Bisection and visual exploration strategy in hemineglect: eye-movement measures for rehabilitation treatment

Matteo Sozzi [1] **- Michela Balconi** [2]
Luigi Pisani [1] **- Claudio Mariani** [3]

[1] *Department of Neuro-Rehabilitative Sciences, Casa di Cura Privata del Policlinico, Milan, Italy*

[2] *Research Unit in Neuropsychology of Language, Department of Psychology, Catholic University of Sacreted Heart of Milan, Italy*

[3] *Unit of Neurology, Hospital L. Sacco, University of Milan, Italy*

doi: 10.7358/neur-2013-013-sozz m.sozzi@ccppdezza.it

Abstract

Aim of this study is to explore behavioral responses and eye movements of unilateral neglect patients in a virtual bisection task. Space to be bisected was included between two endpoint, segment length together with segment spatial dislocation were varied in order to test the presence of a "gradient effect" in both bisection behavior and visual exploration. Ten right neglect patients took part to the study, all data were then matched with those obtained from ten healthy participants. Behavioral measures (bisection and RTs) and eye-movements (fixation count and duration; first fixation count) were analyzed. Consistent spatial biases were found for bisection responses, RTs, fixation count and duration, as well as for the first fixation count. We then find a significant rightward bias in patients, i.e. increasing rightside bisection and rightward fixations when the stimuli were in the extreme left-position. Concerning merely segment length, we observed significant differences between-groups only for eye movement behavior, with increased rightward fixation count and duration in response to longer segments. In conclusion, "left-to-right" and "longer-to-shorter" continuous-gradient effects were not totally supported by our results, whereas an "extreme-left" gradient effect was suggested and discussed.

Keywords: Spatial neglect; Bisection task; Visual search; Eye movement measures; Spatial gradient

1. Introduction

Neglect patients generally show an inability to take into account information coming from the left side of space. Typical symptoms of neglect are rightward bias in line bisection and left-side deficits in visual search task (Bisiach & Vallar, 1988). Systematic spatial biases in the visually guided actions were observed for patients with right hemisphere damage. Symptoms are supramodal and involve generally vision, motor activity, tactile sensation, hearing or olfaction. Moreover, neglect may affect different spatial planes, such as personal, peripersonal, extrapersonal, representational, and may be space- or object-centered, referring to an egocentric or object-centered reference frame. Different neural networks were indicated as the anatomical correlates of neglect, such as temporo-parietal junction and the inferior parietal lobule (Vallar, 2001). Rostral portions of the superior temporal gyrus was suggested, highlighting the central role of ventral visual stream in spatial perception (Milner & Goodale, 1995). In addition insula and basal ganglia were reported to be a critical focus of neglect (Karnath, Fruhmann Berger, Küker & Rorden, 2004).

Many theories tried to explain this specific syndrome, claiming about perceptual, representational or motor explanations. In the first case it was underlined that many neglect patients underestimate the horizontal extent of stimuli presented in leftward locations (Milner, Harvey & Pritchard, 1998). Secondly, motor deficits were represented as the patients' inability to respond to the controlesional stimuli (Harvey, Olk, Gilchrist & Muir, 2002), that is patients may be slower to initiate a motor response to targets appearing in the left hemispace, even when using their unaffected arm (directional hypokinesia). The core symptom of motor neglect is under-utilization of contralesional limbs without hemiparesis, ataxia, extrapyramidal symptoms, or sensory neglects deficits. This under-utilization is characterized by marked reversibility when someone strongly encourages the patient to use the limbs (Coulthard, Rudd & Husain, 2008).

In accordance to attentional model, neglect is a consequence of a hemispherical imbalance, since when an hemisphere is lesioned, the intact one biases attention towards the ipsilesional side (Kinsbourne, 1993). In this case, the contralesional hemifield (generally the left) would show a gradient of decreasing attentional performance from the centre to the periphery, and, contrarily, an inverted gradient would increase from center to periphery in the ipsilesional hemifield. A similar model based upon the concept of attentional shift was proposed, where parietal lesions would produce a selective impairment of a disengagement mechanism causing difficulties in redirecting attention towards the contralesional side (Posner, Walker, Friedrich &

Rafal, 1984). Reaction time tasks supported this model, although successive studies showed the disengagement deficit is consistent for peripheral but not for central cues (Losier & Klein, 2001). Moreover, Heilman (1979) assumes that the human attentional system consists of two circuits: a first network connecting the thalamus, inferior parietal cortex and the prefrontal cortex subserves spatial attention; a second network connecting the supplementary motor area (SMA), the basal ganglia and the prefrontal cortex subserves intentional neglect. The right hemisphere would be responsible for both hemifields, while the left hemisphere would be just serving the contralateral right hemisphere. Damage to this attentional system causes neglect. This model explains why right-hemispheric damage leads to a more pronounced neglect and it also predicts that, depending on the site of damage, different types of neglect (sensory versus motor neglect) will occur.

