

NATURAL EXTINCTION: A CRITERION SHIFT PHENOMENON

Andrei GOREA*¹ & Dov SAGI**

*Laboratoire de Psychologie Expérimentale, CNRS & René Descartes University,
71 Ave. Edouard Vaillant, 92774 Boulogne-Billancourt, FRANCE

**Department of Neurobiology/Brain Research, Weizmann Institute of Science
Rehovot, 76100 ISRAEL

(extinction, neglect, sensitivity, decision, criteria drift)

Previous detection performances obtained in a multi-varied contrast environment showed that observers tend to report significantly less the occurrence of the relatively lower contrast targets and significantly more the occurrence of the higher contrast ones than in conditions where each of these stimuli was tested in isolation (Gorea, A. & Sagi, D. (2000) Failure to handle more than one internal representation in visual detection tasks. *Proc. Natl. Acad. Sci. USA*, 97, 12380-12384). This *criterion shift* phenomenon is a form of contrast-dependent *extinction* in normal observers. To add more ground to the analogy between this type of 'natural' extinction and the stroke related one, we present a series of experiments where identical targets are displayed (1) at the same eccentricity but in opposite hemifields (along both the horizontal and vertical meridians), (2) at different eccentricities and where (3) different spatial frequency targets of equal contrasts are displayed at the same eccentricity. Hemifield, eccentricity and spatial frequency manipulations were intended to entail sensitivity differences for identical contrast stimuli. Some observers showed up to 3 and 1.5 d'-units differences between their left and right and between their upper and lower hemifields, respectively. While observers may show significant response biases even for isolated stimuli as well as for equally visible ones presented together, it is always the case that they use higher response criteria (extinction) for the less visible targets and lower response criteria for the more visible ones (*counter-extinction*) when these stimuli are mixed in one experimental block. The observed criterion shifts translate into as much as 3 times more 'Not seen' responses for the less visible targets and into about 1.3 times more 'Seen' responses for the more visible ones. Taken together, the present data support the notion that at least some forms of extinction (and perhaps neglect) are contingent on *relative* sensory/perceptual impairments and that they reflect more or less drastic forms of criterion/decision shifts.

¹ Corresponding author. Email : gorea@psycho.univ-paris5.fr

INTRODUCTION

Ever since the foundations of the Signal Detection Theory (SDT; Green and Swets, 1966) psychophysical measurements of perception have made a clear distinction between *sensitivity* and *decision-criterion*. The former is taken to characterize the processing efficiency of the underlying sensory system and it increases with target strength and/or with its physical difference from an arbitrary reference (noise) stimulus. The latter is regarded as the manifestation of a subjective operation whereby individuals decide on (as opposed to react reflexively to) the occurrence of an event based on factors such as expectation and pay-off, in addition to its strength or discriminability. Gorea and Sagi (1999, 2000, 2001) have recently shown that, in a behaviorally *relevant* multi-stimulus environment, while preserving their sensitivity intact, observers use a *unique* decision criterion, that is they shift the criteria they typically use in single stimulus environments toward higher and lower values on the internal response continuum for the relatively lower and higher visibility stimuli, respectively. As a consequence, lower and higher visibility events tend to be reported respectively *less* and *more* frequently than when they are presented in isolation. This behavior was shown to be in quantitative agreement with predictions of a model according to which observers represent a multi-stimulus environment as a *unitary* internal distribution to which each stimulus contributes proportionally to its probability of occurrence. The general implication (a basic limitation of the brain's capacity to sample reality at any given moment – Cowan, 2001), and the philosophical bearing (a fundamental constraint imposed by the unity of action or of decision on the environment – Cotterill, 1995) of the unitary distribution model remain to be assessed.

The original results reported by Gorea and Sagi for normal observers have however a direct bearing on the well known phenomenon of extinction observed in patients with unilateral parietal damage. First reported by Critchley (1949) and Bender (1952), extinction refers to the condition where patients are able to detect a single stimulus presented in either visual field but frequently fail to detect (or rather fail to *report*) the more contralesional event when two stimuli are presented simultaneously. Insofar as they present a critical sensitivity drop contralateral to the injury (Marshall, Halligan et al., 1993), patients of this kind are in a situation analogous to the one studied by Gorea and Sagi: extinction could then be regarded as the consequence of these patients' response criterion shift toward the mean of the internal responses evoked in their non-affected sensory space. Presumably related neurological conditions such as neglect (Halligan and Marshall, 1993, 1994; but see Goodrich and Ward, 1997; Cocchini, Cubelli et al., 1999) and blind-sight could be accounted for, if only in part, in a similar way: the stimulation of the affected visual field is 'extinguished' as a consequence of the inescapable stimulation of the unaffected (higher sensitivity) field. Criterion shifts in these neurological conditions have been invoked (Campion, Latto et al., 1983; Klein, 1998) and actually observed (Azzopardi and Cowey, 1997).

The present study is meant to provide additional ground for the proposed likeness between 'natural' and stroke-related extinction. If this conjecture is correct (but not as a proof of it), one should expect that, in normal observers (i) the decision criteria associated with *equal strength* stimuli presented at *unequally sensitive* sites on the retina should yield criterion shifts of the same order of magnitude as the unequal contrast stimuli we have originally tested. Equivalently, (ii) *qualitatively different* stimuli of equal contrasts presented at the same retinal location but yielding different sensitivities should also entail, when presented together, a criterion shift.

The first hypothesis was tested under two experimental formats. In the first format (Experiment 1), we took advantage of the fact that some observers show dramatic sensitivity

differences between their left and right, and/or between their upper and lower visual hemifields. For such observers, the detection of identical stimuli presented symmetrically about fixation should display the expected criterion shift. In the second format, observers *not* showing such an unbalanced hemifield sensitivity should nevertheless display an equivalent criterion shift when identical stimuli are presented at different eccentricities chosen in such a way as to yield different sensitivities (Experiment 2). The second hypothesis was tested by using two stimuli of identical contrasts but differing in their spatial structure (i.e. spatial frequency) so as to yield equivalent sensitivity differences at the same eccentricities (Experiment 3).

DATA FORMAT AND HYPOTHESES OPERATIONALIZATION

In Signal Detection Theory (SDT; Green and Swets, 1966), observers decide on the occurrence of a signal according to some optimization rule. A standard optimization rule maximizes the percentage of correct responses (hits and correct rejections). SDT poses that its implementation is achieved by way of making a decision with reference to a given likelihood-ratio criterion, β , a number that depends *only* on the signal probability, p , and the pay-off. As such, β is an estimator of the observer's decision behavior independently of this observer's sensitivity, d' . In contrast, other criterion indexes derived from β (i.e. c and c_A ; see Figure 1a) do vary with d' . The criterion shift hypothesis is operationalized here in terms of both β and the absolute criterion, c_A .

The general claim of the *criterion shift hypothesis* is that, when assessed together within one experimental block, β will decrease (observers will be more 'liberal') for the higher d' stimulus and increase (more 'conservative') for the lower d' stimulus relative to conditions where the two (or more) stimuli are tested in isolation (reference condition). An equivalent test of the criterion shift hypothesis may take advantage of the fact that, under SDT, β should be independent of d' . Instead, the criterion shift hypothesis predicts that, for a stimulus pair i,j (with i and j referring to the lower and higher d' stimuli tested within the same experimental block), their β -ratio = β_j / β_i should covary negatively with their d' -difference, $\Delta d' = d'_j - d'_i$, i.e. β -ratio $\propto 1 / \Delta d'$. Inspection of this relationship is useful under circumstances such as those of Experiment 1 where testing one hemifield at a time (the reference condition) could entail systematic fixation shifts and thus potential sensitivity changes disjoint from those originally intended.

The criterion shift hypothesis is a consequence of Gorea and Sagi's (2000) unitary distribution model. According to this model, two different sensitivity stimuli presented with equal probabilities in a mixed block of trials should yield *identical absolute criteria*, c_A , so that $\Delta c_A = c_{Aj} - c_{Ai} = 0$. Instead, SDT predicts that $\Delta c_A = \Delta d' / 2 + \Delta c$ (with Δc the difference between the *relative criteria*; see Fig. 1a and caption), that is a linear function of d' with slope 0.5^2 . Thus, the criterion shift hypothesis and SDT yield contrasting predictions in terms of both β and c_A .

² Because $c = \ln(\beta)/d'$ (Green & Swets, 1966), $\Delta c = 0$ for $\beta = 1$. Since, in average, β was indeed close to 1 (see Results), the Δc term was negligible so that the SDT prediction for Δc_A is a straight line passing through the origin.

