with 1726 trials reached 6° , and U.L. with 601 trials reached 4° .

Next, we separated performance scores on trials with co-oriented coaxial targets (Figure 1a) from trials with co-oriented parallel targets (Figure 1b). Figure 3 shows gains in detection due to orientation similarity

for the horizontal and the vertical targets, separately (relative to the values expected from the observed individual target detection rates, i.e. discounting the neglect effects, assuming statistical independence). The data show a larger gain for horizontal targets within the eccentricity range where orientation similarity plays a significant role ($1^\circ - 4^\circ$), indicating advantage for collinear targets and thus implying a mechanism linking co-oriented and co-axial stimuli. This collinearity advantage is in particular impressive in the case of patient B.G. where his high score with horizontal pairs indicates a significant reduction of left spatial neglect with these stimulations ($P_c(H_l H_r) = 77\%$, $P_c(H_l) = 56\%$, $P_c(H_r) = 90\%$, as compared with $P_c(V_l V_r) = 66\%$, $P_c(V_l) = 66\%$, $P_c(V_r) = 97\%$). The two other patients show a smaller, but consistent, effect of collinearity (Figure 3; performance gains with pairs of different orientations, not shown, are reduced by $10 \pm 2\%$ relative to those of the vertical pairs). A similar range-limited advantage of collinearity was recently found for observers with normal vision when measuring their contrast detection thresholds[14]. Contrast detection for a foveal Gabor target improves in the presence of two peripheral co-oriented and co-axial high contrast Gabor signals[13], with the range of interaction increasing with practice[15]. In further experiments we tested three of the right-hemisphere damaged patients using diagonal Gabor signals, so that signals could be left or right tilted (Figure 1e-f). Here, pairs could also be of same or of orthogonal orientations but always tilted relative to the connecting axis, thus predicting no linkage by lateral interactions[3, 14]. This prediction is being confirmed by the data presented in Figure 4, where the three pa-

tients tested show no obvious advantage for diagonal co-oriented targets. All three patients show a significant advantage of target orientation similarity when tested (D.H. retested) with vertical/horizontal pairs (Figure 4). Extinction with the diagonal pairs, estimated as the difference between actual pair performance and expected pair performance (as in Figure 3), was found to depend on practice. Patients D.H. and E.A. showed only a small deviation from expected performance (-4% and -5% respectively), while S.S., not having much practice before being tested on the diagonals, showed a strong extinction (-23%).

Our experiments show that extinction is dependent on some simple stimulus properties, known to reflect connectivity constraints at early stages of visual processing[3, 6, 12, 13, 14, 9]. Thus two remote visual stimuli are processed as a single object when the corresponding neuronal activities are linked via long range lateral interactions. It seems that intact parietal lobes are not necessary for correct linkage of spatially separated parts of an object, though they may have a role in linking color with shape[5]. The interactions observed here, having a range of a few degrees of visual angle around the fovea ($4^\circ - 8^\circ$, depending on practice), seem to exclude an underlying mechanism consisting of direct connections within primary visual cortex. It is possible that interactions propagate through multiple connections[15], assuming inter-hemispheric connections are functionally equivalent to intra-hemispheric connections[18, 11], or are carried by direct long range connections within extra-striate visual areas.

The results support a theory of recognition according to which visual

objects compete for attention allocation. According to this theory, extinction reflects failure of shifting attention from the attended (winning) object to the unattended one (and does not necessarily reflect competition over spatial locations)[7, 4]. Previous studies have found effects of perceptual grouping on extinction, though these effects showed both increased[2] and decreased[17, 10] extinction depending on stimuli and task (e.g. recognition of individual targets may require individualization and thus may not benefit from grouping, though detection of simple features may[1]). While perceptual grouping is only subjectively defined, we show here that rules underlying cortical neuronal connectivity can predict complete elimination of extinction. This correspondence between reduction of extinction and visual cortex architecture suggests that the early stages of visual cortical processing function properly in patients with extensive parietal damage leading to extinction.

It seems that lateral interactions do not only provide the cortex with activity modulation, but also underlie perceptual grouping and binding, essential for elementary figure-ground segregation.