Different variables were found to affect the patients' performance in left side direction. The type of task used was found to be relevant, such as in case of a selection task (Schubert & Spatt, 2001) or a bisection procedure (McIntosh, Schindler, Birchall & Milner, 2005). In case of bisection some adjunctive factors may have a significant role, as the segment length (Nichelli, Rinaldi & Cubelli, 1989), and the segment spatial localization (on more left or right side) (Heilman, 1979), as well as the presence of a solid line or an unfilled gap between two points (McIntosh, McClements, Dijkerman & Milner, 2004). About the last variable, it was found the rightward bias in line bisection in patients tends to be reduced when gaps are presented instead of lines (Bisiach, Pizzamiglio, Nico & Antonucci, 1996). This result was explained taking into account the importance of the fact patients direct their attention to both the endpoints of the line (Ishiai, Koyama, Seki, Hayashi & Izumi, 2006; Ishiai, Seki, Koyama & Okiyama, 1995). Secondly, it was observed the specific effect produced by different segment length, with more rightward bias for longer lines (Bisiach, Bulgarelli, Sterzi & Vallar, 1983; McIntosh, 2006), and as a function of spatial position within the left/right hemifield, with more rightward bias for lines presented at increasing leftward locations (Nichelli et al., 1989; Riddoch & Humphreys, 1983).

More generally, these results could be based on the relative importance and the weight given to each endpoint in determining the response. It was actually found that neglect patients attribute a lower weight to the left endpoint than to the right endpoint. Therefore, the bisection errors should increase as a function of left side orientation more than right side (McIntosh et al., 2004). Nevertheless, the presentation of two points, rather than a solid segment, could have opposite consequences in different patients: neglect may be magnified in some patients due to the increased salience of the right endpoint, whilst other patients might benefit from the greater degree of contralesional exploration required to identify the left endpoint of the gap. Generally, the reduction of rightward error for gap stimuli is much more common that the reverse pattern (Bisiach et al., 1996; Kerkhoff, 2000; McIntosh et al., 2004).

Taking into account the central role of left/right endpoints, in the present study we used a modified version of the classical bisection task (Bisiach, Rusconi, Peretti & Vallar, 1994), that is it unfilled segment determined by two ending points (McIntosh et al., 2005). Secondly, segment length and its spatial position were monitored, in order to verify the consistency of rightward bias increasing as a function of left-side dislocation more than right and of longer segments more than shorter.

In addition, the behavioral response may be integrated with eye-movement measure that includes the control of eye-movement during task execution (Sozzi, Balconi, Arangio, Pisani & Mariani, 2012; Balconi, Amenta, Sozzi, Cannatà, Pisani, 2013). As it was found in previous studies, it is important to monitor the eye behavior during a visual search task, in order to analyze the modality to explore the visual space by neglect patients during task execution (Himmelbach, Erb & Karnath, 2006; Müri, Cazzoli, Nyffeler & Pflugshaupt, 2009).

Central components of disorders typically characterized by reduced attentional performances such as neglect could be reliably described by means of eye movements (Malhotra, Coulthard & Husain, 2006; Van der Stigchel & Nijboer, 2010). Evidences supporting a left-to-right gradient, with improving performance from left to right side, were revealed by some studies based on eye movements (Behrmann, Watt, Black & Barton, 1997) or manual RTs (De Renzi, Gentilini, Faglioni & Barbieri, 1989). A marked lack of active exploration of the contralesional side was found, visual fixations and focus of attention being oriented towards the ipsilesional side (Barton, Behrmann & Black, 1998; Ishiai, Furukawa & Tsukagoshi, 1989; Sprenger, Kömpf & Heide, 2002). Nevertheless, the left-to-right gradient account was discussed and criticized by other researches, that underlined the presence of an orienting bias in neglect, with an increasing performance going from the most peripheral target location in the controlesional field to a limited off-set centered sector of the ipsilesional field (Fruhmann-Berger & Karnath, 2005; Harvey, Gilchrist, Olk & Muir, 2003; Marzi, Natale & Anderson, 2002; Natale, Posteraro, Prior & Marzi, 2005).

What determines whether a region of a stimulus is selected for fixation or omitted by gaze? It was showed that observers direct their gaze toward particularly informative regions. Therefore, fixation density and fixation duration during visual exploration are highest in regions rated as particularly informative, and the monitoring of fixation modulation becomes an important way to relate neglect deficit and visual exploration impairment. Secondly, types of task (for example bisection task vs. visual exploration) may affect patients' performance in relationship with the cognitive complexity of the task itself (Pflugshaupt et al., 2004). Moreover, although previous studies have carried out eye movement analysis, they have not specifically addressed the question of how attention is distributed as a function of stimulus position in the visual field and, secondly, of the relative distance of the segment endpoints, by adopting a bisection task.

In the present study we explored the eye movements behavior in three neglect patients during an online bisection task, taking into account fixations (first fixation time, the total fixation count and duration) in response to the specific modulation of segment length and segment spatial dislocation. Significant variations in fixation count and duration was attended as a function of these variables, with a general rightward bias in segment exploration (more fixations count and duration rightward-oriented) in case of more left-side dislocation and in case of longer segments. Secondly, the relative left-to-right gradient effect could be tested to support the continuous increasing rightward bias from ipsilesional to contralesional side (Behrmann et al., 1997; Fruhmann-Berger & Karnath, 2005).

Finally, different exploration patterns in relation to the gradient effect hypothesis are expected to provide important suggestions to potentiate new techniques for rehabilitation of neglect patients.

2. Method

2.1. Participants

Ten neglect patients took part to this study; all of them presented a right hemisphere lesion and a visuo-spatial neglect assessed by means of clinical and neuropsychological evaluation. None had history of dementia or psychiatric problems. Neuropsychological assessment concerned the administration of well-known tests, including the BIT (Wilson, Cockburn & Halligan, 1987), the figure and shape copying, and testing for personal neglect (Bisiach et al., 1996; Gainotti, Messerli & Tissot, 1972). All the three patients presented similar and consistent deficits, that may suggest an analogous severity of their neglect syndrome. Furthermore, no one of them showed a visual field deficits at visual field examination.

