Neuroscience Letters 446 (2008) 51–55

Contents lists available at ScienceDirect

Neuroscience Letters

journal homepage: www.elsevier.com/locate/neulet

When they see, they see it almost right: Normal subjective experience of detected stimuli in spatial neglect

Yoram S. Bonneh [a,b,*], Dov Sagi [a], Andrei Gorea [c], Nachum Soroker [d], July Treger [d], Marina Pavlovskaya [d]

[a] Department of Neurobiology, Brain Research, The Weizmann Institute of Science, 76100 Rehovot, Israel
[b] Faculty of Science, University of Haifa, Haifa, Israel
[c] Laboratoire Psychologie de la Perception, Paris Descartes University & CNRS, 45 Rue des Saints Pères, 75006 Paris, France
[d] Loewenstein Rehabilitation Hospital, Raanana and the Sackler Faculty of Medicine, Tel Aviv University, Ramat Aviv, Israel

ARTICLE INFO

Article history:
Received 6 December 2007
Received in revised form 9 July 2008
Accepted 10 September 2008

Keywords:
Spatial neglect
Contrast sensitivity
Perceived contrast
Visual awareness

ABSTRACT

Unilateral spatial neglect (USN) patients show reduced contrast sensitivity on their contralesional side and often miss their non-salient stimuli. What their subjective experience is when successfully reporting a stimulus remains unclear. Here, we report that despite large contrast sensitivity differences between the sides, the relative attenuation in perceived contrast measured in a contrast-matching task was small. This was true even at threshold levels where the patients missed up to 40% of the contralesional target patches, in contrast to a 100% detection rate on their ipsilesional side. When the misses were counted as zero perceived contrast events, the attenuation in perceived contrast was less than half of the sensitivity loss. When the misses were ignored, there was almost no attenuation in perceived contrast, implying that whenever the patients detected a target, they perceived it with the correct contrast. These findings suggest that contrast sensitivity reduction in USN is not due to attenuation occurring at a peripheral low-level processing stage. More likely it reflects a high-threshold added at a higher level of processing, which prevents sensory events from reaching conscious awareness. Hence, patients may often miss contralesional stimuli but see them in full contrast once they clear the high-level hurdle.

Unilateral spatial neglect (USN) is a common sequel of stroke, which affects the right cerebral hemisphere, characterized by a failure to perceive and report stimuli in the contralesional side of space (for a review, see [14]). This “invisibility” of salient stimuli has been widely used to investigate the mechanisms underlying perceptual awareness [7]. Most of these studies used supra-threshold stimulation conditions and relatively complex perceptual tasks. Investigations of basic visual functions such as contrast sensitivity (detection tasks) have been less frequent (but see [1,2,18,20]). The purpose of the current study was to examine the fundamental aspects of contrast sensitivity and perceived contrast in USN, in order to reveal the mechanisms subserving perceptual awareness and its loss under this condition. Specifically, we were interested in patients’ subjective experience of those stimuli that manage to gain access to conscious awareness despite being located on the contralesional side. We asked whether such stimuli are experienced as being attenuated relative to ipsilesional stimuli.

Two central themes in the study of USN – the occurrence of perceptual distortions and the loss of conscious awareness – are relevant to the current study. Spatial distortion on the “neglected” side was found in various forms, including the perception of smaller than real objects and their mislocalization (see [17] for a review). Loss of awareness of contralesional stimuli was demonstrated in identification as well as in detection tasks (see [7] for a review), and its enhancement was shown when competing stimuli were presented simultaneously on the ipsilesional side (called extinction; e.g. [6]) Accumulating evidence shows that neglected as well as extinguished stimuli undergo elaborate processing, as reflected in priming tasks or Gestalt grouping of otherwise invisible stimuli (e.g. [19]). Neglect and extinction are generally interpreted in terms of disruption of the normal mechanisms underlying spatial attention [15,21] or space representation [3,12], both implying an attenuated “perceptual gain” on the contralesional side. However, the level at which this attenuation operates remains unclear. It could be located at the early stages of sensory processing, possibly entailing a reduction in perceived luminance and contrast, or at later stages, possibly operating like a perceptual gate and causing a total loss of awareness of some stimuli and normal perception of others.

