Activitas Nervosa Superior Rediviva Volume 63 No. 1 2021

ORIGINAL ARTICLE

Visuospatial asymmetries for behavioral judgments and eye scanning patterns in the landmark task depend on horizontal and vertical stimulus alignment

Emel Güneş [1], Erhan Nalçaci [1], Mutlu Erdoğan [2], Evrim Gökçe [1], Fikret Ari [3]

[1] Ankara University School of Medicine, Department of Physiology, Ankara, Turkey, [2] Ankara University, Institute of Biotechnology, Ankara, Turkey, [3] Ankara University Faculty of Engineering, Electrical & Electronics Engineering Department, Ankara, Turkey.

Correspondence to: Emel Güneş, Ankara University School of Medicine, Department of Physiology, Ankara, Turkey
TEL: +90-312-595-8272; E-MAIL: emelgunes@ankara.edu.tr

Submitted: 2020-12-08 *Accepted: 2021-02-15* *Published online: 2021-02-15*

Key words: **pseudoneglect; Landmark task; visuospatial attention; representational asymmetry; eye scanning**

Act Nerv Super Rediviva 2021; **63**(1): 11–21 ANSR63121A02

Abstract

OBJECTIVES: Pseudoneglect is the general bias for the healthy population to over-attend to the left hemispace. This phenomenon is classically demonstrated in visuospatial modality using various line bisection tasks. The present study investigates the effect of horizontal and vertical spatial fields on the presence of pseudoneglect using the "Landmark Task".
MATERIAL AND METHODS: Depending on the horizontal spatial location, thirty-one healthy subjects carried out the same task in three separate sessions, in left, central, and right visuospatial positions. The stimuli at each session were vertically located at the upper, middle, and lower screen fields. We recorded the participant's eye movements to analyze scanning patterns in the course of their judgments.
RESULTS: In horizontal alignments, we replicated the previous finding that pseudoneglect was stronger in the left visual field. In terms of vertical alignment, pseudoneglect was found to be stronger in the lower field than in the middle field. The leftward judgment bias was observed in the left – lower field greater among whole fields. The scanning bias was also found to be consistent with pseudoneglect in the left session.
CONCLUSION: Our results indicated that the contribution of the right hemisphere to the allocation of attention exists mainly for horizontal alignment, and more pronounced in the left hemispace.

Introduction

Numerous studies have shown that humans do not attend equally to the right and left sides of the visual space. Generally, healthy individuals over-attend to the left side of visual stimuli and show a leftward attentional spatial bias (McCourt & Jewell, 1999). Drawing on comparable underlying mechanisms defined as clinical hemi-neglect, Bowers & Heilman (1980) identified this phenomenon as pseudoneglect. Patients with clinical hemispatial neglect show a strong preference for objects located in the right hemispace (Buxbaum *et al.* 2004; Heilman & Valenstein, 1979). Like neglect, pseudoneglect is observed in visuospatial modality using the line bisection task. When healthy humans bisect a horizontal line, they tend to manifest a slight leftward bias relative to the exact center, whereas neglect patients place their mark to the right of the midpoint (Jewell & McCourt, 2000).

Another type of line bisection task used to evaluate pseudoneglect is the "Landmark task" (LT). This task reveals perceptual biases in pseudoneglect and neglect in the absence of a motor response (Milner *et al.* 1992). In LT, participants are presented with pre-transected lines and asked to assess whether the transecting bar is closer to the left or the right end of the line (Harvey *et al.* 1995; Olk & Harvey, 2002). Irrespective of whether healthy individuals manually place a bisection mark or judge the midpoint on a pre-bisected line, they overestimate the length on the left. In line bisection-type tasks, healthy young adults demonstrate a leftward bisection bias and are more likely to report that the transecting bar is nearer to the right end (in this case, the left portion of the line appears longer) (Barrett *et al.* 2000, Greene *et al.* 2010, Rueckert & McFadden, 2004). Schuster *et al.* (2017) compared the robustness and reliability of different fMRI tasks for evaluating visuospatial processes and concluded that the LT was the most robust and reliable, reproducibly determining hemispheric dominance in 93% of subjects.