Ten healthy participants underwent to the same experimental procedures as control subjects (4 females; 6 males); they were matched with patient group in age (controls mean = 68.81; *S.D.* = 3.4) handedness and education (mean = 13.60; *S.D.* = 0.81). No neurological or cardiovascular diseases were present, and they all had normal or corrected to normal vision in both eyes. Both patients and controls gave their written consent to participate to the experiment and the local ethical committee approved the study.

2.2. Stimulus and setting

Bisection stimuli were horizontal gaps represented by two red points of the same dimension (20 mm – 1.64°), one to either side of the midline, that were presented, after a fixation point, on a white background for a duration of 5000 ms, followed by a 5000 ms blank. A fixation point was presented at the center of the screen. Segment parameters varied from trial to trial in terms of length (from shorter to longer) and spatial horizontal location (from extreme left to extreme right of the visual field). For the first condition, we used six different lengths (20 mm – 1.64°; 40 mm – 3.27°; 80 mm – 6.55°; 120 mm – 9.82°; 160 mm – 13.10°, and 240 mm – 19.64°). In this case segment maintained an identical spatial position and the segment midpoint coincides with the screen midline. Secondly, with respect to the spatial dislocation, equal segment could appear in five different positions (respectively left localized: -60 mm, -20 mm; 0 mm, coincidence with the midline; right localized: +20 mm, +60 mm) (Figure 1).

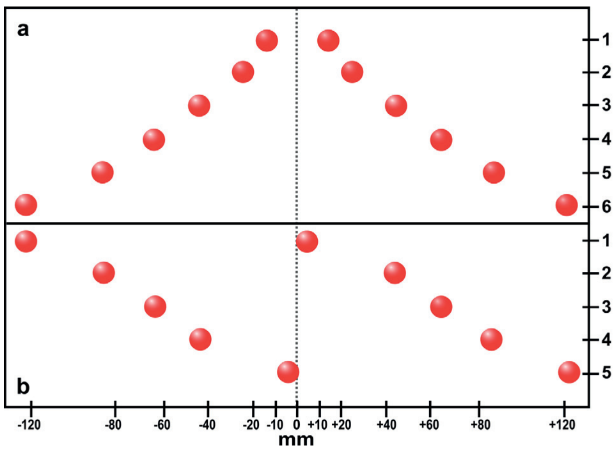

Figure 1. Visual stimuli (gap lines). Segment length levels (from shorter to longer) and spatial dislocation (from left to right)

Each possible level in terms of length and dislocation was replicated for 20 times, for a total of 200 trials. In the bisection task subjects were asked to judge the midpoint between the two endpoints of a virtual line (empty space). Each subject completed 3 blocks of 65-65-70 trials respectively. Stimuli within each block were presented in a pseudo-random order, preventing the same configuration to be repeated for more than one time consecutively. The order was varied between the three subsequences and across- the subjects.

PHASE 1: ONLINE BISECTION TASK

2.3. Procedure

Subjects were required to mark the midpoint in the gap between the two points with a mouse in the right hand. All trials began with the onset of two points lasting until response; partecipants were told to find the exact midpoint between the two points on the screen by means of the mouse devise; they were told to give the most accurate response without time limit. For each trial participants had the opportunity to see they response but no correct solution were provided. Moreover, all of them were required to move their hand from the mouse after each response to prevent them adopting an invariant response position. The experimental task was preceded by a familiarization task in order to allow a training in using the mouse (Figure 2).

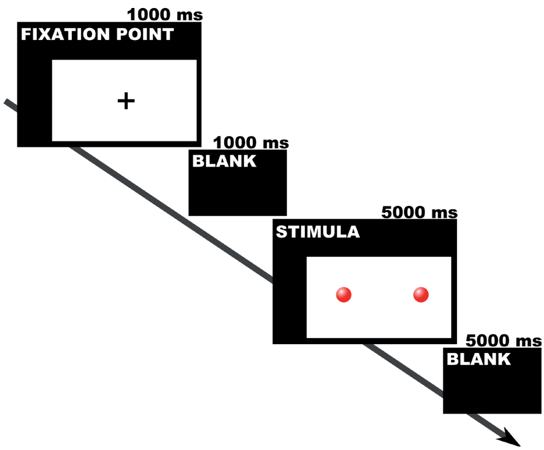

Figure 2. Experimental device and procedural steps

3. Results

3.1. Data analysis

The behavioral dependent measure was the space between the position of the response and the real bisection point. An index (*In*) was calculated to obtain the magnitude of asymmetry: we so considered the distance between the real midpoint and the point indicate by the patient (Milner & McIntosh, 2004). A positive value represents a more right asymmetry in the subjective bisection response. Moreover, the RTs were calculated for each bisection trial, taking into account the time required to execute the task from the segment onset, up to the effective bisection behavior.

To assess whether there were significant differences between patients and control participants, distinct repeated measure ANOVAs were applied to *In* and RT measure. Greenhouse-Geisser correction was adopted to compensate for violations of the sphericity assumption. Successive post-hoc paired comparisons were used in case of significance: η^2 coefficient was reported for each specific effect.