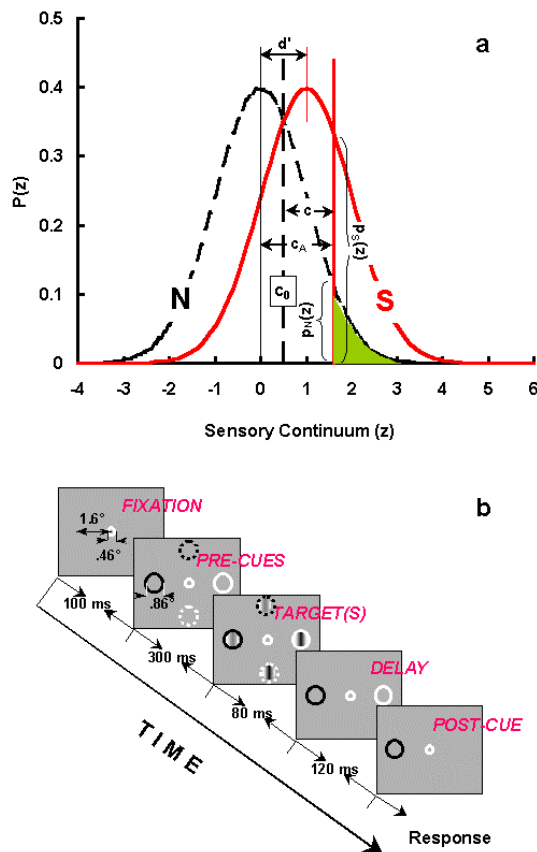


Figure 1. (a) The Signal Detection Theory framework. Gaussian functions describe the probability density, $p(z)$, of the internal response distributions (in standard z -scores; abscissa) for the Noise alone [N : $p_N(z)$; dashed curve] and for the Signal+Noise [S : $p_S(z)$]. Thin vertical lines show their means with *sensitivity* ($d' = z_{Hit} - z_{FA}$, where z_{Hit} and z_{FA} are the z -scores for the observed correct target-detection and false alarm rates) being the distance between these means ($d' = 1$ in this case) measured in units of the noise standard deviation, σ_N , and assuming that N and S are normally distributed with $\sigma = \sigma_N = \sigma_S$. The standard criterion as measured along the abscissa, c , is the z -score relative to the intersection point of the N and S distributions (c_0). We define an ‘absolute’ criterion $c_A = -z_{FA}$ which is independent of the univariance assumption (i.e. $\sigma_S = \sigma_N$), since it depends on the N distribution only. The corresponding values of the likelihood ratio criterion, $\beta = p_S(z = c_A) / p_N(z = c_A)$, characterize observers’ response bias independently of d' . Error rate is minimized when $\beta = P_N / P_S$, (with P_N and P_S the a-priori N and S probabilities) but experimental results show that observers adopt a more conservative behavior with β -s closer to one (Green and Swets 1966). The vertical dashed and continuous heavy lines show optimal criteria for $P_S = .5$ and $P_S = .25$, respectively. The shaded area denotes the FA rate for the latter case. **(b) One trial sequence** as detailed in the text. The stimulus presentation stage (third slice from the left) shows both horizontally and vertically displayed cues and targets but only one of these two configurations was shown in one block of trials.

METHODS

Stimuli

The stimuli were Gabor patches presented on a Sony Trinitron 1280×1024 pixels driven by an Octan2 Silicon Graphics workstation at a refresh rate of 60 Hz. The Gabors were displayed within black or white circles 0.9° in diameter on a 29 cd/m^2 gray background at 100 cm from the observer. The contrasts of the Gabors were chosen so as to yield d' -s in-between 0.5 and 3 (i.e. most of the measurable d' range) as assessed in preliminary experiments. A white circle 0.5° in diameter was used for fixation. In Experiments 1 and 3, the Gabor patches were symmetrically displayed 1.6° to the left and to the right of fixation (see Figure 1b); in Exp. 1, three observers were also run a few sessions with the stimuli displayed 1.6° above and below fixation. In Experiment 2, the two Gabors were presented asymmetrically about fixation, one at 1.6° and the other more peripherally at an eccentricity chosen for each observer so as to yield, at the same contrast, a d' significantly lower than the more central Gabor. The spatial frequency (SF) of the two Gabors in Exps. 1 and 2 and of one of the two Gabors in Exp. 3 was 3 c/deg with the standard deviation of the Gaussian envelope of one period; in Exp. 3, the SF of the second Gabor was set at a higher value chosen for each observer so as to yield a significantly lower d' . The standard deviation of this higher SF Gabor yielded about the same spatial extent as the lower frequency one. All Gabors were vertical with the exception of the higher SF one in Exp. 3 which was horizontal. The Gabor patches were used as target stimuli while their circumscribing white and black circles served as pre- and post-cues as explained below.

General Procedure

Fig. 1b illustrates the temporal sequence of events within one trial in all three Exps; these events were as follows: (1) a fixation white circle present during the whole trial, (2) one white and one black ‘pre-cue’ circles (with location randomized across trials), (3) two Gabors of contrasts C_1 and C_2 presented within the pre-cue circles (along the horizontal or vertical meridians) with probabilities, p_1 & p_2 ; (4) the offset of the Gabor(s) followed 120 ms later by (5) the random disappearance of one of the two pre-cues. Observers had to respond whether or not a target was presented inside the persistent (post-cue) circle *only*. This experimental format combines *partial report* (Sperling, 1960) and signal detection techniques. It requires that observers monitor both locations until the ‘appearance’ of the post-cue.

The original work by Gorea and Sagi (1999, 2000) from which the data of Experiment 1 are derived was intended to assess the decision behavior of observers under conditions where they were presented with either one stimulus (‘single’ condition), or a pair of identical (‘dual-same’), or different contrast stimuli (‘dual-different’). In all cases, the presentation of any given stimulus was randomized from trial to trial over the two (left/right or upper/lower) hemifields tested within a block. Conceptually, the ‘single’ condition can be conceptualized as a ‘dual’ condition with the probability, p (or, equivalently, the contrast), of one stimulus in a pair set to zero. It involved three such p -pairs, namely 0-.25, 0-.50 and 0-.75 with the contrast of the stimulus being fixed for the whole block of trials. Thus, one experimental block of the ‘single’ type consisted of 25%, 50% or 75% *one-signal* trials (with, respectively, 75%, 50% or 25% *no-signal* trials) and 0% *two-signals* trials. In short, the ‘single’ condition never involved the presentation of two stimuli – or, equivalently, the stimulation of the two hemifields – at a time. It should be noted that this condition is a hybrid of what neuropsychologists working on extinction refer to as a single-block design as it involved the random stimulation of the two hemifields within the same block. An additional, control experiment where one experimental block involved the stimulation (with a signal probability of 0.5) of only one hemifield (left or right) was also run with one observer. The d' and β values obtained under this single-block design were compared with those obtained by this same observer when the stimulus was presented randomly across trials to the left or to the right of fixation. Because testing one hemifield at a time may entail systematic fixation shifts and thus potential sensitivity changes, the remaining observers were not tested in this control condition.

The ‘dual’ condition involved only two p -pairs, i.e. .25-.75 and .50-.50 with the first pair yielding two distinct conditions for the ‘dual-different’ case depending on whether the low probability was applied to the low or to the high contrast in a pair. The two probabilities in a pair were strictly independent so that each trial could involve (a) no signal [with $p_{[0 \text{ Signal}]} = (1-.25) \times (1-.75) = .1875$, for the ‘.25-.75’ pair and $(1-.50) \times (1-.50) = .25$, for the ‘.50-.50’ pair], (b) one signal only [with $p_{[1 \text{ Signal}]} = .25 \times (1-.75) + (1-.25) \times .75 = .625$, for the ‘.25-.75’ pair and $2 \times .50 \times .50 = .50$, for the ‘.50-.50’ pair], and (c) two signals [with $p_{[2 \text{ Signals}]} = .25 \times .75 = .1875$, for the ‘.25-.75’ pair and $.50 \times .50 = .25$, for the ‘.50-.50’ pair]. Independently of the p -pair used in any given experimental block, the ‘dual’ condition can be regarded as a hybrid of what neuropsychologists working on extinction refer to as a mixed block design as it involved not only a mixture of one and two stimuli trials with the stimulated hemifields randomized over trials, but also no stimulus trials according to the proportions just mentioned.