* Corresponding author. Tel.: +972 8 9434206.
E-mail address: yoram.bonneh@weizmann.ac.il (Y.S. Bonneh).

0304-3940/$ – see front matter © 2008 Elsevier Ireland Ltd. All rights reserved.
doi:10.1016/j.neulet.2008.09.031

Table 1
Patients' demographic and clinical data

Patient	Age/sex	Ed (years)	Neurological impairment		BIT	Anatomical regions involved
			Motor	Sensory		
AY	62/M	10	++	++	86	F, P, CP, IHWM
KE	54/M	17	++	+	117	F, T, P, CP, IHWM
NE	53/M	12	++	++	135	T, P, CP, IHWM
RM	21/M	13	++	++	67	F, P, IHWM
SE	63/M	15	+	+	119	T, P, F, IHWM

All patients were right-handed. Patients AY, KE, NE and SE had ischemic infarctions and RM had an extensive parenchymal hemorrhage following rupture of an arterial-venous malformation. In all patients the lesion was confined to the territory of the right middle cerebral artery. The visual fields were preserved but contralesional extinction was shown under conditions of bilateral simultaneous stimulation, in all cases. Testing took place during the rehab hospitalization period, 3–6 months after the onset of stroke. Ed = years of formal education; Impairment: −/±/+/++ = no/mild/moderate/severe, respectively; BIT = Behavioral Inattention Test ([22]; cut off score for normality: 130, maximal score: 146). The BIT scores presented here, were obtained shortly before the experimental testing (patient NE showed neglect in part of the subtests and in activities of daily living); lesion location: F/P/T/CP/IHWM = frontal/parietal/temporal/capsular-putaminal region/intra hemispheric white matter.

Our approach in the current study was to explore the loss of awareness associated with USN as it relates to the processing of contrast. We questioned whether the perceptual deficiency in USN is restricted to an increase in the contrast detection threshold or, alternatively, involves distortion of the perceived contrast (the subjective experience of the contrast) throughout the entire range of supra-threshold contrasts. The former predicts normal processing of detected targets, whereas the latter predicts reduced processing across the whole range of available contrast stimuli. In the experiments, we measured both detection thresholds and perceived (subjective) contrast. We tested whether the perceived contrast of targets detected in the neglected hemifield correlates with the corresponding contrast sensitivity loss measured in detection tasks. A complete translation of the sensitivity loss to perceived contrast may point to a peripheral attenuation in contrast processing, whereas the absence of a correlation points to a deficiency at a more central stage of processing, where, as a consequence of abated attention, processed stimuli require higher saliency to gain access to awareness. Such a theory predicts subjective contrast perception of detected stimuli to be essentially normal (though some attenuation is expected from the recent finding of attentional effects on perceived contrast [4]). Normal contrast perception is also expected in the case of sensory loss if a correction mechanism is active. Such a correction mechanism is known to be active in normal vision, subserving contrast constancy [8,9], but not when stimuli are at, or slightly above, detection threshold. Our results show that although patients had large contrast threshold increments in the contralesional hemifield, their perceived contrast at detection thresholds and above was surprisingly preserved with attenuations that were only fractions of their sensitivity losses.

We tested five right-hemisphere-damaged stroke patients with left-side neglect. Damage was confined to the territory of the right middle cerebral artery. The primary visual areas in the occipital lobes and the geniculo-striate pathways were intact, and visual fields were normal in all cases (see Table 1 for demographic and clinical data). We did not test other patients without neglect or normal controls because a lack of perceived contrast difference would trivially follow from a lack of sensitivity difference expected in these two groups.

Stimuli were displayed on a 19″ color CRT monitor controlled by dedicated OpenGL-based software running on a Windows PC. The video format was true color (RGB), 100 Hz refresh rate, with a 1024 pixel × 768 pixel resolution occupying a 14° × 11° area. Luminance values were gamma corrected, and the mean luminance was 40 cd/m^2. The sitting distance was 1.5 m, and all experiments were administered in the dark. Auditory cues were given using two PC speakers. Trials were initiated by the experimenter and responses were given orally and recorded by the experimenter.