It is broadly assumed that clinical hemi-neglect and pseudoneglect both result from functional asymmetries in the control of visuospatial attention (Adair, 2008). It is known that signs of unilateral neglect are associated with right hemisphere lesions, especially at the inferior parietal and superior temporal gyrus or temporoparietal junction (Mesulam, 1981; Roselli *et al.* 1985). Patients with such right hemisphere lesions pay less attention to the left side of the visual space and therefore, targets in the left hemispace appear smaller to them. Healthy participants, in contrast, are hypothesized to pay more attention to the left side of the visual space, and consequently will tend to overestimate the size of stimuli that appear there.

According to the activation-orientation model of attentional asymmetry, spatial attention is governed by two antagonistic attentional gradients, which are directed by the contralateral hemisphere (Kinsbourne, 1970). A particular activation within a hemisphere increases the slope of the attentional gradient and the bias of attention towards the contralateral hemispace. Different attentional cueing studies support the activation-orientation model (Bultitude & Aimola Davies, 2006; Nicholls & Roberts, 2002). Also, some studies show that certain conditions could exacerbate right hemisphere activation and therefore increase the magnitude of pseudoneglect. For example, use of the left hand (Fukatsu *et al.* 1990; McCourt *et al.* 2001), or presentation in the left hemispace, (McCourt *et al.* 2000, McCourt & Jewell, 1999) enhance pseudoneglect. Siman-Tov *et al.* (2007) suggested models of neural connectivity within the right hemisphere and connectivity from the right to the left hemisphere. The asymmetry in connectivity results in intensified involvement of both hemispheres in the processing of objects placed in the left visual space.

One aspect that has been less investigated is how pseudoneglect is affected by the vertical spatial position of the visual stimuli. Studies have suggested that visual processing also varies across the upper and lower visual fields (Skrandies, 1987). The differences between upper and lower visual fields have been reported on some spatial based tasks, but there are inconsistencies between the related studies. For example, the left visual

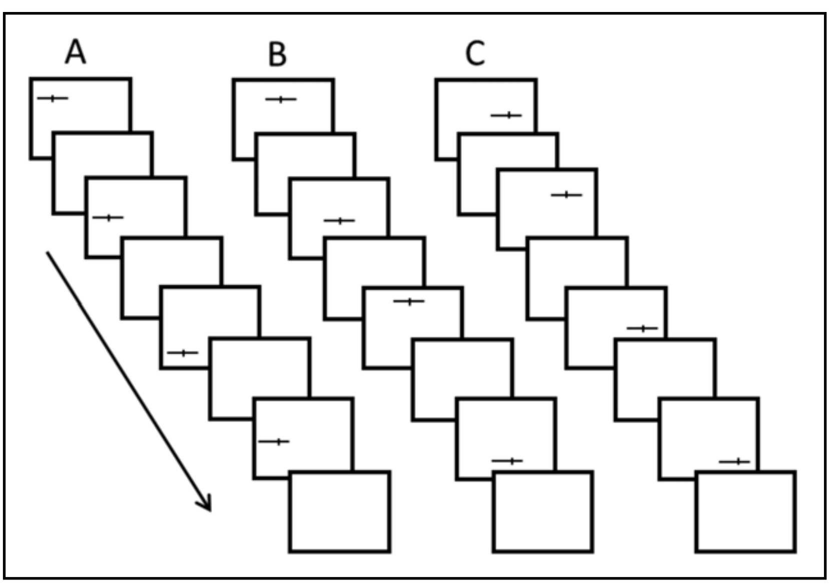

Fig. 1. The representation of landmark stimuli in three different free viewing trail sequences.
A – Presentation of the lines on the left half of the screen – "Left session";
B - Presentation of the lines on the central part of the screen – "Central session";
C – Presentation of the lines on the right half of the screen – "Right session"

field advantage was reported for spatial resolution (Rezec & Dobkins, 2004), visual search (Nicholls *et al.* 2017) or spatial frequencies (Edgar & Smith, 1990). There is also some evidence from various line-bisection tasks, but the observed findings are mixed. Stronger leftward bias was found by McCourt & Jewell (1999) and McCourt & Garlinghouse (2000) in the upper visual field. However, Barrett *et al.* (2000) and Thomas & Elias (2010) found the leftward bias to be stronger in the left visual field.