In the ‘single’ condition, the signal was presented randomly across trials within a white or a black cue-circle so that cue-polarity yielded no meaning in this condition. In the ‘dual’ conditions the pairs C_1, p_1 and C_2, p_2 were consistently associated with the cue polarities and observers were informed of this mapping before each block. Gorea & Sagi (1999, 2000) focused on the observers’ decision behavior as a function of the type of $C_1, p_1 - C_2, p_2$ pairing,

that is on this behavior's dependence on the probabilities and on the relative contrasts of (and thus sensitivities to) the paired stimuli. Details on these pairs and the order in which they were presented can be found in Gorea & Sagi (2000). Suffice here to note that each experimental point (d' and criterion) was obtained out of at least 312 but more typically 416 to 932 trials over both locations of presentation (left and right or up and down).

For the present analysis of these data (Experiment 1) the specific $C_{1,p_1} - C_{2,p_2}$ pairings, as well as the specific contrasts and probabilities defining each stimulus are of no consequence. This is so because the data (d' and β) for any given stimulus presented in one hemifield are compared here with the data for this *same* stimulus when presented in the opposite hemifield within the same experimental session and with the same occurrence probability. Thus, all the effects to be described in Exp. 1 will reveal hemifield differences and *not* stimulus differences.

Because the hemifield related analysis imposed halving the number of trials used for each stimulus, each datum point (d' and β) was computed from 156, but more typically 208 to 466 trials. Along the horizontal meridian, d' -s and β -s were collected from 18 stimulus configurations (defined by the contrast, probability and the pairing type) for observers GS, AG, and VR, 45 stimulus configurations for EL and 16 for DS. Along the vertical meridian, there were 18 conditions for GS and 2 for AG and VR.

In Experiments 2 and 3, all stimuli had an occurrence probability of 0.5 and each stimulus had only one contrast. Thus d' -s and β -s were collected from only one stimulus configuration per observer. Each d' - β pair was computed out of minimum 300 and maximum 600 trials cumulated over the two hemifields.

Preliminary experiments were run with each observer in order to choose the contrasts (Exps. 1-3), eccentricities (Exp. 2) and spatial frequencies (Exp. 3) of the paired stimuli so that they yielded d' differences in-between 1 and 2.

Observers

The two authors (age 48) and three naive observers (GS and VR female, EL male; ages 18-22) were run in Experiment 1. One of the three naive observers (GS) was well trained with the present task, while the remaining two naive observers were trained over at least 400 trials in preliminary sessions. Two additional naive observers (one male and one female; ages 21-22; also trained over at least 400 trials) and the first author were run in Experiments 2 and 3. Observers had normal or corrected to normal vision. None of them had any known neurological condition so that the hemifield sensitivity and/or decision criteria asymmetries found in some of them are to be considered as 'natural'.

RESULTS

Experiment 1

In this experiment sensitivity (d') and response criterion (β , c_A) were assessed in the left and in the right hemifields (1.6° from fixation) of five normal observers for a number of different contrast Gabor-patches. Three of these observers were also tested with stimuli displayed in the upper and lower hemifields (also 1.6° from fixation). The Gabor-patches were presented either one at a time ('single' condition), or in pairs of equal ('dual-same' condition), or different contrasts ('dual-different' condition). With one exception, one experimental block of the 'single' type involved the random presentation of the stimulus in the left or right or in the upper or lower hemifields. Observer VR was also run in a control condition where only one hemifield (left or right) was stimulated during one experimental block (208 trials per hemifield) and her d' -s and β -s were compared with those obtained for

the same stimulus when randomly presented to the left or to the right hemifield. The random presentation of either a signal or a noise event independently in each hemifield yielded 0-, 1- ('single' and 'dual' conditions), or 2-signal trials ('dual' condition; see the Procedure section). It should be remembered that within the present experimental paradigm where (with one exception) the two hemifields were tested within the same experimental block (in both 'single' and 'dual' conditions), the criterion shift hypothesis predicts a negative correlation between the ratios of the β values, and the differences of the d' values assessed for each of the two hemifields tested within the same experimental block. Equivalently, the criterion shift hypothesis predicts that the c_A -indexes assessed for these two hemifields should be equal and independent of their respective sensitivities. Thus the β -ratios and the c_A and d' differences presented below were all computed (with the exception of the control condition run with observer VR) from one experimental condition at a time rather than across experimental conditions.

When averaged across observers, the horizontal meridian yielded a mean d' of 1.73 and a mean β of 1.13; the vertical meridian yielded (for the same contrasts) a mean d' of 0.77 and a mean β of 1.14. Figure 2 displays β -ratios (a, b) and Δc_A -s (c, d) computed across the horizontal (a, c; five observers) and the vertical (b, d; three observers) meridians as a function of the corresponding sensitivity difference, $\Delta d'$, across these same hemifields as assessed within the same experimental block. Different symbols are for different observers. Because the relevant comparisons (across hemifields) bear on stimuli having the same occurrence probability (i.e. .25, .5 or .75) and because, according to SDT, β depends exclusively on this probability, all the measured β -ratios should equal 1 independently of $\Delta d'$ (horizontal line in Fig. 2a,b). Equivalently, SDT predicts a (quasi-) linear relationship between Δc_A and $\Delta d'$ with a slope close to 0.5 (dotted lines in Fig. 2c,d; see Note 2). The data clearly countered both SDT predictions: β -ratios dropped more or less exponentially with $\Delta d'$ (straight lines with exponents .58 and .36 in 2a and b), whereas Δc_A -s were close to 0 and depended only marginally on $\Delta d'$ (linear slopes of .16 and -.27 in 2c and d, respectively; note that the latter slope is negative while SDT predicts a positive correlation).

Hemifield-related sensitivity differences. Observers GS and AG (circles and squares) showed systematically higher sensitivities in their left than in their right hemifields ($d'_R - d'_L \leq 0$). On average, these differences were rather small ($\overline{\Delta d'_{R-L}} = -0.4$). Observer VR (diamonds) showed an opposite and quite stronger tendency: a substantially higher sensitivity in her right hemifield ($\overline{\Delta d'_{R-L}} = +1.8$). Finally, observers EL (triangles) and DS (asterisks) showed a more or less balanced sensitivity across hemifields ($\overline{\Delta d'_{R-L}} = +0.05$ and $+0.25$, respectively). All three observers tested along the vertical meridian showed a higher sensitivity in their lower than upper hemifield ($\overline{\Delta d'_{U-L}} = -0.66, -0.37$ and -0.71 , for GS, AG and VR).

The variability across observers of the left-right hemifield sensitivity differences is not surprising in view of the literature. While this imbalance is currently attributed to hemispheric processing asymmetries, its sign appears to depend on a number of stimulus- and task-related parameters, varies across subjects and studies (see reviews by Sergent & Hellige, 1986; Hellige & Sergent, 1986; Boles, 1994) and may change with practice (Zenger & Fahle, 1997). Instead, despite the more diffuse anatomo-functional substrate of the upper-lower field dichotomy, the presently found imbalance (a lower visual field superiority) appears to be more consistently reported in the literature (see Previc, 1990; Graham, Rico et al., 1999).