Secondly, linear regression analyses were performed: independent variables were respectively the segment length and the segment spatial position, and dependent variables were the *In* value and RTs. The second set of analysis was performed in order to test the linear relationship between segment length and segment spatial position and the magnitude of the asymmetry between the right and the left endpoints in subjects' response.

3.2. Segment length effect

Bisection. A repeated measure ANOVA with two factors (group 2 × segment length, SL, 6) was applied to the bisection response. Groups differed for *In* ($F(1,10) = 7.76$, $p \leq .001$; $\eta^2 = .31$), since patients showed an increased rightward bisection than controls. Contrarily, no significant effect was observed for group × SL ($F(5,10) = 1.06$, $p = .329$ 1; $\eta^2 = .07$) (Figures 3a and 3b).

RTs. Also RT measure showed significant differences between groups ($F(1,10) = 8.64$, $p \leq .001$; $\eta^2 = .39$), and group × SL ($F(5,10) = 7.12$, $p \leq .001$; $\eta^2 = .30$). In general, it was revealed an increased RT for patients than controls, more specifically in response to longer segments. In fact, contrast effects showed significant differences in response to the two longer segments (respectively $F(1,10) = 8.09$, $p \leq .001$; $\eta^2 = .33$; $F(1,10) = 7.78$, $p \leq .001$; $\eta^2 = .26$) for patients compared to controls (Figure 3b).

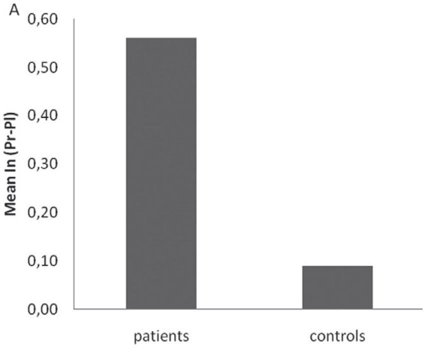

Figure 3a. Asymmetry index (right/left side comparison) in bisection task. Patients showed an increased rightward bias in bisection than controls

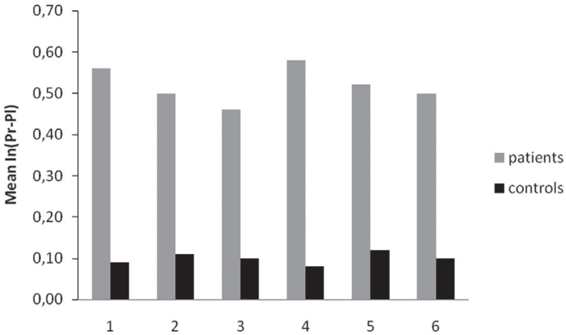

Figure 3b. Asymmetry index (right/left side comparison) in bisection task. No significant differences were observed between patients and controls as a function of segment lenght

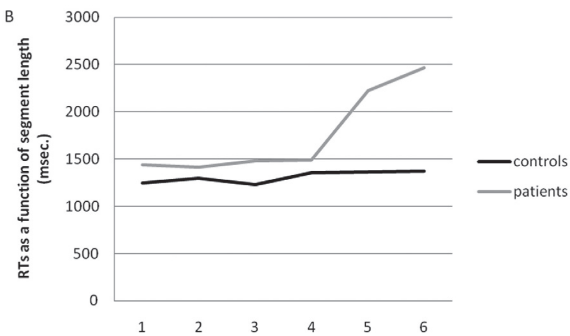

Figure 3c. RT modulation as a function of segment length (1 shorter; 6 longer). RT increasing was revealed for patients than controls in longer segments

The linear regression showed no significant effect of segment length on the *In* variations. Actually, the amplitude of *In* was not linearly accounted by segment length ($R = 0.29$, $R^2 = 0.08$, $t = 1.13$, $p = .22$). The same effect was found for RTs predicted variable, since no significant linear relationship was found between RTs and segment length ($R = 0.15$, $R^2 = 0.02$, $t = 1.11$, $p = .20$).

3.3. Segment spatial position effect

Bisection. Repeated measure ANOVAs with two factors (group 2 × segment dislocation, SP, 5) were applied to the bisection response, result analysis revealed significant group ($F(1,10) = 8.60$, $p \leq .001$; $\eta^2 = .35$), and interaction group × SP ($F(4,10) = 9.13$, $p \leq .001$; $\eta^2 = .40$) significant effects. In particular patients showed a rightward bisection bias compared to controls. Secondly, patients revealed a rightward bias in case of left-located segments in comparison with controls, respectively for the two leftward positions ($F(1,10) = 10.13$, $p \leq .001$; $\eta^2 = .42$; $F(1,10) = 10.09$, $p \leq .001$; $\eta^2 = .41$) (Figure 4a).

RTs. In addition, there were significant differences between groups for RT measure: generally it was found an increased RT for patients than controls in response to bisection task ($F(1,10) = 9.33$, $p \leq .001$; $\eta^2 = .39$). Moreover significant interaction group × SP ($F(4,10) = 7.13$, $p \leq .001$; $\eta^2 = .30$) showed patients increased their RT for the left-located segments than for the central and right position (all comparisons $p < .001$) (Figure 4b).