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Figure Captions

Figure 1: Stimuli were computer generated and displayed on computer driven high resolution (1280×1024) monitor. Pairs of Gabor signals (40% contrast, $\lambda = \sigma = 0.225^\circ$) were presented on half of the trials while on the other half only one of the signals was presented. Patients responded verbally with the number of detected targets (0,1,2) and when detected one indicated its location (left, right). Frames 1a-d were used in the first experiment, while frames 1e-f (and two other frames with Gabor signals rotated by 90° , not shown) were used in the second experiment. Note that the two targets in frames 1a, 1b and 1e share the same orientation. Previous results from observers having normal vision have shown a hierarchy of interactions with frame 1a producing strongest excitatory interactions and with frame 1e showing no interactions[14].

Figure 2: Target detection as a function of eccentricity for patients D.H. and B.G. (right-hemisphere damage) and U.L. (left-hemisphere damage). Performance scores (% correct detection) are shown for single targets, for the left side (\blacktriangleleft) and the right side (\blacktriangleright), and for double targets, separately for targets with the same orientations (\bullet) and targets with different orientations (\times) [performance rates were estimated using an average number of 77 trials per datum point]. Pairs of targets sharing the same orientation are better detected than pairs having different orientations, if eccentricity is not too large [χ^2 test, D.H: $p < 0.03$ at 2° , $p < 0.001$ at 3° and $p < 0.01$ at 4° , B.G: $p < 0.001$ at $1.4^\circ - 3^\circ$, U.L: $p < 0.001$ at $1^\circ - 2^\circ$]. At small eccentricities (e.g.

D.H. at 1°) our paradigm does not provide a sensitive measure of performance as detection rates are error free on most conditions. At larger eccentricities orientation similarity does not affect performance, though extinction exists.

Figure 3: Interaction strength of collinear pairs compared with that of parallel pairs. Histogram bars show pair detection similarity gain, relative to the values expected from individual detections (assuming statistical independence of the two single detection processes): $\Delta = 100(P_c(\Theta_l\Theta_r) - P_c(\Theta_l) \cdot P_c(\Theta_r))$ where P_c , $0 \leq P_c \leq 1$, is the probability of correct detection, Θ_{side} being either horizontal (H) or vertical (V) and *side* is left or right (i.e compare Fig 1a with 1b). Results show a larger performance gain due to similarity when both targets are horizontal as compared with vertical pairs, supporting co-oriented and co-axial range limited interactions. (Averaged across eccentricities B.G: $1^\circ - 3^\circ$, D.H: $2^\circ - 4^\circ$, U.L: $1^\circ - 2^\circ$, each P_c estimate is based on about 140 trials for B.G., 80 trials for D.H. and 75 trials for U.L., with $H_lH_r - V_lV_r$ (each pair relative to expected) being significant for B.G. ($p < 0.001$) and U.L. ($p < 0.05$), but not for D.H.)

Figure 4: Orientation similarity effects, $\Delta = 100(P_c(\Theta_l = \Theta_r) - P_c(\Theta_l \neq \Theta_r))$, target pairs of $\Theta_{side} = 0^\circ, 90^\circ$ (as in Figure 2) compared with target pairs of $\Theta_{side} = 45^\circ, 135^\circ$ (patients D.H. retested at $3^\circ - 4^\circ$, E.A. tested at 3° and S.S at 4° , with about 60 *same* and 60 *different* trials). The data for the diagonal targets do not show any significant effect due to orientation similarity (χ^2 test), while the horizontal/vertical targets do support significant similarity effects (χ^2 test: $p < 0.05$ for each patient, $p < 0.005$ with pooled data).