Contrast sensitivity: contrast detection thresholds were measured for a single even-symmetric Gabor patch briefly presented on either side of the horizontal axis. The stimulus parameters were customized for each observer in order to obtain a significant contrast sensitivity difference between the two sides in a measurable range: a spatial frequency of 4–6 cpd, an eccentricity of 1.5–3°, and a duration of 120–250 ms (in most cases 120 ms). Each presentation was accompanied by a brief (50 ms) auditory white noise (1000–3000 Hz) at about 85 dB to reduce temporal uncertainty. Two different paradigms were used to determine the contrast detection threshold: an adaptive Yes/No paradigm of target detection and an adaptive 2AFC orientation identification paradigm. We did not use a temporal 2AFC paradigm, since initial tests indicated that the patients had severe difficulties in judging temporal order. In the Yes/No paradigm, the patch could appear (50% of the trials) on either side of fixation and the observer had to reply with Yes/No to indicate a detection of a patch without reporting its location. An adaptive 3:1 staircase procedure [16] with 0.1-log unit contrast steps was applied on each side independently, and the threshold was taken as the geometric average of the last 6 of 8 contrast reversals. Since this procedure, unlike a 2AFC paradigm, is not criterion-free, we tested three of our patients in an alternative criterion-free procedure where patients had to identify the orientation of the Gabor (horizontal or vertical) presented in a single interval and where the Gabor contrast was monitored via the same adaptive staircase procedure. This procedure yields a threshold estimation at 79% correct in normal observers [16]. In all cases, the difference (log scale) between thresholds on the left and right sides was averaged across sessions. The two methods (Yes/No and 2AFC) yielded similar thresholds for the three patients so far tested.

Perceived contrast: The stimulus sequence is shown in Fig. 1. A reference patch appeared briefly (120–250 ms) on either side of fixation and was followed (SOA of 500 ms) by a comparison central patch presented for 500 ms. Both events were accompanied by the same auditory signal as in the contrast detection experiment. The observers had to judge whether the central patch was "stronger" or "weaker" than the peripheral patch, with no feedback given. An adaptive staircase procedure was applied on the contrast of the central patch, increasing or decreasing it by 0.1 log units with every response, and the point of subjective equality (PSE) was calculated as the geometric average of the last 20 of 22 contrast reversals. One experimental session consisted of one contrast sensitivity and one perceived contrast (PSE) assessment, thus ensuring a balanced sample for comparison, not affected by performance changes owing to recovery during the several weeks of testing (in some cases). During every session, the reference stimuli were set at one of two contrast levels for each side, i.e., at once or twice the contralesional (left hemifield) contrast threshold, as measured during that session. Occasionally observers reported not having seen the peripheral reference patch. These trials were skipped by the adaptive staircase procedure and either were (1) not taken into account in computing the PSE or (2) counted as zero perceived contrast trials and used as such in the final weighted average computation [9], i.e., $C = P_{\text{no-skip}} {}^{*} C_{\text{no-skip}} + P_{\text{skip}} {}^{*} 0$, where P_{skip}, the skip rate, denotes the fraction of skipped trials and $P_{\text{no-skip}} = 1 - P_{\text{skip}}$.

Statistical analysis: We used the Wilcoxon sign rank test, comparing the contrast ratios of left and right (log units differences) for detection and for "perceived contrast". This test was chosen because it does not assume normal distribution of the ratios, and we applied it first to each observer and for each perceived contrast level (once