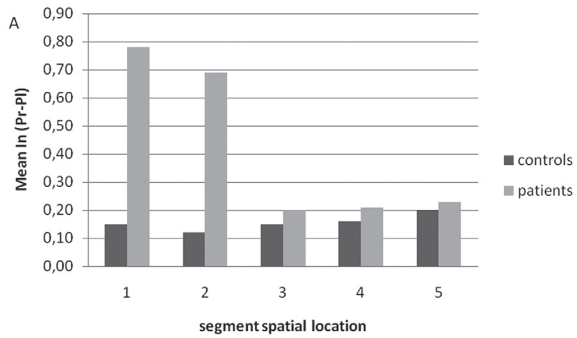

Figure 4a. Asymmetry index (right/left side comparison) in bisection task as a function of segment length (1 left-position; 5 right-position). Patients showed an increased rightward bias than controls in response to more leftward located segments

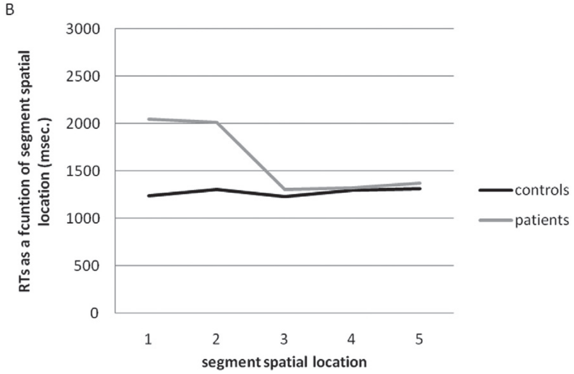

Figure 4b. RT modulation as a function of segment spatial location. Patients revealed increased RTs in response to more left eccentric segments

The linear regression analysis showed no significant effect of segment spatial position on *In* variations. In fact, the amplitude of *In* was not accounted by segment length ($R = 0.26$, $R^2 = 0.06$, $t = 1.01$, $p = .22$). Moreover no significant linear relationship was found between RTs and segment length ($R = 0.18$, $R^2 = 0.03$, $t = 1.03$, $p = .15$)

4. Discussion

Three main points can be elucidated by these results. Firstly a reduced weighting for the left endpoint is consistent with higher directional right bisection errors, increasing proportionally to the spatial dislocation effect and to the segment length. Secondly, the spatial gradient effect was not completely verified, since the side-effect was found only in response to specific "left-eccentric" positions. Finally, bisection behavior and RT measures showed similar profiles.

The segment length variable did not show consistent differences between groups as a function of the increasing of length level, whereas it was able to produce distinct performance for patients and controls in terms a systematic rightward bias for neglects patients. In other words, we did not found a real "gradient" from long-to-short that may justify a continuous rightward bias from shorter to longer segments (Kinsbourne, 1993; Müri et al., 2009). Regression analysis confirmed this assumption, since no linear relationship was found between segment length and rightward bias for both In and RT measures. In other words, the increasing of segment length did not systematically predict the increasing of attentional rightward bias.

In general it is observable a slight rightward bias in response to longer segments (that is the last two "longer" conditions) for patients, whereas no significant rightward error was observable for shorter segments. RTs partially confirmed these results, since it was observable a general increased RT for patients than controls, with significant higher RTs in response to longer segments. Nevertheless, in order to discuss the present results, we may state the gap line task may have modulated the error bias, making more relevant the endpoint cues and thus limitating the gradient effects, despite a general error bias effect for patients (McIntosh et al., 2004).

About the second parameter (segment spatial location) a main result concerns the relative rightward biases for neglect patients. Thus, we can state that the endpoints may have specific and independent influences on bisection responses, since a spatial dislocation effect was observed, with errors becoming more rightward for gap segments in further leftward position. It was hypothesized that, when a shift is presented for the segments (from right to left), the patients seem to look for an anchoring point more right located, underestimating the weight of the left located endpoint. In addition, no crossing-over effect was observed for more rightside positions, since patients produced a substantially normal performance in case of more rightside located segments (Halligan & Marshall, 1989). Nevertheless, previous studies found significant cross-over effect related to very short lines (generally 1-2 cm in length), whereas in the present research segments were longer (12 cm in length). For this reason, no conclusive remarks may be done on this effect in the present research. Also RTs increased as a function of more spatial left-side positions, showing an increased difficulty to produce the correct bisection response in case of a leftward visual cue.

However, the distribution of right-error bias showed a left-to-right horizontal gradient which was not linear but only responsive to the left spatially located stimuli. In other cases the patients performance was similar to the control performance with a quite correct bisection at midpoint. Regression analysis supported this considerations, since no linear effect of segment spatial position was observed on right-oriented attentional bias. We may state our results may be partially in contradiction to the orientational bias model by Kinsbourne (1993), supposing a constant increasing contralesional-ipsilesional gradient. On the other hand, they may be favorable to the model that hypothesizes a pathological expansion towards the contralesional side and a compression towards the ipsilesional one, and that rightward bias may demonstrate impaired automatic orienting towards the left eccentric stimuli. In addition, when the attracting right-cues are more salient (related to more longer segments and, more specifically to left-spatially oriented cues) its effect is consistent, whereas, when the left-right endpoints distinction is less relevant, the rightward bias is less consistent. In other words, the right "attracting" effect would be more relevant and effective in case of a significant spatial shift from right to left, becoming more significant the "underestimation" of the contralateral left-part of the segment in concomitance with an "overestimation" of the ipsilateral right-part giving support to techniques which involve an increasing salience of stimuli in controlesional spaces.