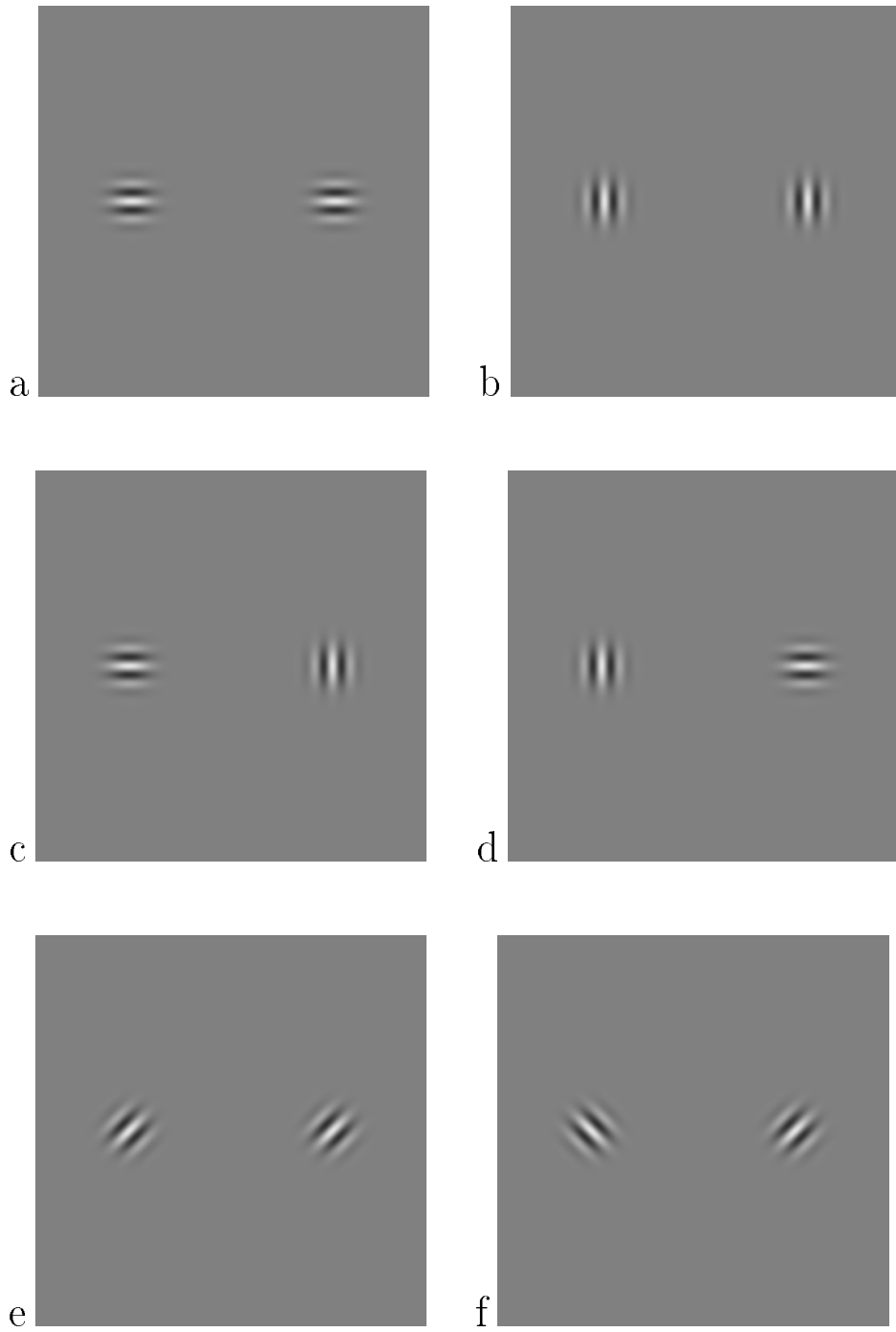


Figure 1:
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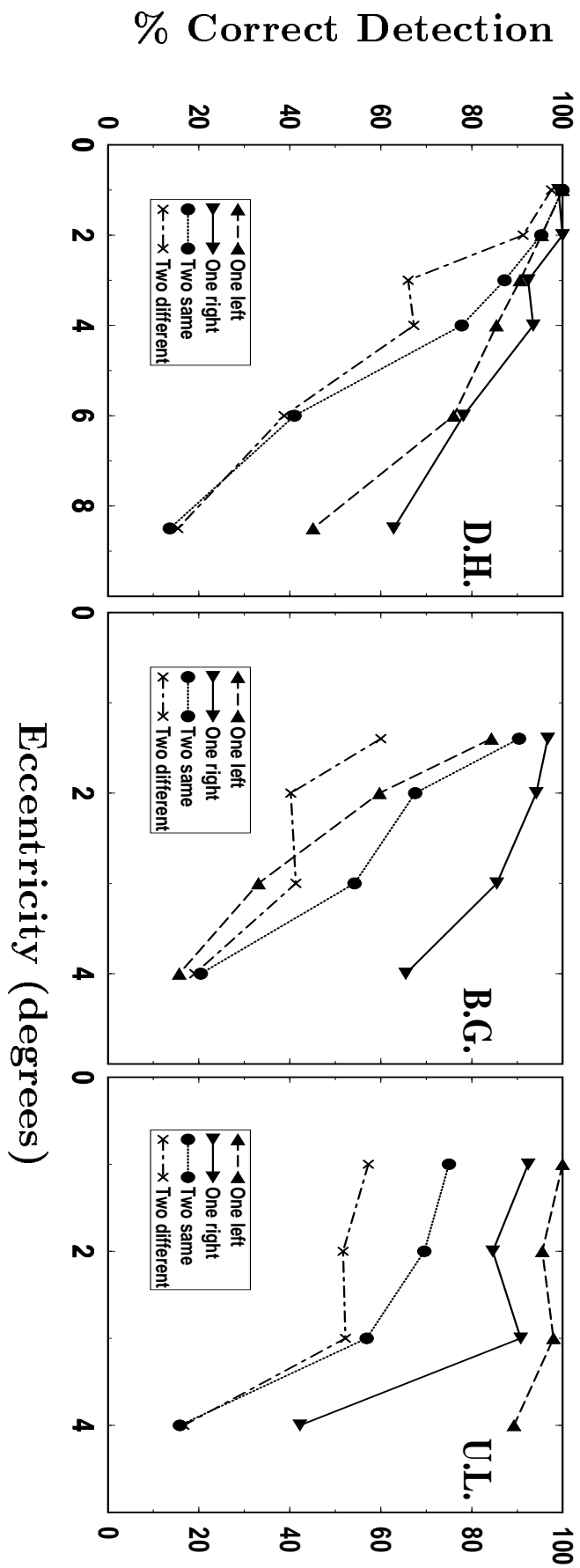