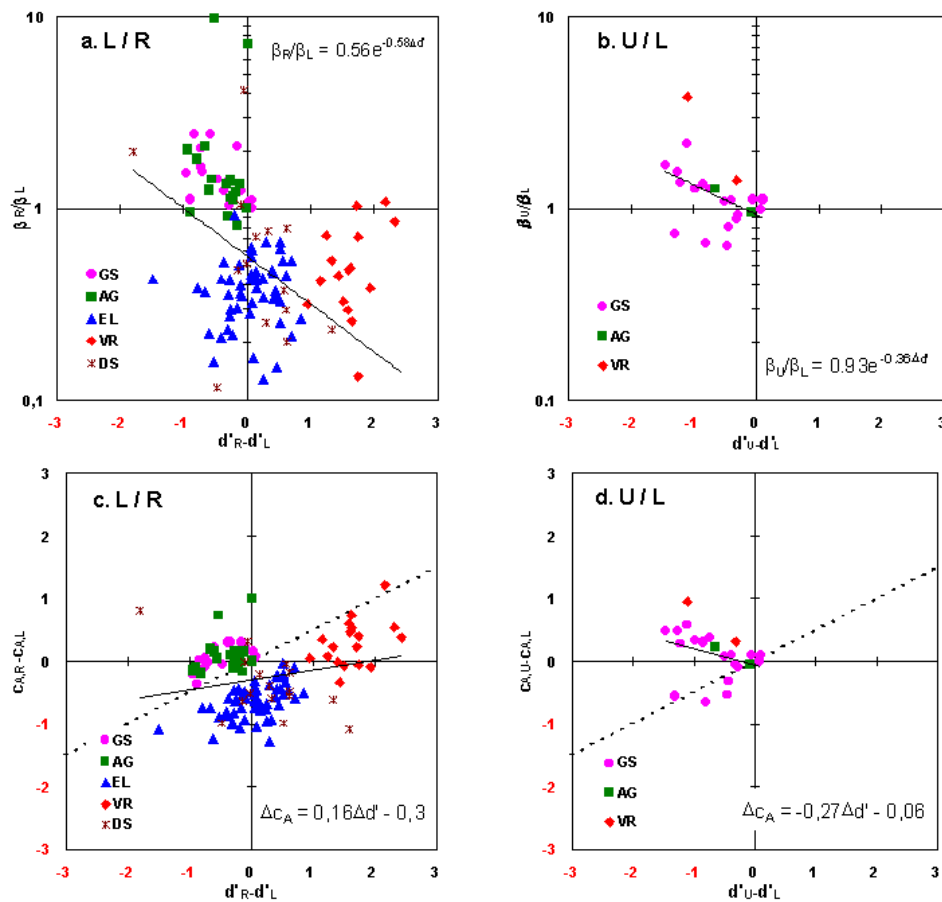


Figure 2. Experiment 1. β -ratios (top panels) and c_A -differences as a function of d' -differences for the Right and Left (a, c) and for the Upper and Lower (b, d) hemifields. Different symbols are for different observers (five and three in the left- and right-hand panels, respectively). Solid oblique lines are log-linear (a, b) and linear-linear (c, d) regression lines obtained with all the displayed datum points (see insets). These lines are to be contrasted with SDT predictions (horizontal lines of ordinate 1 in a and b and dotted lines in c and d).

Sensitivity-related decision behavior. Taken together, the data supported the criterion shift hypothesis: they showed a decrease of both β_R/β_L and β_U/β_L ratios with an increase in $\Delta d'$ (the correlation coefficients for the L-R and U-L hemifields were -0.28 and -0.42, respectively). Log-linear regression analyses using all the datum points collected over the horizontal and vertical meridians yielded significant correlations ($r_{R/L}^2 = 0.16$; $F_{1,122} = 23.6$, $p \ll .001$; $r_{U/L}^2 = 0.18$; $F_{1,20} = 4.3$, $p < .05$). Instead, a linear regression analysis performed on the Δc_A datum-points yielded no such significant trend implying that observers used close to identical *absolute criteria* for hemifields yielding different sensitivities and stimulated within the same block of trials. For the horizontal meridian, this general result requires some qualifications.

The criterion shift expected for unequal sensitivity hemifields was observed in four (GS, AG, VR and DS) out of five observers: each of these four reported the occurrence of a target in their *less* sensitive hemifield *less* frequently than in their more sensitive hemifield. The expected negative correlation between β -ratio and $\Delta d'$ was nonetheless absent for VR although, in accord with the criterion shift hypothesis, the criterion she used in her most sensitive hemifield (β_R) was, overall, almost a factor of 3 lower than the one she used in her

less sensitive hemifield ($\overline{\beta_R/\beta_L} = 0.35$). Finally, observer EL displayed practically identical sensitivities across hemifields and yet exhibited a response bias comparable to the one observed in VR ($\overline{\beta_R/\beta_L} = 0.33$). Thus, *response biases may occur even in the absence of sensitivity differences*. As for the vertical meridian (Fig. 2b,d), the data of each of the three observers complied with the criterion shift hypothesis.

Figure 3 illustrates the decision behavior of observer VR (in terms of β -ratios – left ordinate and circles –, and in terms of Δc_A -s – right ordinate and squares) in two contrasting conditions: one where each hemifield was tested separately (blocked sessions; open symbols), and the other where the two hemifields were tested in mixed blocks (as for all the remaining datum points in Fig. 2; solid symbols). Both conditions yielded about equally higher sensitivities in the right relative to the left hemifield ($\Delta d' = 1.55$ and 1.17 in the blocked and mixed conditions respectively) but strikingly different β -ratios and thus Δc_A -s: VR strongly favored the stimuli presented in her left (less sensitive) hemifield when this hemifield was stimulated in isolation, and reversed her tendency when the two hemifields were jointly stimulated (blocked sessions: $\beta_R/\beta_L = 2.22$, $\Delta c_A = 1.10$; mixed sessions: $\beta_R/\beta_L = 0.25$, $\Delta c_A = -.03$).

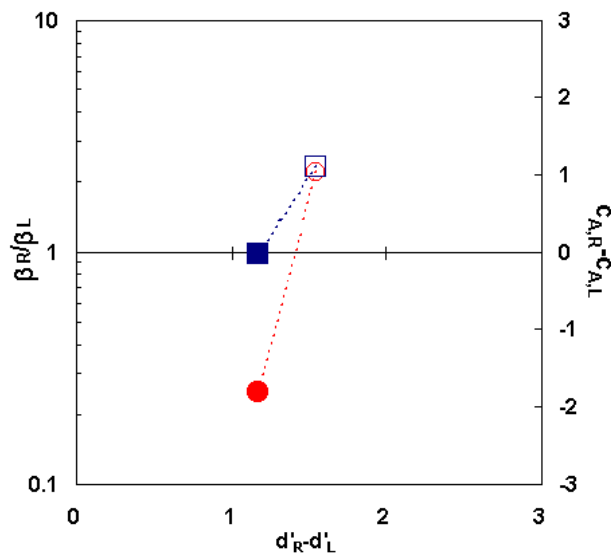


Figure 3. Experiment 1, control condition. β -ratios (circles and left ordinate) and c_A -differences (squares and right ordinate) as a function of d' -differences for the Right and Left hemifields for observer VR when only one (open symbols), or the two hemifields (solid symbols) of this observer were stimulated in one experimental block.

It should be reminded that the hemifield-related criterion asymmetry observed along both the horizontal and the vertical meridians is tantamount to an imbalance between ‘Yes’ and ‘No’ responses. As such, it describes a form of *natural extinction*. Observers EL and VR were the most ‘negligent’ ones across the horizontal meridian: in average, they responded about three times more ‘No’ in their Left than in their Right hemifields. With the exception of EL, this natural extinction was always observed in the less sensitive hemifield, as predicted by the criterion shift hypothesis and at odds with the SDT (according to which the Yes/No response ratio should depend *only* on the probability of the stimulus and *not* on the sensitivity to that stimulus). The EL exception, and VR’s strong response bias when tested for each horizontal hemifield in isolation point to the fact that factors other than pay-off, signal probability and relative sensitivity play a role in the observers’ decision behavior.

The large dispersion of the response biases across (and within) observers along the horizontal meridian is in accord with the bisection behavior observed along this meridian in normal adults (e.g. Manning, Halligan et al., 1990) and children (e.g. van Vugt, Fransen et al., 2000). Instead, the rather systematic decision imbalance along the vertical meridian (with the

upper hemifield yielding a more conservative decision behavior than the lower hemifield) is at odds with the bisection behavior reported in normal adults (Drain and Reuter-Lorenz, 1996) but not in neglect patients (Pitzalis, Spinelli et al., 1997)³.

Experiments 2 and 3

In these experiments sensitivity and response criteria were assessed on the horizontal meridian of three observers with *identical stimuli* presented at *different eccentricities* (Exp. 2, Figure 4a,c) and *with different spatial frequency (SF) stimuli* presented at the *same eccentricity* (Exp. 3, Fig. 4b,d). To demonstrate the generality of our findings, the stimuli used in the latter case also differed in their orientation. This time, d' -s and β -s were computed from the responses cumulated over the two, randomly stimulated hemifields. In each experiment the critical variables (eccentricity and SF) were either blocked ('dual-same' condition; also referred to as non-mixed or reference), or mixed ('dual-different' condition) within one experimental session. For each observer the eccentricity-pair and the SF-pair (two SF-pairs for observer AG) were chosen so as to yield d' differences in-between 1 and 2.

The criterion shift hypothesis requires that the β -ratio between the criteria associated with the higher and lower d' stimuli be lower in the mixed than in the non-mixed conditions ($\beta\text{-ratio}_{\text{mixed}} < \beta\text{-ratio}_{\text{non-mixed}}$). This is to say that observers were expected to be relatively more 'liberal' with the more detectable stimulus than with the less detectable one when the two were presented together than when they were presented in separate blocks of trials. On the more specific assumption of no response bias in the non-mixed conditions ($\beta\text{-ratio}_{\text{non-mixed}} \approx 1$), the mixed conditions should yield $\beta\text{-ratio}_{\text{mixed}} < 1$. The data from both experiments support the general prediction of the criterion shift hypothesis, namely $\beta\text{-ratio}_{\text{mixed}} < \beta\text{-ratio}_{\text{non-mixed}}$ and, with one exception, the more specific one, $\beta\text{-ratio}_{\text{mixed}} < 1$.