PHASE 2: EYE MOVEMENT MONITORING

5. Eye movement acquisition

Eye-movements were monitored by counting the total number of fixations, fixation length and direction of the first fixation, they were recorded using a infrared-based video tracking (Tobii X120). The system device registered data at sampling rate of 120 Hz with a spatial resolution of less than 0.3°. It provides an accuracy of gaze-position relative to stimulus coordinates of 0.5°. A chine rest was used to be sure of the constant distance and to minimize head movements. Fixation was defined as the stable horizontal and vertical eye position between the end of one saccade and the start of the following saccade; the fixation radius value (smallest distance that can separate distinct fixations) was set to 50 pixel, and minimal fixation duration was set to 100 ms. First fixation was considered as the first fixation directed towards the segment during task execution. Eventual first fixations not directed to the ROI (region of interest determined by the segment itself) were not considered for the analysis. Participants were seated 70 cm in front of a 16'' screen subtending a visual angle of approximately 27° × 21°. Eye movements of either the right or the left eyes were registered. The system was calibrated prior to each block of stimuli by mean of 3 × 3 point grid. The output of eye movement acquisition was a series of horizontal and vertical coordinates of each fixation period and its corresponding fixation duration. Left and right eye positions were determined taking into account the midline of the segment. Thus, we assumed a frame of reference (spatial coordinates) to subdivide the two left/right hemifields with respect to the stimulus, determined by the edges of the stimulus itself (Behrmann et al., 1997).

6. Results

6.1. Data analysis

The visual left/right shift of eye fixations from the stimulus midline was calculated for each trial. Successively a specific index was obtained comparing the right/left weight effect (see also previous procedure), expressed by the measure: EM = (right shift - left shift), where positive values represent a more rightward eye fixation. Distinct repeated measure ANOVAs were performed for the dependent variables of fixation count, fixation length, and first fixations count. Successively, linear regression analyses were applied to each predicted variables, respectively EM for fixation count, fixation length, and first fixation count. Predictor variables were the segment length and the segment spatial position.

6.2. Segment length effect

Fixation count. For the total fixation count, significant effects were observed for group ($F(1,10) = 7.34$, $p \leq .001$; $\eta^2 = .30$) and group × SL interaction ($F(5,10) = 9.10$, $p \leq .001$; $\eta^2 = .40$). Patients showed a general increased rightside fixation count than controls. In addition, they showed a rightward bias in response to longer than shorter segments. This result was observed between groups for the two longer segments (respectively $F(1,10) = 10.65$, $p \leq .001$; $\eta^2 = .42$ and $F(1,10) = 8.10$, $p \leq .001$; $\eta^2 = .37$), whereas no significant differences were revealed for shorter segments. Controls equally distributed fixations within the left and right side (Figure 5).

Fixation duration. About the fixation duration, statistically significant effects were found for group ($F(1,10) = 10.16$, $p \leq .001$; $\eta^2 = .38$) and interaction group × SL ($F(5,10) = 8.99$, $p \leq .001$; $\eta^2 = .35$). It was revealed a longer duration of fixations in rightside for patients than controls. Secondly, increased rightside fixations were found in response to longer segments for patients than controls (respectively $F(1,10) = 12.09$, $p \leq .001$; $\eta^2 = .44$; $F(1,10) = 10.70$, $p \leq .001$; $\eta^2 = .41$).

First fixation count. Finally, about the first fixation no significant differences were revealed*:* controls and patients showed an analogous exploration behavior, with an equivalent left/right first fixation localization.

The linear regression analyses showed no significant effect segment length on the EM variations, respectively for fixation count ($R = 0.28$, $R^2 = 0.07$, $t = 1.13$, $p = .13$), fixation duration ($R = 0.22$, $R^2 = 0.08$, $t = 1.45$, $p = .10$), and first fixation count ($R = 0.25$, $R^2 = 0.06$, $t = 1.12$, $p = .13$).

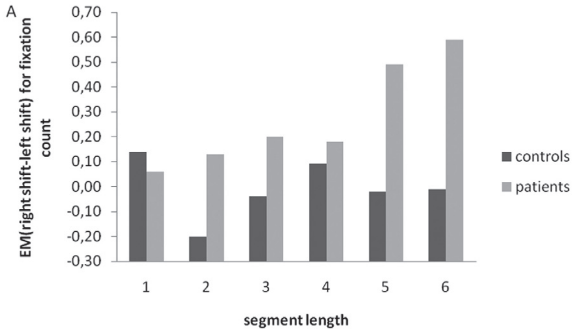

Figure 5. Asymmetry fixation index (count). A more rightward bias in the visual search (more fixation count towards segment rightside) was observed for patients than controls in response to longer segments

6.3. Segment spatial position effect

Fixation count. With regard to the spatial position effect, fixation count showed significant differences as a function of group ($F(1,10) = 8.13$, $p \leq .001$; $\eta^2 = .38$) and interaction group × SP ($F(4,10) = 9.33$, $p \leq .001$; $\eta^2 = .40$). Primarily, it was observed an increased number of fixations in rightside than left in patients than in controls. For all the successive comparisons it was revealed an increased number of rightside fixations for patients than controls in response to two more left-dislocated stimuli (comparisons significant at $p \leq .001$) (Figure 6a).