Few studies have used visuospatial stimuli to examine both the horizontal and vertical alignment interactions. The differences between upper and lower visual fields have been reported in various tasks such as visual search (Previc, 1990) and categorical judgment (Niebauer & Christman, 1998). Rubens (1985) observed that hemispatial neglect is most influenced in the left and lower visual fields. Studies that observe a left-field visual advantage display a left-field advantage, whereas those that indicate an upper field advantage have found a right-field advantage (Christman & Niebauer, 1997).

Understanding the attentional bias across the broad visual fields has also great practical significance. Spatial distribution of attention is correlated with the performance of daily activities such as walking (Broman *et al.* 2004) and driving (Clay *et al.* 2005).

Our study aims to investigate the effect of stimulus presentation across locations on the horizontal plane, and also over the vertical plane on asymmetric visuospatial perception using LT. In addition, scanning eye movements provides an efficient way to examine which portions of the screen are examined during the task and to determine whether eye movements are congruent with responses. There is evidence that eye movements share common neural pathways with the attentional circuits in the brain (Corbetta *et al.* 1998). Therefore, we conducted an LT in which the subject's eye movements were scanned simultaneously. Hence, another purpose of this study was to assess the extent of the contribution of visual scanning to pseudoneglect's manifestation in different spatial conditions and elucidate the potential associations between eye movements and pseudoneglect.

Materials and methods

Subjects

Thirty-one healthy, right-handed volunteers (15 female) with normal vision were studied. All subjects gave their informed consent for inclusion before they participated in the study. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the local

Ethics Committee. Hand preference was assessed using the Chapman & Chapman Handedness Questionnaire (Chapman & Chapman, 1987), adopted in Turkish by Nalcaci *et al.* (2002). All participants were naïve as to the purpose of the study and had normal or corrected-to-normal vision. A total of 31 subjects (mean age = 22.3 ± 3.9 years, mean laterality score = 13.8 ± 1.2) participated in the behavioral experiment. Eye movements were recorded from fifteen subjects.

Task

Stimuli were horizontal lines in black on a white background, presented at an 800 x 600-pixel resolution, on a 17" flat-screen monitor controlled by a desktop computer. Lines were presented in a free viewing LT. The lines were either correctly (in 50% of trials) or incorrectly (25% to the left, 25% to the right) pre-bisected by a vertical mark (transector). The incorrectly placed transector was misplaced either 0.2° to the left or the right.

Participants were falsely informed that none of the transaction marks were placed at the actual center. We instructed them to judge whether the transector appeared closer to the left or right end of the line. The incorrectly transected lines were included to help to convince individuals that the lines were not transacted in the center.

Landmark stimuli (horizontal lines of the length corresponding to a visual angle of 14-15°) were presented in three experimental sessions (see Figure 1). Each session includes 96 lines (48 correctly, 48 incorrectly pre-bisected), equally distributed in three different vertical plane positions; upper, middle, and lower. In the *Left session*, the presentation of the lines was on the left half of the screen (see Figure 1.A). The *Central session* was designed using midsagittal presented lines (see Figure 1.B). The *Right session's* presentation was on the right half of the screen (see Figure 1.C). Thus, each line had two dependent positionings. The order of presentation of the sessions was counterbalanced across subjects.