Fig. 4a,b uses the same format as Fig. 2a,b: it displays β -ratios as a function of $\Delta d' = d'_{\text{High}} - d'_{\text{Low}}$ for identical stimuli presented at different eccentricities (4a), and for different SF stimuli presented at the same eccentricity (4b). Different symbols are for different observers. The two sets of datum points for observer AG (circles in Fig. 4b) are for the two different SF-pairs this observer was run with. Symbols connected by dotted lines show β -ratio vs. $\Delta d'$ datum-points for the same two stimuli presented in non-mixed ('same'; open symbols) and mixed ('different'; solid symbols) conditions. Because the two stimuli in both mixed and non-mixed sessions were purposefully chosen to yield different sensitivities, $\Delta d'$ -s were always larger than 0 ($\Delta d' \approx 1.5$). SDT predicts $\beta\text{-ratio} = 1$ under all circumstances. This is the case for five out of seven $\beta\text{-ratios}_{\text{non-mixed}}$ and for one out seven $\beta\text{-ratios}_{\text{mixed}}$ (Experiments 2 and 3 confounded). Of the remaining eight β -ratios, one was significantly higher than 1 (showing a more conservative behavior for the stronger stimulus in the non-mixed sessions; open square in Fig. 4a; Obs. NS) and seven (one non-mixed and six mixed conditions) were significantly lower than 1 (a less conservative behavior for the stronger stimuli).

In the context of the criterion shift hypothesis, the comparison of interest pertains to the decision behavior adopted in the mixed *relative* to the non-mixed conditions. For an ideal SDT observer, both β -ratios and $\Delta d'$ -s should have been the same whether assessed in the mixed or non-mixed conditions so that the connected open and closed symbols in Fig. 4a,b should have lied on the top of each other. This was definitely not the case. Whereas $\Delta d'$ -s did show some nonsystematic variability between mixed and non-mixed conditions (within the standard error of measurement, with the exception of Obs. NS; see Fig. 4a), all $\beta\text{-ratios}_{\text{mixed}}$

³ It has been recently reported that some stroke patients may show severe left neglect on cancellation and right neglect on line bisection or the reciprocal (Halligan & Marshall, 1998).

were lower than β -ratios_{non-mixed}, as predicted by the criterion shift hypothesis. The only case where β -ratio_{mixed} > 1 (solid square in Fig. 4a; Obs. NS) was the one where this observer showed a very strong response bias (more conservative for the higher than for the lower d' stimulus) in the corresponding non-mixed condition (open square in 4a; β -ratio_{non-mixed} = 2.77). An equivalent but reversed bias was observed for one of the two SF pairs tested with Obs. AG (open circle in 4b; β -ratio_{non-mixed} = 0.29).

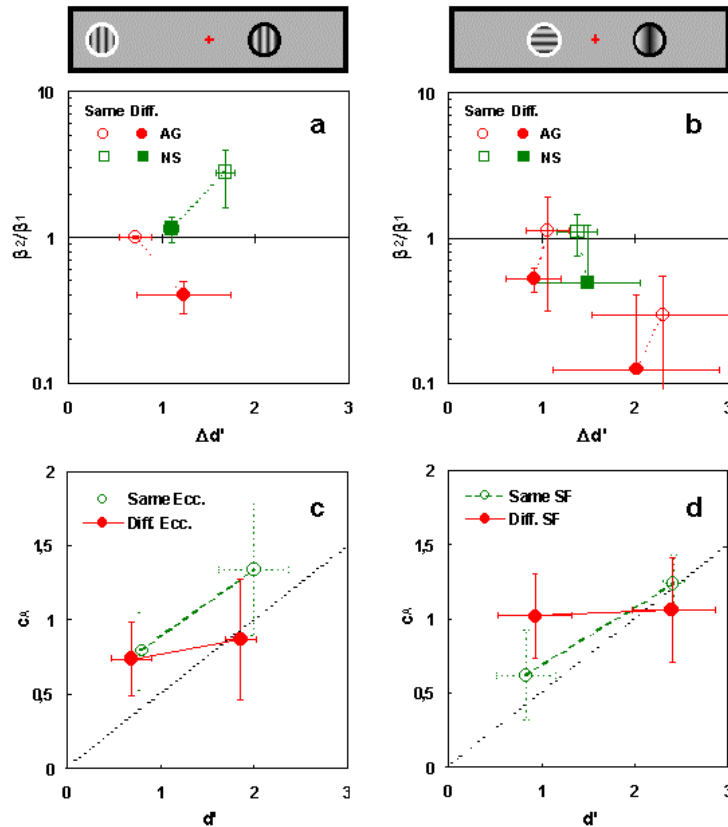


Figure 4. Experiments 2 (a, c) & 3 (b & d). β -ratios as a function of the d' -differences (top panels) and c_{A-S} as a function of d' (bottom panels) for two identical stimuli presented at different eccentricities (a, c) and for two different stimuli presented at the same eccentricity (b, d) as exemplified by the top insets. In the top panels different symbols are for different observers with open and solid symbols showing datum points collected respectively for one stimulation type at a time (one eccentricity or one SF; non-mixed/same conditions) and for the two stimulation types mixed within one experimental block. Comparisons between non-mixed and mixed conditions are to be made only between symbols connected by dotted lines. Obs. AG was run with two SF-pairs, thus the two sets of circles. The bottom panels show the same data averaged over observers with open and solid symbols for non-mixed and mixed conditions, respectively. Note that the absolute criteria measured in the mixed blocks for very different sensitivity stimuli are practically identical, while they lie pretty much along the SDT predictions (dotted lines with a slope of 0.5) in the non-mixed conditions; their (slight) shift above these predictions indicates an overall response bias (a tendency to respond 'No').

Fig. 4c,d displays the data of Fig. 4a,b under a different format: absolute criteria, c_{A-S} (rather than Δc_{A-S}) are shown as a function of the corresponding d' -s (rather than $\Delta d'$ -s) in the non-mixed (open symbols connected by dashed lines) and the mixed (solid symbols and solid lines) conditions. This time c_A and d' indexes were averaged over the three observers. The averaged d' -s are practically identical across mixed and non-mixed conditions. The criterion shift hypothesis requires that, when presented in a mixed experimental block, equal

probability stimuli yield a unique c_A (i.e. zFA) independently of their relative strength. In contrast, SDT predicts a linear $c_A = f(d')$ relationship with a slope 0.5 (dotted line; see also Note 2). The data verified the SDT prediction for the non-mixed blocks (on which the criterion shift hypothesis has no bearing; open symbols), but complied with the criterion shift hypothesis for the mixed blocks (solid symbols).

For the different eccentricity stimuli (Fig. 4c), the c_A shifts observed in the mixed relative to the non-mixed condition were about symmetrical. For the different SF stimuli (Fig. 4d), the higher c_A drifted downward while the lower c_A remained practically unchanged. Whether symmetrical or not, the net result of these drifts is a criterion equilibrium. It is this criterion uniqueness that translates into the β -ratio biases observed in Figs. 2a,b and 4a,b.

In short, Experiments 2 and 3 confirm the criterion shift hypothesis: when higher and lower sensitivity events are presented together, (1) the former are usually reported more frequently than the latter and (2) they are reported respectively *less* and *more* frequently than when they occur in isolation.

DISCUSSION

The criterion shifts originally observed by Gorea and Sagi (1999, 2000) for unequal contrast stimuli presented in mixed blocks were accounted for in terms of a *unitary* internal response distribution used by observers to judge the occurrence of such events. While different strength stimuli evoke distinct internal response distributions, observers fail to represent them as such. Instead, they appear to merge these two (or more) distributions within a unique one where each individual distribution is weighed in proportion to the occurrence probability of each stimulus. Observers decide on the occurrence of a signal in the standard way, that is by reference to a likelihood ratio criterion, β . However, they compute this number from the merged distribution, hence its shift relative to what it would have been had it been computed from the individual distributions associated with each stimulus. In short, in a multi-stimulus environment observers behave as if they have access to only one internal response distribution generated by the incoming stimuli and thus fail to adopt an optimal response behavior.