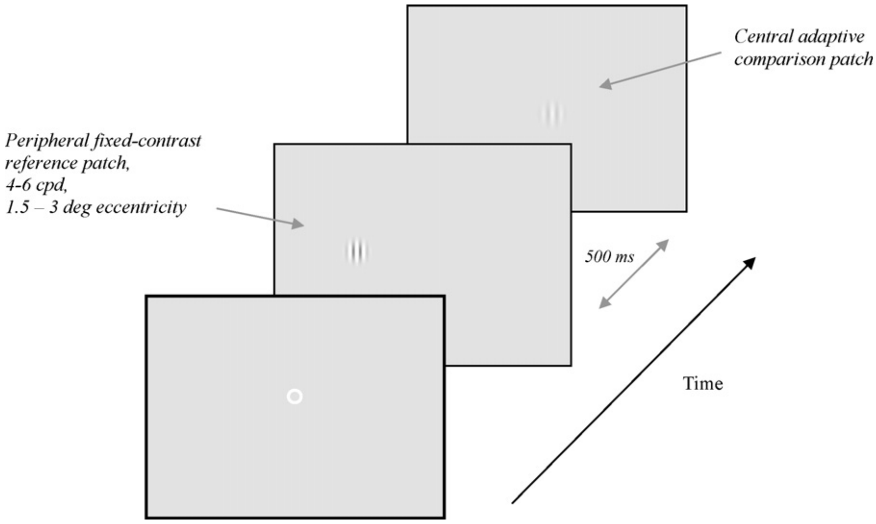

Fig. 1. Stimulus sequence used to measure perceived contrast on the two sides. A reference fixed-contrast (at threshold and at two times the threshold) appeared briefly followed after 500 ms by a central comparison patch. Subjects had to determine which patch was "stronger" and the point of subjective equality was determined adaptively.

or twice the threshold), testing the hypothesis that the sensitivity ratio is higher than the perceived contrast ratio. We then combined the computed *p*-values across subjects per condition, using Fisher's inverse chi-square method (see [13]).

The results for all five patients are summarized in Fig. 2a as the individual mean logarithms of their right-to-left contrast sensitivity (1/threshold, blue bars) and PSE-ratios, with the latter measured with reference patches set at one and two times their left-side thresholds (filled and empty yellow and brown bars). PSEs were computed when the skipped trials were ignored (filled bars) or counted as zero perceived contrast trials (empty bars). Fig. 2b shows these PSE means averaged over the two reference contrast levels within observers and then across the five observers (blue, dark-brown, and light-brown are, respectively, for threshold ratios and for PSE ratios with skip trials ignored or counted as zero perceived contrast).

Contrast sensitivity differed between sides for all patients, as previously reported [1,20]. The sensitivity differences (higher thresholds on the left side) ranged from 0.18 to 0.6 log units (factor 4), with four (out of five) patients showing over a 0.3-log unit difference. Note that the threshold differences for three of the five patients (including one with a 0.6 difference) were obtained using the 2AFC orientation identification paradigm, which rules out the possibility of criterion differences between sides as the single cause for the higher thresholds measured on the left side with this procedure. At the same time, the Yes/No threshold estimations for 3 of the patients revealed their very conservative behavior (high criterion) because their false alarm (FA) rate at threshold was about 3% on average across the 3 patients. This low FA rate was similar on the left and right sides.

The main finding is that the difference in log-perceived contrast between sides was much smaller than the log-sensitivity difference. This main effect was large (about 0.3 log units on average) when trials of invisible targets were skipped (filled yellow and brown bars), but still evident (about 0.2 log units) when these trials were counted as zero perceived contrast (dotted empty bars). The group average effect (Fig. 2b) shows that when invisible targets are ignored (dark-brown bar), the perceived contrast on the left side is almost identical to that on the right side (a 0.05-log unit difference), and that the discrepancy between sensitivity ratios and PSE ratios is highly significant ($p < 0.0001$, combined *p*-values of individual one-sided Wilcoxon sign rank tests; $p < 0.002$ for only the low-contrast reference, same test). In other words, the perceived contrasts of the visible targets were roughly the same on the left and right sides. When invisible targets were counted in the PSE computation as zero perceived contrast, the group average difference between left and right was larger, but still small (0.15 log units) relative to the sensitivity difference of 0.38 log units, with the difference between the two being highly significant ($p < 0.001$, same test).

An important aspect of the data is the number of trials in which the patients reported invisibility of the peripheral patch. The percentage of these trials appears in Fig. 2a above each PSE-filled bar and shows cases of high skip rates (e.g. 40% for KE). Note that an error rate of about 20% was expected on the left side for the contrast threshold condition (1×Thr), which is expected to reflect 79% detection; thus, very high skip rates point to a conservative decision strategy that adopts a high criterion. A high criterion is also implicated by the very small numbers of FAs, as observed in the detection experiments. In comparison, skipped trials on the right side occurred in less than 5% in all patients, also as expected, given that the reference contrast used was the left-side threshold, highly above the right-side threshold. This indicates that highly above threshold patches presented to the non-affected USN hemifield were almost always visible, but not so for the left side (for example, patient KE failed to perceive the patch presented on his left hemifield and set at twice its threshold in 30% of the trials).