Fixation duration. About the fixation duration patients showed longer fixations within the rightside of segment than controls ($F(1,10) = 7.90$, $p \leq .001$; $\eta^2 = .33$). Secondly the interaction effect group × SP ($F(4,10) = 8.65$, $p \leq .001$; $\eta^2 = .35$) showed longer fixations in response to more left-located segments. Specifically, post hoc comparisons showed an increased rightward fixation duration for the two left-located segments for patients than controls ($F(1,10) = 9.34$, $p \leq .001$; $\eta^2 = .38$; $F(4,10) = 6.45$, $p \leq .001$; $\eta^2 = .28$) (Figure 6b).

First fixation count. The first fixation count showed a significant difference between groups ($F(4,11) = 7.89$, $p \leq .001$; $\eta^2 = .30$), with an increased number of rightside first fixations for patients than controls. Secondly it was found a more right side orientation of the first fixations as a function of group × SP ($F(4,10) = 12.09$, $p \leq .001$; $\eta^2 = .43$), since the two more left-dislocated segments showed an increased rightward first fixation for patients ($F(4,10) = 9.32$, $p \leq .001$; $\eta^2 = .39$; $F(1,10) = 10.05$, $p \leq .001$; $\eta^2 = .40$). Contrarily controls had a prevalent leftside first fixation towards the segments indistinctly from their location (all comparisons $p \leq .001$) (Figure 6c).

The successive linear regression analyses did not find significant effect of segment length on the EM variations, for fixation count ($R = 0.22$, $R^2 = 0.04$, $t = 1.11$, $p = .18$), fixation duration ($R = 0.20$, $R^2 = 0.04$, $t = 1.09$, $p = .23$), and first fixation count ($R = 0.30$, $R^2 = 0.09$, $t = 1.10$, $p = .23$).

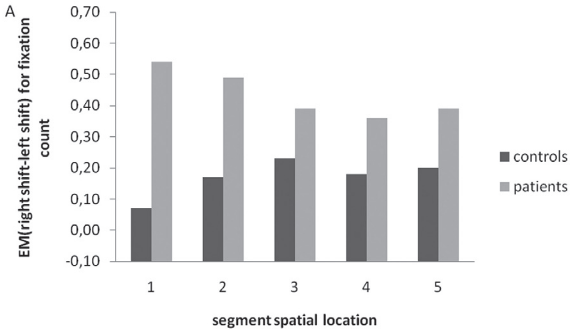

Figure 6a. Asymmetry fixation index (count). A rightward bias in the visual search (more fixation count towards segment rightside) was observed for patients more than controls in response to left eccentric positions

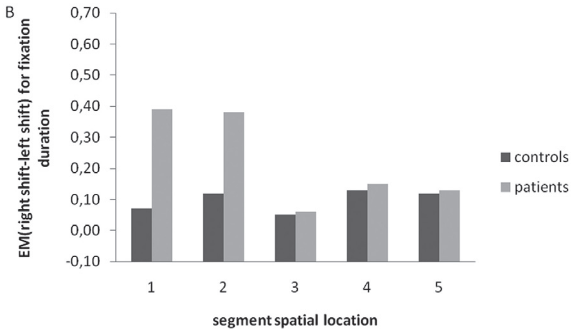

Figure 6b. Asymmetry fixation index (duration). A rightward bias was observed in the visual search (more fixation duration towards segment rightside) for patients more than controls in response to left eccentric position

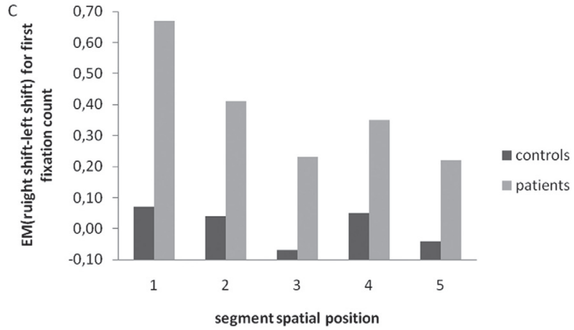

Figure 6c. Asymmetry fixation index (first fixation count). A rightward bias was observed for the first fixation count for patients more than controls in response to left eccentric position

7. Discussion

Visual-exploratory behavior in neglect could be explained as an exploration bias towards the right side of virtual segments; moreover our data showed that eye-movement analysis is consistent with the well-known spatial rightward bias during the bisection task. These results were found to be linked to the segment features, i.e. length and spatial position. Some specific effects should be additionally considered respectively in response to the spatial segment dislocation and segment length. In particular, about the latter, longer segments showed an increased eye rightward bias for patients, with more number of fixations and fixation duration in rightside of the segment. More specifically, patients produced more and longer fixations in the right part of the segment when they were observing longer than shorter segments. Our study confirms previous results reporting a significant anomaly in fixation measure, with a similar inter-field asymmetry observed for patients with regards to different eye measures (saccades and fixations: Chiba, Nishihara, Yamaguchi & Haga, 2008; Müri et al., 2009). Nevertheless, rightward bias in spatial visual orientation of neglect patients for longer segments did not result in a progressive facilitation (increasing of fixation count and duration) in the ipsilesional (right) part of the segment for shorter segment. Actually, a substantial equivalence of right/left side exploration was registered for patients in response to the central and rightsided segments.