The present experiments extended the original findings to situations where stimuli had identical contrasts but yielded different sensitivities either because they tapped on different sensitivity retinal areas (Exps. 1 and 2), or because of differences in their spatial structure (spatial frequency; Exp. 3). In the former case we took advantage of natural sensitivity differences at the same eccentricity across the horizontal and vertical meridians (Exp. 1), a situation analogous to that observed in stroke patients. Out of the five observers tested along the horizontal meridian, two showed a moderately higher sensitivity in their left hemifield ($\Delta d' = -0.4$), one displayed an opposite and stronger tendency ($\Delta d' = 1.6$) and two showed an overall balanced left-right sensitivity. All three observers tested along the vertical meridian showed a higher sensitivity in their lower hemifield ($\Delta d' = -0.6$). With one exception, the data confirmed the criterion shift phenomenon, namely the use by observers of relatively higher (more conservative) decision criteria in the less sensitive hemifield than in the more sensitive one. Equivalently, the data showed that, contrary to SDT predictions, the absolute criteria c_A (i.e. in zFA units) used in the different sensitivity hemifields tended to be very similar, a behavior complying with the unitary internal distribution model. This behavior observed in normal observers is clearly analogous (although not necessarily equivalent) to the extinction phenomenon observed in stroke patients.

The exception mentioned above concerned observer EL who showed a significant criterion imbalance across hemifields in the absence of a sensitivity asymmetry between

hemifields. This points to the fact that the decision behavior is governed by factors other than signal probability, pay-off and sensitivity differences among stimuli upon which observers have to make decisions within a mixed environment. It is indeed known (since Green and Swets' seminal work) that observers may differ over the liberality with which they decide on the occurrence of sensory events. Contextual factors (other than personality-related) may very well induce persistent decision behaviors within the same observer both within and across sensory modalities (e.g. Goodrich and Ward, 1997; Vaishnavi, Calhoun et al., 2000).

Experiments 2 and 3 allowed the appraisal of the sensitivity related criterion shifts observed in the mixed conditions with reference to the non-mixed conditions. When averaged over observers, the data showed symmetrical shifts in Exp. 1 (i.e. the criteria associated with the more and with the less sensitive stimuli in the non-mixed condition respectively dropped and increased by about equal amounts in the mixed condition) and asymmetrical shifts in Exp. 2 (mainly a drop of the criterion associated with the higher sensitivity stimulus). Either way, the net consequence of these shifts was, as predicted by the criterion shift hypothesis, the equalization of the criteria used for the higher and lower d' stimuli when they were mixed in the same block of trials.

The debate on the equivalence between the presently observed criterion shifts and the classical, stroke-related extinction phenomenon is clearly open to further investigations. It should be already noted that a *direct* comparison between the present results and those typically obtained with stroke patients is not possible for at least two reasons. First, standard (and even less standard) clinical tests rarely involve d' and criterion measurements: the extinction phenomenon (as well as potentially related phenomena such as neglect and blindsight) is typically assessed with suprathreshold stimuli and on the sole faith of the patient's affirmation of having or not having experienced a stimulus (for notable exceptions, see Azzopardi and Cowey, 1997, 1998; Vaishnavi, Calhoun et al., 2000). Second, the standard extinction phenomenon is assessed under experimental formats where the extinguishing and the extinguished stimuli are *always* presented together, that is in the absence of 'noise' trials (and thus of false alarms). For both these reasons, standard extinction experiments rule out the possibility of assessing d' and criterion indexes. It then follows that assessing the equivalence between the 'natural' extinction revealed in the present study and the stroke-related one requires testing the latter with the present methodology (including the use of spatial precues whose role in reducing spatial uncertainty has not been assessed within the context of the extinction phenomenon). The resemblance as well as potential discrepancies between the two conditions are further discussed below.

For two equally likely stimuli, the *total* c_A shift predicted by the unitary distribution model equals half of their d' difference (Gorea and Sagi, 2000). Given the limited range of reliably measurable d' -s (from about 0.5 to about 3), the maximum expected total shift cannot exceed 1.25σ -units. In view of the rather large extinction effects reported in the literature, such a shift may appear minor. A simple simulation will help put this comparison into perspective. Figure 5 displays the percentage of 'Yes' responses (i.e. the sum of the cumulative probability density functions for Hits and False Alarms) as a function of $c_A = -z_{FA}$ for two stimuli yielding a d' of 1 (dashed curve) and of 3 (solid curve). When these signals have an occurrence probability of 0.5, the c_A -s used by an ideal observer are, respectively, 0.5 and 1.5 σ -units (shorter dashed and solid vertical lines). The criterion shift hypothesis predicts that, when measured within the same experimental block, these criteria will drift so as to collapse on each other at some point in-between. For symmetrical drifts ($\pm 0.5\sigma$), the predicted unique criterion will be at 1σ (longer solid vertical line) so that the proportion of 'Yes' responses, $p(\text{Yes})$, will drop (*extinction*) from 0.50 to 0.32 for the lower, $d' = 1$ stimulus (dotted arrow pointing downward), and increase (*counter-extinction*) from 0.50 to 0.56 for the higher, $d' = 3$ stimulus (solid arrow pointing upward). Thus, an observer

would report the higher sensitivity stimulus $.56/.32 = 1.75$ times more frequently than the weaker stimulus⁴. Equivalently, this observer would report the weaker and stronger stimuli respectively $1.56 \times (.5/.32)$ less (extinction) and $1.12 \times (.56/.5)$ more frequently (counter-extinction) than when they are tested in isolation. This is close to the case observed in Experiment 3 (Fig. 4d). In the event of the criterion associated with the lower sensitivity stimulus drifting alone so as to equal the criterion associated with the higher sensitivity stimulus ($+1\sigma$), $p(\text{Yes})$ would drop from 0.50 to 0.18, that is by a factor of 2.77 (extinction)! This is close to the effect observed by Vaishnavi, Calhoun et al., (2000) for tactile extinction. Finally, in the symmetrical case where only the criterion associated with the higher sensitivity stimulus were to drift so as to equal the criterion associated with the lower sensitivity stimulus (-1σ ; similar to what was observed in Exp. 2; Fig. 3c), $p(\text{Yes})$ would increase from 0.50 to 0.64, i.e. 1.28 times more than when tested in isolation (counter-extinction). The main conclusion to be drawn from these simulations is that presumably small criterion shifts ($\pm 1\sigma$) observed for jointly presented stimuli translate into up to 3 times less (extinction), and up to 1.3 more 'Yes' (counter-extinction) responses in the lower and higher d' stimuli, respectively, than when these responses are obtained for isolated stimuli. These multiplicative factors may be impossible to compare with the standard extinction effects obtained with stroke patients presented with highly suprathreshold stimuli and frequently in the absence of catch/noise trials⁵. They indicate however that the presently documented natural extinction phenomenon may be rather large and even spectacular. As for the counter-extinction revealed in the present study, we know of only two studies having reported a potentially related though different phenomenon in stroke patients (Goodrich and Ward, 1997; Vaishnavi, Calhoun et al., 2000). The criterion shift hypothesis predicts that a more liberal response bias should occur in the ipsilesional field (insofar as this field displays a higher sensitivity than the contralesional one). Instead, Goodrich & Ward's and Vaishnavi et al.'s patients show it in the contralesional field⁶. This condition is surprising particularly since these patients display the usual contralesional neglect, a condition frequently associated and even confounded with extinction (Halligan and Marshall 1993, 1994; but also distinguished from it: Goodrich and Ward, 1997; Cocchini, Cubelli et al., 1999). As for the reason why the expected ipsilesional counter-extinction has not been reported in the neuropsychological literature, it may reside in the fact that its assessment requires the use of close to threshold *extinguishing* stimuli, a pretty rare practice in neuropsychology.

Gorea & Sagi, (1999, 2000) reported a series of experiments in which observers were never asked to decide on the occurrence of one out of two jointly presented stimuli. No criterion shift (for the reported stimulus, of course) was found under such conditions whether the never reported – 'companion' – stimulus was close to (within the measurable d' range), or well above threshold. These observations point to the fact that criterion shifts of the type described here reflect a *purely decision* phenomenon. Rather than being entailed by the mere presence of two targets of different contrasts, they require that observers be compelled to estimate the internal distributions associated with each of these stimuli. Not being asked to judge the occurrence of one of them renders the estimation of its evoked internal distribution

⁴ Note that for signal probabilities of 0.5, $p(\text{Yes})$ should equal $p(\text{No})$ whatever d' .

⁵ Even when such noise trials are inserted within a session, they rarely induce false alarms (e.g. Goodrich & Ward, 1997) so that sensitivity and criterion indexes cannot be computed.