The current study demonstrates that although USN patients can have contrast thresholds about twice higher on their left than on their right hemifields, their perceived contrast on the left-side is much less attenuated. This was shown by first measuring the contrast detection threshold on each side for a small Gabor patch and then measuring its perceived contrast when at threshold or twice the threshold by asking the patients to compare its contrast to a central patch presented half a second later. We obtained two measures for the point of subjective equality (PSE) of the contrast: one that ignores trials in which the target was reported invisible, and another, more conservative, where the invisible targets were included in the PSE computation and were taken to represent zero perceived contrast. The more conservative measure (Fig. 2b, right-hand bar) shows perceived contrast attenuation of less than half of the sensitivity deficit (left-hand bar). When invisible targets were ignored, the estimated perceived contrast was almost identical across sides so that whenever the patients saw the target, they saw it with the correct contrast.

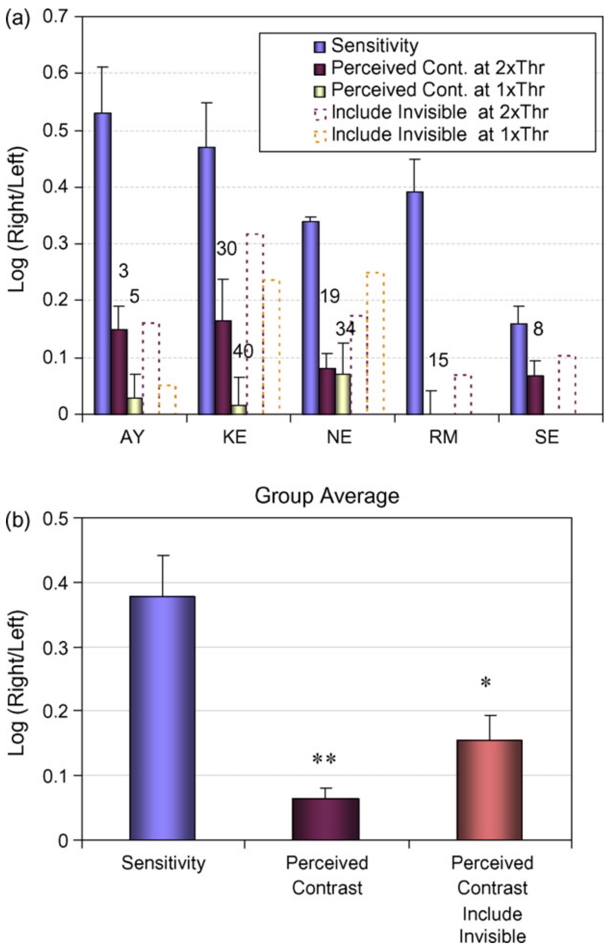

Fig. 2. Sensitivity and perceived contrast ratio between the right and the left sides for five USN patients. The sensitivity ratio is expressed in log scale (log of the threshold ratio left/right, equivalent to the sensitivity ratio right/left). Perceived contrast difference is expressed in terms of a difference in the point of subjective equality on a log scale, as measured for two different contrast levels (at threshold and twofold). Error bars show one standard error of the mean. Patients RM and SE were only tested on twice the threshold. (a) Individual data. There are two bars for the two contrast levels for which the skipped trials (invisible target) were ignored (filled bars) and two bars where skipped trials were included, averaged as zero contrast (dotted empty bars). The numbers above each bar reflect the percentage of the skipped trials. (b) Group averages in which data for the two contrast levels (except for two patients) were first averaged within a patient and then over the whole group. The sensitivity ratio is compared to the perceived contrast ratio, with (right bar) and without (middle bar) including the skipped trials as zero contrast in the average. Note the difference between the large ratio of contrast sensitivity and the smaller ratio of perceived contrast, even when skipped trials were included in the calculation. These differences were highly significant, see text. (For interpretation of the references to color in the artwork, the reader is referred to the web version of the article.)