Moreover the segment dislocation showed an increased rightward bias in response to more left-located segments, since fixation count and fixation length revealed a significant increasing for patients in rightside part of the stimulus. More specifically, fixation count and duration always presented a consistent rightward direction in response to the more extreme spatial positions (the left-side eccentric segments), whereas no between-group differences were observed in response to central or rightside segment positions. In fact, whereas patients exhibit a gradient of increasing rightward bias for the more eccentric left stimuli, the inverse gradient, with increasing better performance from the centre to the periphery of the right spatial position, was not supported. This is in contrast with left-to-right gradient hypothesis and may be explained taking into account a sort of "extreme gradient" related to the eccentric left side, and they induce to discard the "continuous gradient" proposed by previous studies that postulated a constant increasing performance from left-to-right (Kinsbourne, 1993). In parallel, the present results cannot confirm the hypothesis of a distorted distribution of visual exploring behavior that hypothesized neglect patients opt for an ipsilesional off-centered sector of space, as found in previous studies on exploration behavior (Natale, Marzi, Bricolo, Johannsen & Karnath, 2007) or RTs (Natale et al., 2005). Taking into account the significance of fixation measure in terms of attentional focus, we may suppose neglect patients in bisection task adopt an "anomalous" behavior only in case of very decentered cues, whereas quite normal performance characterizes their visual search in more central and rightward position.

The initial exploration behavior confirmed these results, since the first fixation was directed preferentially to the rightside part of the segment (Azouvi et al., 2002; Olk, Harvey & Gilchrist, 2002; Pflugshaupt et al., 2004). It was found left neglect patients have a tendency to orient initially rightward (Kinsbourne, 1993), increasing the probability that scanning will commence from this side and that errors are rightward. Nevertheless, no differences were revealed as a function of segment length, where both patients and control generally oriented equivalently towards the ipsilateral and controlateral side. In other words, the orientation bias in patients was observed only in response to left eccentric position, since only in this condition rightward first fixations prevailed on leftward ones.

8. Conclusion

The most striking feature of the neglect performance is that patients showed a consistent biases in their bisection response and eye movements. In neglect patients a systematic error is conducted with a pathological default position of the fixation behavior on the right side of the stimulus. More generally eye movements confirmed behavioral trend and contribute to describe the neglect patient error bias. As the segment progressed leftward, they made significantly fewer and shorter fixations on the left part of the segment in favor to the right one. In addition, for the "extreme left position" it was observed the neglect patients initiate (first fixation) their search to the right of the segment midline.

Nevertheless, the left-to-right gradient of attentional orienting predicting a progressive improvement of patients' performance from the extreme contralesional to the extreme ipsilesional side cannot totally explain the spatial distribution of bisection and the eye behavior found in the present experiment. Previous studies observed a stable pattern of exploration behavior, namely that in neglect patients fixation distribution was shifted towards the ipsilesional side (Karnath, Niemeier & Dichgans, 1998). In line with these results, we have observed a significant rightward bias for stimuli presented at the extreme left side of the visual field, but an absence of continuous gradient shifting from left-to-right side position, as well as the absence of a central facilitation effect. Other studies presented a gradient of fixation distribution left-to-right within a displacement of the peak of the fixation distribution curve that was not located at a medium eccentricity (Behrmann et al., 1997). We can explain these findings as evidence for a bilaterally constrained ocular explanatory space in neglect patients, where the right-side of the stimulus is more scanned and processed in comparison with the left side especially when the stimulus is presented in the left hemifield. Moreover, these results in tandem with the eye movement measures, may evidence a systematic line bisection left-gradient, where both behavioral bisection and visual search converge to define patient inability to attribute the same attentional relevance to the two endpoints, in favor to the right one (Ishiai, Koyama, Seki & Nakayama, 1998).

Concerning implications for rehabilitative procedures, we know that there is a general classification of rehabilitation approaches in two main groups: top-down mechanisms and bottom-up processes. The latter ones are based one stimulation aimed to reduce the visuo-spatial deficit (e.g. ear caloric stimulation, optokinetic stimulation, TENS etc.). On the other hand top-down mechanisms characterized by continuous active scan of the peripersonal space throughout specific visuo-spatial exercises. These scanning therapies can have several forms: trainings characterized by insight-oriented instruction or, programs in which instructions may be incidentally given to orient eye movements and motor executions (Pizzamiglio, Guariglia, Antonucci & Zoccolotti, 2006; Sozzi et al., 2012).

Present data are in line with our previous results obtained by different sample of patients on bisection and virtual grasping tasks (Balconi, Sozzi, Ferrari, Pisani & Mariani, 2012). The sum of our findings could be then considered in realization of top-down mechanisms of rehabilitation: the attentional relevance of endpoints stimuli may be considered as attentional cues which guide the subject visual search and, consequently, the limitation of neglect bisection errors for gap stimuli could depend on the greater degree of attentional implicit cueing in gap line bisection.

Future research should verify the presence of similar differences between left-right endpoints when a continuous line is provided to be bisected. If fact we may suppose the present results are directly produced by the attentional relevance the two endpoints have in conditioning subjects' performance. Secondly, in order to generalize the main results of the present research, we are aware about the fact that the patient sample should be increased, taking into account especially the heterogeneity of lesional sites (such as parietal and frontal sites) that may introduce important variable in attentional spatial deficits. Thirdly, it seems important to underline that severity of neglect syndrome may be very different between-subjects and this element may introduce important factor to explain the gradient effect modulation; this variability in gradient effect may subserve implementation of cognitive techniques based upon eye-movement monitoring as a rehabilitation training for visuo-spatial neglect.

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