Figure 2:
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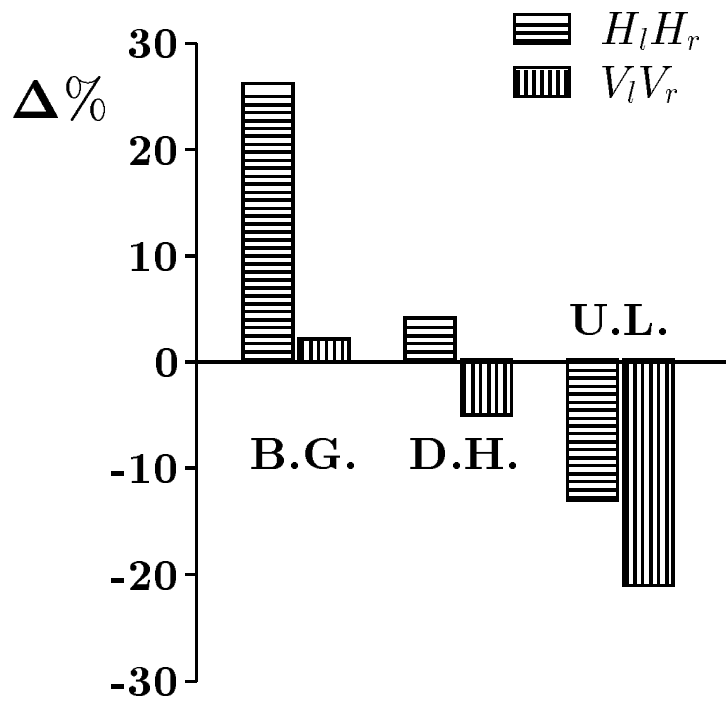


Figure 3:
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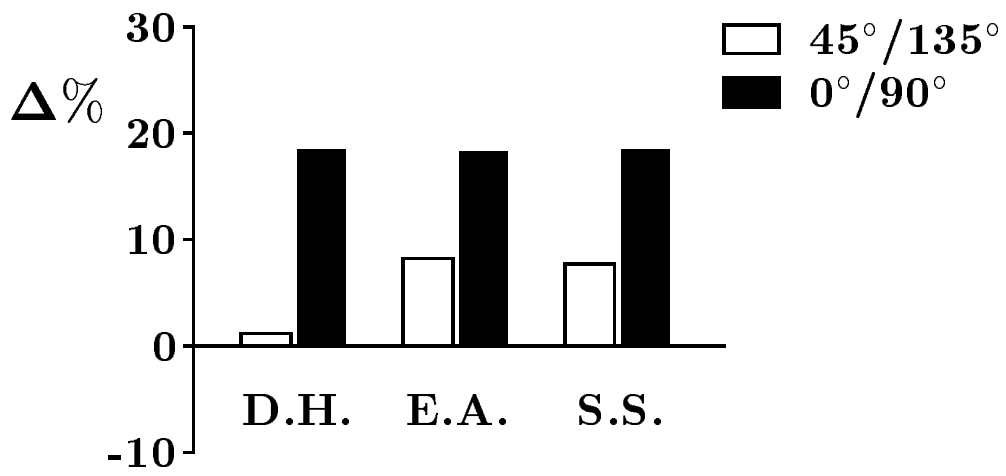


Figure 4:
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