⁶ These authors clearly show that this *contralesional anti-extinction* (as they call it) was due to a criterion shift effect. This is in apparent contradiction with the present criterion shift hypothesis which predicts such a criterion change in the *ipsilateral* (presumably higher sensitivity) hemifield. However, sensitivity (d') values (for either visual or roughness discrimination) are not specified for the unilateral stimulations in this study (perhaps because of the very few false alarms; see Note 6) so that the sensitivities of the two hemifields cannot be compared. In all events, the relationship between the presently reported counter-extinction and the previously reported anti-extinction remains to be assessed.

pointless so that no distribution merging occurs and thus no criterion shift. Because the highly suprathreshold companion is necessarily seen (i.e. endogenously reported) any time it occurred, it is reasonable to assume that the same result (i.e. the absence of a criterion shift) would have been obtained had observers been asked to report it.⁷ Along this line of argument, we suggest that stroke-related extinction (and/or neglect?) is not triggered by the highly visible, extinguishing stimuli *per se* but rather by the fact that observers are required to report on their occurrence, shape, etc. (see Karnath, 1988; Goodrich and Ward, 1997) and inasmuch as this report involves a decisional process. We therefore propose that the extinguishing events are those stimulus parts or characteristics necessary for the fulfillment of the current task and occurring on the fringe of the affected field where they are less visible and hence require a decisional operation. Such subtle sensitivity gradients could underlie a variety of extinction phenomena observed in stroke (e.g. Halligan and Marshall, 1992; Baylis, Driver et al., 1993), as well as in normal subjects (e.g. McCourt and Jewell, 1999; Jewell and McCourt, 2000; McCourt, Garlinghouse et al., 2000).

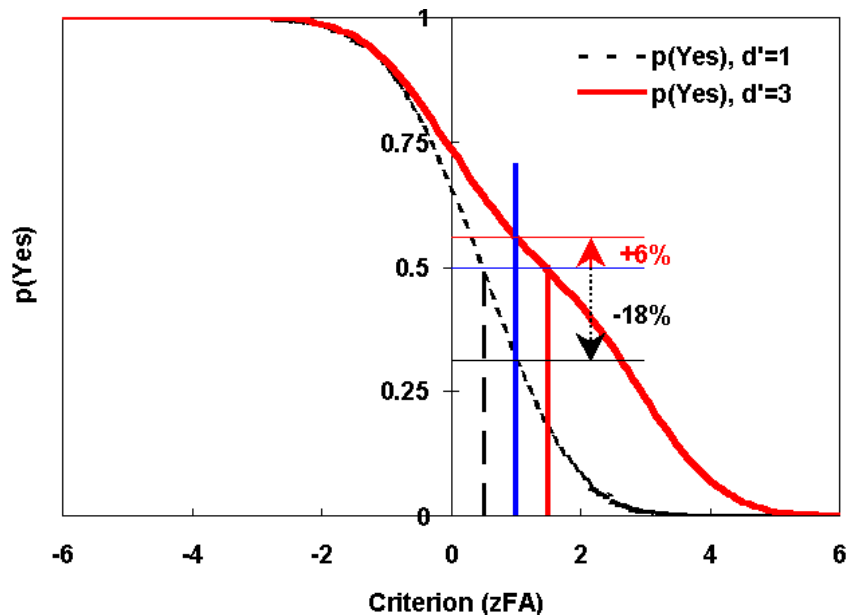


Figure 5. Theoretical proportion of ‘Yes’ responses in a Yes/No task as a function of the absolute criterion (in zFA units) for two stimuli yielding d' -s of 1 and 3 (dashed and solid curves). The dashed and solid shorter vertical lines show where these criteria should be for each of these stimuli when they have an occurrence probability of 0.5. The longer solid vertical line exemplifies the case where the two ideal criteria drift toward each other and overlap. The two vertical arrows show the respective increase and drop in $p(\text{Yes})$ given such a drift (+6 and -18%). See text for more details.

The present observations bring up to date the debate on the sensory-perceptual foundation of the extinction as well as of the neglect (and perhaps blindsight) syndrome in stroke patients⁸. Stroke related extinction (and neglect) is a ‘highly heterogeneous condition’

⁷ The estimation of the internal response distribution associated with a given stimulus is needed in order for the observer to derive his response criterion under that particular stimulating condition. The assumption here is that subjects may very well have ‘internalized’ during their life a very high ‘default’ criterion beyond which any internal event will be associated with an external one. Therefore, the estimation of the internal response distributions associated with highly suprathreshold stimuli may not be needed for a decision on their occurrence.

⁸ Other sensory deficits may lead to similar effects on decision. Sharma, Levi, et al. (2000) reported that amblyopic observers underestimate the number of targets presented to their less sensitive (amblyopic) eye

(Stone, Halligan et al., 1998). We have no claim that the hypothesis of a criterion shift due to a sensory-perceptual impairment accounts for such a wide diversity and definitely not for extinction (or neglect) cases observed in the absence of any sensitivity loss (including one of our five observers in Fig. 2a,c). It is worth noting, however, that bedside clinical tests as well as some more rigorous sensitivity tests used with brain damaged subjects (e.g. visual perimetry) may very well let pass unnoticed a wide variety of potential sensory-perceptual losses (see Marshall, Halligan et al., 1993; Halligan and Marshall, 1994; Angelelli, De Luca et al., 1998). Also, many experimental techniques used with neglect patients (including standard visual perimetry) fail to distinguish between genuine sensitivity impairments and criterion shifts. Be that as it may, at least some of the heterogeneity observed in the extinction and neglect syndromes is certainly due to the heterogeneity of the tests (including tasks, stimulus types and methods) used to assess it.

Many accounts of the extinction (and neglect) syndrome are in terms of an attentional disorder. In most of these accounts attention is regarded as a sensitivity (d') modulator. It has been convincingly argued, however, that attention and particularly selective attention may reflect the (intentional or automatic) modulation of the response criterion⁹ (e.g. Sperling 1984; Sperling and Doshier 1986; Palmer, Ames et al., 1993; Palmer, 1994; Shiu and Pashler, 1994; Shiu and Pashler, 1994; Lu and Doshier, 1998; Doshier and Lu, 1999). Considered under this angle, the present results add support to the attentional interpretation of the extinction phenomenon and put forth the notion that such attentional ‘disorders’ are, at least in part, triggered by a sensitivity imbalance between two or more simultaneous events. As recently demonstrated in healthy subjects, such an imbalance can be transient and due to hemispheric rivalry (Pollmann, 1996, 2000; Fink, Driver et al., 2000). This sensory imbalance claim seems difficult to reconcile with the existence of non-egocentric extinction or neglect syndromes (object-, space-, or mental image-centered). It is possible, however, that criterion shifts originally occurring within an egocentric space (as a consequence of some form of sensory-perceptual impairment) generalize over time (within days or weeks) to other, non-egocentric dimensions (see Driver, 1999).

CONCLUSION

Simultaneously tested retinal sites of unequal sensitivity intrinsic to those sites or brought about by stimulus characteristics yield *criteria shifts* entailing more (counter-extinction) and less (extinction) ‘Yes’ responses in the higher and lower sensitivity locations, respectively, than when these sites are tested separately. Stroke-related extinction (and perhaps hemineglect) may represent a pathological reinforcement of sensitivity-associated response-biases found in normal observers. Counter-extinction should be studied more systematically in neglect patients.

Acknowledgments. Parts of this work were presented at the *Association for Research in Vision and Ophthalmology*, Fort Lauderdale, 2000. We thank Yoram Bonne for providing the software. This work was supported in part by a joint French-Israeli grant ‘Arc-en-ciel’ and by a CNRS-*Cognition* grant to A. Gorea.

(despite their perfect visibility) and overestimate the number of targets presented to their normal eye. This effect is consistent with the observers using a decision variable corresponding to target *numerosity* and setting it at the same value in both eyes.

⁹ Criterion shifts may entail noise suppression and thus sensitivity changes (see Lu & Doshier, 1998).

