Neuropsychologia 48 (2010) 3245–3251

Contents lists available at ScienceDirect

Neuropsychologia

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

The vertical–horizontal illusion in hemi-spatial neglect

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ARTICLE INFO

Article history:
Received 23 December 2009
Received in revised form 24 April 2010
Accepted 2 July 2010
Available online 17 July 2010

Keywords:
Vertical–horizontal illusion
Hemi-neglect
Bisection

ABSTRACT

The vertical–horizontal illusion is a robust phenomenon of length mis-estimation between two orthogonal lines. This illusion involves an anisotropy component that makes the vertical line appear longer than the horizontal one and a bisection component that makes the bisected line shorter than the bisecting one. Six patients presenting a moderate left hemi-neglect (N-patients) were compared to four right brain damaged patients without neglect (RH-patients) and with control participants in the perception of various spatial configurations of the vertical–horizontal illusion. Relative to controls, we found that both components of the illusion increased in patients: the anisotropy component rose from 5 to 11% and 10% (for N- and RH-patients, respectively) and the bisection component from 17 to 22% and 20% (for N- and RH-patients, respectively). In addition, we found that an horizontal-'T' figure oriented to the left produced much less bias than the same figure oriented to the right. These results are discussed in light of explanations based on attentional disengagement from an image junction and strength of the representation of objects extending over the neglected side.

1. Introduction

In the contemporary literature on spatial neglect, a debate prevails between representational and attentional accounts of left neglect after right brain damage (for a review, see Kerkhoff, 2001). A central aspect of the representation account is a perceptual distortion of objects in the left part of visual space (e.g., Ferber & Karnath, 2001; Milner & Harvey, 1995). Perceptual distortions also occur in observers with no neurological damages for specific stimuli such as the vertical–horizontal illusion. The purpose of the present study is to compare the strength of this illusion between right brain damage and control participants, in order to better understand which aspects of the perceptual distortion are responsible for the neglect effects.

Visual illusions often provide important clues for perceptual mechanisms (Gregory, 1991) and the vertical–horizontal illusion is a strong and popular example of perceptual distortion (Künnapas, 1955, 1957; Valentine, 1912/1913). When observers have to judge the length of a vertical and a horizontal line of the same physical length (see Fig. 1A and B), they typically over-estimate the length of the vertical line. Two main hypotheses have been made in the literature to explain the processes leading to the vertical bias, one related to the depth interpretation of two-dimensional drawings (Gregory, 1991, 1997; Williams & Enns, 1996; Woodworth, 1938), and the other to some intrinsic properties of the visual system (e.g., Künnapas, 1955).

According to the first hypothesis, the illusion figure is seen in perspective in such a way that the vertical segment is interpreted as a vertical line in a slanted plane receding into the distance. For instance, Woodworth (1938) argued that observers should perceive the stimuli extending in depth, out of the picture plane. This depth hypothesis relies on the misapplication of size-constancy scaling by assuming that the vertical dimension is subject to a foreshortening of objects lying on the (invisible) ground plane. The size-constancy scaling would lead to a vertical line length overestimation. In agreement with this hypothesis, vertical overestimation increases in natural scenes, presumably because more pictorial cues are available (e.g., Von Collani, 1985; Williams & Enns, 1996).

The alternative hypothesis to explain the vertical bias relies on some intrinsic properties of the visual system, more specifically the visual field anisotropy. In general, the closer a line extends toward a surrounding frame, the longer it appears (Künnapas, 1955). Because the overall visual field (i.e., left and right eyes combined) is a horizontally oriented ellipse, vertical lines will generally be closer to the boundary of the visual field than will the horizontal lines, and hence vertical lines should appear longer. Experiments to test this hypothesis were carried out by Prinzmetal and Gettleman (1993).

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doi:10.1016/j.neuropsychologia.2010.07.002

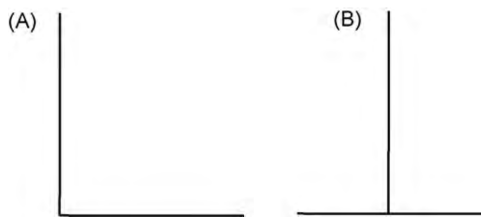

Fig. 1. Two visual illusions of length. Wolfe et al. (2005) called stimulus. (A) The vertical–horizontal illusion and stimulus. (B) The bisection illusion. In each, the vertical line appears to be longer than the horizontal line.

They showed that the illusion was reduced with monocular presentation, presumably because the monocular visual field is more circular than the binocular one.

While both hypotheses are still investigated, it is clear that they cannot fully account for the length illusions by themselves. In particular, the vertical–horizontal illusion is strongly affected by the spatial configuration of the figure and by its orientation in the image plane (Künnapas, 1955). In a recent study, Wolfe, Maloney, and Tam (2005) studied a wider range of stimuli than just the traditional illusion configurations. Each of their stimuli consisted of two-line segments joined at a point (Fig. 1). They named Fig. 1A, the "vertical–horizontal illusion" and Fig. 1B, the "bisection illusion". The magnitude of the two illusions varied with the viewing conditions, but the former illusion is usually stronger than the latter. They developed a model that combined a preference for a 3D interpretation of intersecting lines as orthogonal with a bias toward interpreting the stimulus configuration as slanted away from the line of sight (both of them are well-known prior constraints for the visual interpretation of scenes; Mamassian & Landy, 1998). Contrary to the prediction based on the orthogonal preference hypothesis, they found that deviations from a right angle in the vertical–horizontal configuration (Fig. 1A) led to an increase in illusion only if the angle was made obtuse. If the angle was made acute, a decrease in the illusion, and sometimes a reversal, resulted. This result is inconsistent with a model containing only assumptions about a preference for orthogonality.