The high rate of left-side skipped trials, even for patches set at twice their detection threshold, requires further clarification in relation to the two perceived contrast estimates. If the invisibility of the targets reflects an attenuated internal response, then ignoring these trials will be equivalent to truncating the lower part of the response distribution and will bias the perceived contrast estimate upwards, making the left-side measure more similar to the right side. It follows that the corrected PSE computation (where these trials were counted as zero perceived contrast) represents a lower bound PSE estimate. On the other hand, if the source of invisibility is unrelated to the contrast response function but reflects instead an extinction process or inattention, then the non-corrected PSE computation (where skipped trials are ignored) is a better perceived contrast estimate that shows that USN patients exhibit normal perceived contrasts.

There are several arguments against an account of skipped trials (invisible stimuli) in terms of an attenuated internal response (and, as a consequence, of using the "corrected" PSE measure above). First, one patient (AY) showed a large left- vs. right-side sensitivity difference (0.5 log units) and a small perceived contrast difference (0.15 log units) despite his very few (<5%) skipped trials. Second, if the skipped trials affect the estimated perceived contrast significantly, the skip rate should correlate with the perceived contrast attenuation, as assessed when these trials are ignored; no such correlation was found ($r = -0.01$). Third, the high skip rate could reflect extinction by the central (probe) patch presented 500 ms after the peripheral patch. Indeed, extinction was shown to operate within a ±600 ms temporal window [6]. Also, when tested in a separate extinction experiment where lateral and central patches similar in parameters to those used here were presented simultaneously (see [20] for details), patients KE and NE (showing high skip rates in the present experiments) also showed relatively high extinction rates. This suggests that the source of the invisibility could be extinction and not an attenuated internal response. In sum, our results appear to show that whenever USN patients do see the contrast patch, they see it with a normal or close-to-normal contrast. We will now elaborate on the putative *sensory attenuation* vs. the alternative *attentional gating* interpretation of the current results.

A priori, the *sensory attenuation* hypothesis refers to a contrast processing dysfunction of the affected neural pathway at an early processing stage (e.g. V1). However, since none of the present patients had any visible damage to the occipital lobe, this dysfunction must involve higher levels, possibly efferent neural signals subtending, for example, a top-down attention gradient biased in favor of the right hemifield. If so, and given the present perceived contrast results, it should be assumed that in order to compensate for such a left-side attenuation (and hence to achieve "contrast constancy"), the system re-calibrates the attentionally degraded signal. The recalibration account is suggested by the work on contrast constancy in normal observers [8,9], where despite large differences in contrast sensitivity across different spatial frequencies, the perceived contrast at supra-threshold levels is identical. The relative reduction in sensitivity for high spatial frequencies in normal observers is attributed to the optics of the eye, which is fully compensated for supra-threshold stimuli at a higher processing level. However, the fact that for close-to-threshold stimuli, contrast constancy breaks down in normal but not in the present USN observers, raises doubts as to the validity of the contrast constancy account in USN patients. This inconsistency brings us to the alternative, most likely *attentional gating* hypothesis discussed next.

The *attentional gating* stand posits that the signal is not attenuated at the early filtering stages, but instead, that the failure to detect a stimulus is due to an attentional mechanism dissociated from the bottom-up processing. This attentional process, possibly related to the perceptually monitored decision criterion [10,11], would act as a gate – when the gate opens, the stimulus is perceived normally – otherwise it is not perceived at all. This explanation is consistent with the notion of "attentional units" that represent the "where" of an object [5]. When the incoming signal exceeds the threshold/gate of these "where units" (presumably in the parietal lobe), the resulting perception is normal. In USN, these units are damaged and their activation requires stronger input (higher contrast). The prediction is that unlike "contrast constancy" in normal observers, the patients will show perfect "perceived contrast" whether the stimulus is set at or above threshold, although the number of trials with invisible patches could be large.

In summary, we found that USN patients exhibit reduced contrast sensitivity on their contralesional side, and often miss on this side non-salient stimuli. Despite the large contrast sensitivity difference between the sides, the attenuation in perceived contrast on the contralesional side is small. We suggest that contrast sensitivity reduction in USN is not due to a peripheral attenuation, but rather to a high-threshold attentional mechanism preventing sensory events from reaching awareness.