REFERENCES

- Angelelli, P., De Luca, M. & Spinelli, D. (1998). Contrast sensitivity loss in the neglected hemifield. *Cortex* **34**, 139-145.
- Azzopardi, P., & Cowey, A. (1997). Is blindsight like normal, near-threshold vision? *Proceedings of the National Academy of Science USA* **94**, 14190-14194.
- Azzopardi, P., & Cowey, A. (1998). Blindsight and visual awareness. *Consciousness and Cognition* **7**, 292-311.
- Baylis, G.C., Driver, J., & Rafal, R.D. (1993). Visual extinction and stimulus repetition. *Journal of Cognitive Neuroscience* **5**, 453-466.
- Bender, M.B. (1952). *Disorders in perception*. Springfield, IL.
- Boles, D.B. (1994). An experimental comparison of stimulus type, display type, and input variable contributions to visual field asymmetries. *Brain and Cognition* **24**, 184-197.
- Campion, J., Latto, R. & Smith, Y.M. (1983). Is blindsight an effect of scattered light, spared cortex, and near-threshold vision? *Behavioral and Brain Sciences* **6**, 423-486.
- Cocchini, G., Cubelli, R., Della Sala, S., & Beschin, N. (1999). Neglect without extinction. *Cortex* **35**, 285-313.
- Cotterill, R.M.J. (1995). On the unity of conscious experience. *Journal of Consciousness Studies* **2**, 290-312.
- Cowan, N. (2001). The magical number 4 in short-term memory: A reconsideration of mental storage capacity. *Behavioral and Brain Sciences*, in press.
- Critchley, M. (1949). The phenomenon of tactile inattention with specific reference to parietal lesions. *Brain* **72**, 538-561.
- Dosher, B. A., & Lu, Z. (1999). Mechanisms of perceptual learning. *Vision Research* **39**, 3197-3221.
- Drain, M., & Reuter-Lorenz, P.A. (1996). Vertical orienting control: evidence for attentional bias and neglect in the intact brain. *Journal of Experimental Psychology: General* **125**, 139-158.
- Driver, J. (1999). Egocentric and object-based visual neglect. In N. Burgess (Ed.), *The hippocampal and parietal foundations of spatial cognition* (pp. 67-89). New York: Oxford University Press.
- Fink, G. R., Driver, J. Rorden, C., Baldeweg, T., & Dolan, R.J.. (2000). Neural consequences of competing stimuli in both visual hemifields: A physiological basis for visual extinction. *Annals of Neurology* **47**, 440-446.
- Goodrich, S. J., & Ward R. (1997). Anti-extinction following unilateral parietal damage. *Cognitive Neuropsychology* **14**, 595-612.
- Gorea, A., & Sagi, D. (1999). Explorations into the psychophysics of decision: Criteria attraction. *Investigative Ophthalmology and Visual Science, Suppl.* **40**, S796.
- Gorea, A., & Sagi, D. (2000). Failure to handle more than one internal representation in visual detection tasks. *Proceedings of the National Academy USA* **97**, 12380-12384.
- Gorea, A., & Sagi, D. (2001). Disentangling signal from noise in visual contrast discrimination. *Nature Neuroscience* **4**, 1146 - 1150.
- Graham, N., Rico, M., Offen, S. & Scott, W. (1999). Texture segregation shows only a very small lower-hemifield advantage. *Vision Research* **39**, 1171-1175.
- Green, D.M., & Swets, J.A. (1966). *Signal Detection Theory*. New York: Wiley.
- Halligan, P.W., & Marshall, J.C. (1992). Left visuo-spatial neglect: A meaningless entity? *Cortex* **28**, 525-535.

- Halligan, P.W., & Marshall, J.C. (1993). The history and clinical presentation of neglect. In I. Robertson & J. Marshall (Eds.), *Unilateral Neglect: Clinical and Experimental Studies* (pp. 3-59). Hove: Lawrence Erlbaum.
- Halligan, P.W., & Marshall, J.C. (1994). Toward a principled explanation of unilateral neglect. *Journal of Cognitive Neuropsychology* **11**, 167-206.
- Halligan, P.W., & Marshall, J.C. (1998). Visuospatial neglect: the ultimate deconstruction? *Brain and Cognition* **37**, 419-438.
- Hellige, J.B. & Sergent, J. (1986). Role of task factors in visual-field asymmetries. *Brain and Cognition* **5**, 200-223.
- Jewell, G., & McCourt, M.E. (2000). Pseudoneglect: A review and meta-analysis of performance factors in line bisection tasks. *Neuropsychologia* **38**, 93-110.
- Karnath, H.O. (1988). Deficits of attention in acute and recovered visual hemi-neglect. *Neuropsychologia* **26**, 27-43.
- Klein, S.A. (1998). Double-judgment psychophysics for research on consciousness: Application to blindsight. In S.A. Hemeroff, A. W. Kaszniak & A.C. Scott (Eds.) *Toward a science of consciousness. II. The second Tucson discussions and debates* (pp. 361-369). Cambridge, MA: MIT Press.
- Lu, Z., & Doshier, B.A. (1998). External noise distinguishes attention mechanisms. *Vision Research* **38**, 1183-1198.
- Manning, L., Halligan, P., & Marshall, J.C. (1990). Individual variation in line bisection: A study of normal subjects with application to the interpretation of visual neglect. *Neuropsychologia* **28**, 647-655.
- Marshall, J.C., Halligan, P.W., & Robertson, I.H. (1993). Contemporary theories of unilateral neglect: A critical review. In I.H. Robertson and J.C. Marshall (Eds.) *Unilateral Neglect: Clinical and Experimental Studies* (pp. 311-329). Hove: Lawrence Erlbaum.
- McCourt, M.E., Garlinghouse, M., & Slater, J. (2000). Centripetal versus centrifugal bias in visual line bisection: Focusing attention on two hypotheses. *Frontiers in Bioscience* **5**, D58-D71.
- McCourt, M.E., & Jewell G. (1999). Visuospatial attention in line bisection: stimulus modulation of pseudoneglect. *Neuropsychologia* **37**, 843-855.
- Palmer, J. (1994). Set-size effects in visual search: the effect of attention is independent of the stimulus for simple tasks. *Vision Research* **34**, 1703-1721.
- Palmer, J., Ames, C.T., & Lindsey, D.T. (1993). Measuring the effect of attention on simple visual search. *Journal of Experimental Psychology: Human Perception & Performance* **19**, 108-130.
- Previc, F. (1990). Functional specialization in the lower and upper visual fields in humans: Its ecological origins and neurophysiological implications. *Behavioral and Brain Sciences* **13**, 519-575.
- Pitzalis, S., Spinelli, D., & Zoccolotti, P. (1997). Vertical neglect: behavioral and electrophysiological data. *Cortex* **33**, 679-688.
- Pollmann, S. (1996). A pop-out induced extinction-like phenomenon in neurologically intact subjects. *Neuropsychologia* **34**, 413-425.
- Pollmann, S. (2000). Extinction-like Effects in Normals: Independence of Localization and Response Selection. *Brain and Cognition* **44**, 324-341.
- Sharma, V., Levi, D.M., & Klein, S.A. (2000). Undercounting features and missing features: evidence for a high-level deficit in strabismic amblyopia. *Nature Neuroscience* **3**, 496-501.

- Sergent, J. & Hellige, J.B. (1986). Role of input factors in visual field asymmetries. *Brain and Cognition* **5**, 174-199.
- Shiu, L.P., & Pashler, H. (1994). Negligible effect of spatial precueing on identification of single dots. *Journal of Experimental Psychology: Human Perception and Performance* **20**, 1037-1054.
- Shiu, L. P., & Pashler, H. (1994). Spatial attention and vernier acuity. *Vision Research* **35**, 337-343.
- Sperling, G. (1960). The information available in brief visual presentations. *Psychological Monographs* **74**, Whole no. 498.
- Sperling, G. (1984). A unified theory of attention and signal detection. In R. Parasuraman & D.R. Davies (Eds.), *Varieties of Attention* (pp. 103-181). New York: Academic Press.
- Sperling, G., & Doshier, B.A. (1986). Strategy and optimization in human information processing. In K. R. Boff, L. Kaufman & J. P. Thomas (Eds.), *Handbook of Perception and Human Performance. I. Sensory Processes and Perception*. (pp 2-1-2-65). New York: Wiley.
- Stone, S., Halligan, P. Marshall, J.C., & Greenwood, R.J. (1998). Unilateral neglect: a common but heterogeneous syndrome. *Neurology* **50**, 1902-5.
- Vaishnavi, S., Calhoun, J., Southwood, M.H., & Chatterjee, A. (2000). Sensory and response interference by ipsilesional stimuli in tactile extinction. *Cortex* **36**, 81-92.
- van Vugt, P., I. Fransen, Creten, W., & Paquier, P. (2000). Line bisection performances of 650 normal children. *Neuropsychologia* **38**, 886-95.
- Zenger, B. & Fahle, M. (1997). Reversing a performance asymmetry through practice. *Investigative Ophthalmology and Visual Science, Suppl* **38**, S963.