In spite of its long history, a complete explanation of this phenomenon is still elusive (for a recent review, see Wolfe et al., 2005). One of the reasons for the elusiveness is that there are at least two separate factors at play (Künnapas, 1955). The first factor is an anisotropy between vertical and horizontal segments, i.e., a bias to overestimate the vertical length. The necessary second factor is a length bisection bias. According to this latter bias, a line that is bisected in two parts will appear shorter than if it were not interrupted (Finger & Spelt, 1947). We proposed a simple model of the vertical–horizontal illusion for various configurations of figures containing a vertical and a horizontal segments (see Mamassian & de Montalembert, 2010). This model is based on two bias parameters combined with the uncertainty to discriminate two lengths. The first bias parameter (parameter '*a*') stands for the anisotropy component of the illusion and represents the overestimation of a vertical segment relative to the horizontal one. The magnitude of this anisotropy bias was on average 6% in adult human observers. The second bias parameter (parameter '*b*') stands for the bisection component of the illusion and represents the underestimation of a segment when it is bisected. The magnitude of this bisection bias was on average 16%. This model involves a third parameter ('*c*') that is proportional to the uncertainty to estimate the length of a segment. This parameter is equal to 0.10.

In the present study, we were interested in how a population of right brain damaged-patients presenting left hemi-spatial neglect interpreted this illusion. The characteristic disturbance of unilateral spatial neglect is a deficient response to stimuli presented to the side contra-lateral to the affected brain hemisphere (Heilman, Watson, & Valenstein, 2003). Spatial neglect is observed following damage to various cortical regions including the parietal, temporal and frontal lobes (Karnath, Berger, Küver, & Rorden, 2004) or subsequent to subcortical lesions such as damage to the thalamus, putamen or globus pallidus (Karnath et al., 2004). Spatial neglect selectively affects different reference frames and regions of space such as personal, peripersonal and extrapersonal space (Buxbaum, 2006). Furthermore, patients sometimes neglect the left side of visual objects (object-based neglect) irrespective of their location is space (Driver & Mattingley, 1998).

Indeed, recent studies indicate that patients with visuo-spatial neglect tend to underestimate horizontal magnitudes in contralesional space. It has been recently hypothesised that this behaviour might be due to anisometry of space perception. Neglect patients tend to bisect horizontal lines ipsilesionally and underestimate the contralesional half of a line (e.g., Bisiach, Ricci, Lualdi, & Colombo, 1998) as well as horizontal objects located in the contralesional space (e.g., Milner & Harvey, 1995).

The following experiment aims at testing spatial perception deficit in left hemi-neglect patients with the use of the vertical–horizontal illusion. In particular, we were interested in comparing performances of right brain damage patients for stimuli oriented to the left *versus* to the right, and we hypothesized that left neglect patients should be impaired to analyze stimuli oriented to the left. We also propose to use this illusion to explore 3D perception of right brain damage patients, who might be specifically impaired in processing 3D scenes.

2. Methods

2.1. Participants

A total of six patients with left neglect (*N*) (mean age = 70.6 years, SD = 13.6, range = 43–78 years) and four patients with right brain damaged without neglect (RH) (mean age = 69.3 years, SD = 5.6, range = 62–75 years) participated in the experiment. Seven patients had a first single unilateral stroke (ischemic *N* = 7) in the right cerebral hemisphere and three other patients had a right hematoma (located in the internal capsule, and/or the thalamus, or the basal ganglia). All patients were right-handed and had no history of psychiatric disorders or dementia. The neuropsychological evaluation of each patient revealed no language disorders and no signs of apraxia or agnosia; none of the patients showed major verbal memory difficulties. All of them had a preserved comprehension of complex sentences. We created a program using Matlab to test hemianopia in patients. They were asked to detect whether a vertical or a horizontal line was present on a computer screen. Targets were presented in the left, right or both hemi-fields. None of them presented hemianopia or any other visual field deficit. This was confirmed with the BEN test (Azouvi et al., 2002; Rousseaux et al., 2001). We evaluated the severity of the spatial neglect for each patient using a set of clinical tests that is frequently used to assess neglect (Azouvi et al., 2002) including two visuo-motor exploratory tasks (line bisection and letter cancellation), a reading task, and a drawing copy task. In all tasks, the center of the display was located on the mid-sagittal plane of the patients' trunk; they were free to move their head and eyes. The patients' demographic and neurological features are summarized in Table 1.

Twelve participants (mean age = 62.42 years, SD = 10.5, range = 47–78 years) with no history or evidence of neurological damage served as controls. Ten of them were right-handed and two were left-handed. There were no difference in terms of age between the group of control participants and the group of patients ($F(1,20) < 1$, NS).

All patients and control participants had normal or corrected-to-normal visual acuity.

All participants gave informed consent prior to the study, but were naive concerning the specific aims of the experiment.

2.2. General neuropsychological evaluation

The neuropsychological neglect examination found no signs of spontaneous head and gaze deviation toward the right or the left side of space. All patients presented visuo-spatial and visuo-graphic impairments and their performance on executive function tests were generally mildly impaired (i.e., problems organizing and initiating actions).

For the Line Bisection Test, positive deviations were rightward for all right-brain-damage patients. The percentage of deviation corresponds to ((left distance − half of stimulus line length)/(half of stimulus line length)) × 100. A deviation greater