Acknowledgements

We thank Dr. Edna Schechtman for valuable statistical advice. This study was supported by grants from the National Institute for Psychobiology in Israel founded by The Charles E. Smith Family to Y. Bonneh and M. Pavlovskaya. A. Gorea was partly supported by a grant ANR-06-NEURO-042-01.

References

[1] P. Angelelli, M. De Luca, D. Spinelli, Contrast sensitivity loss in the neglected hemifield, Cortex 34 (1998) 139–145.
[2] P. Angelelli, M. De Luca, D. Spinelli, Early visual processing in neglect patients: a study with steady-state VEPs, Neuropsychologia 34 (1996) 1151–1157.
[3] E. Bisiach, C. Luzzatti, Unilateral neglect of representational space, Cortex 14 (1978) 129–133.
[4] M. Carrasco, S. Ling, S. Read, Attention alters appearance, Nat. Neurosci. 7 (2004) 308–313.
[5] J. Cohen, R. Romero, M. Farah, D. Servan-Schreiber, Mechanisms of spatial attention: the relation of macrostructure to microstructure in parietal neglect, J. Cogn. Neurosci. 6 (1994) 377–387.
[6] G. Di Pellegrino, G. Basso, F. Frassinetti, Spatial extinction on double asynchronous stimulation, Neuropsychologia 35 (1997) 1215–1223.
[7] J. Driver, P. Vuilleumier, Perceptual awareness and its loss in unilateral neglect and extinction, Cognition 79 (2001) 39–88.
[8] J. Fiser, P.J. Bex, W. Makous, Contrast conservation in human vision, Vision Res. 43 (2003) 2637–2648.
[9] M.A. Georgeson, Contrast overconstancy, J. Opt. Soc. Am. A 8 (1991) 579–586.
[10] A. Gorea, D. Sagi, Natural extinction: a criterion shift phenomenon, Vis. Cogn. (2002) 913–936.
[11] A. Gorea, D. Sagi, On attention and decision, in: l. Itti, G. Rees, J. Tsotsos (Eds.), Neurobiology of Attention, Academic Press/Elsevier, 2005, pp. 152–159.
[12] P.W. Halligan, G.R. Fink, J.C. Marshall, G. Vallar, Spatial cognition: evidence from visual neglect, Trends Cogn. Sci. 7 (2003) 125–133.
[13] L.V. Hedges, I. Olkin, Statistical Methods for Meta-analysis, Academic Press, San Diego, 1985.
[14] G. Kerkhoff, Spatial hemineglect in humans, Prog. Neurobiol. 63 (2001) 1–27.
[15] M. Kinsbourne, Orientational bias model of unilateral neglect: evidence from attentional gradients within hemispace, in: I. Robertson, J. Marshall (Eds.), Unilateral Neglect: Clinical and Experimental Studies, Lawrence Erlbaum Association, Hove, 1993, pp. 63–86.
[16] H. Levitt, Adaptive testing in audiology, Scand. Audiol. Suppl. (1978) 241–291.
[17] A.D. Milner, M. Harvey, C.L. Pritchard, Visual size processing in spatial neglect, Exp. Brain Res. 123 (1998) 192–200.
[18] M. Pavlovskaya, D. Sagi, N. Soroker, Contrast dependence of perceptual grouping in brain-damaged patients with visual extinction, Spat. Vis. 13 (2000) 403–414.
[19] M. Pavlovskaya, D. Sagi, N. Soroker, H. Ring, Visual extinction and cortical connectivity in human vision, Brain Res. Cogn. Brain Res. 6 (1997) 159–162.
[20] M. Pavlovskaya, N. Soroker, Y. Bonneh, Extinction is not a natural consequence of unilateral spatial neglect: evidence from contrast detection experiments, Neurosci. Lett. 420 (2007) 240–244.
[21] M.I. Posner, J.A. Walker, F.A. Friedrich, R.D. Rafal, How do the parietal lobes direct covert attention? Neuropsychologia 25 (1987) 135–145.
[22] B. Wilson, J. Cockburn, P. Halligan, Development of a behavioral test of visuospatial neglect, Arch Phys Med Rehab 68 (1987) 98-L102.