Procedure

Experiments were conducted in a dimly lit and isolated room. Subjects were seated in a comfortable unmovable chair whose height was pneumatically adjusted so that the participants' straight-ahead view was at the midpoint of the screen and their midsagittal plane was aligned with the midsagittal plane of the screen. Behind the monitor was an empty wall. A table-mounted forehead-and-chin rest was used to minimize head movement and fix the subjects' viewing distance at 50 cm from the screen. The participants responded by response box using their index fingers; for "near to left" choice whit the left finger, for "near to right" choice with the right finger. Before administering the trials, the experimenter ensured that the participant had understood the task instructions by applying a short training trial.

The generation and sequencing of stimuli and the collection of subject responses were accomplished using the Neuroscan STIM software package. In all experimental conditions, the subject's eye movements

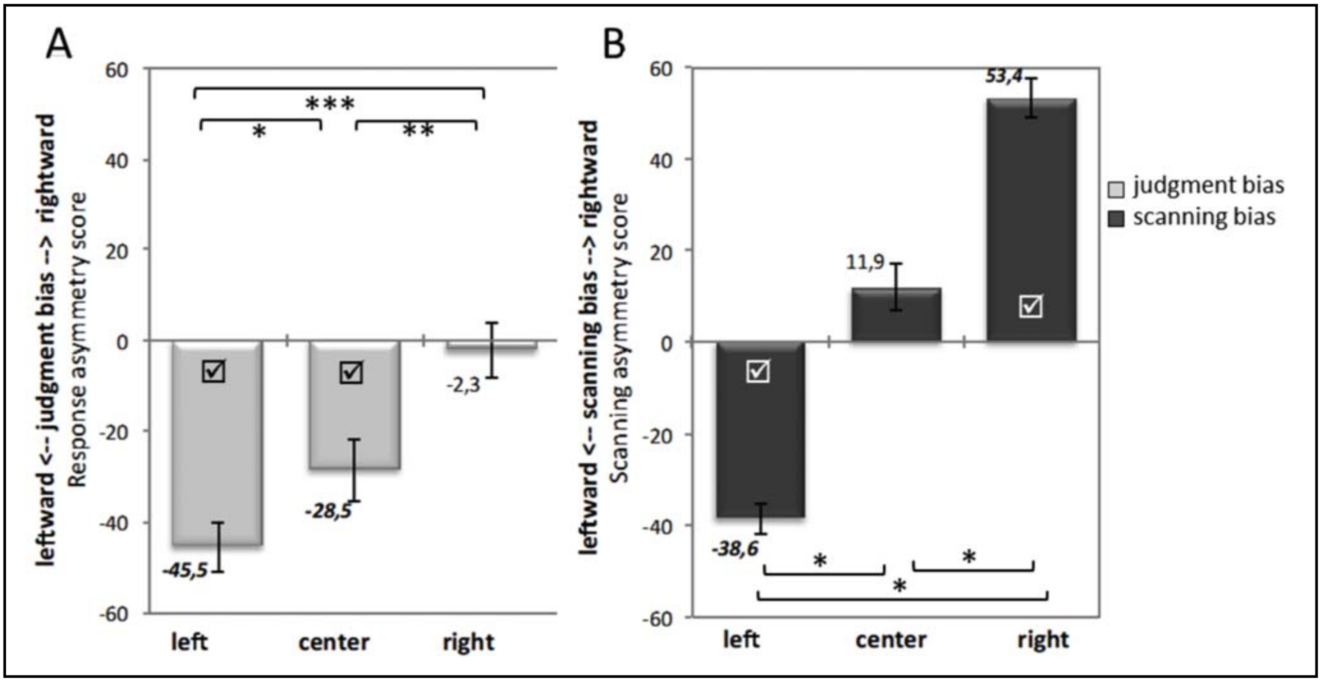

Fig. 2A. Mean response asymmetry scores (M ± S.E.) for the three sessions. B – Mean scanning asymmetry scores for the three sessions.
☑ indicates bias significantly different from zero.
*$p < 0.05$, **$p < 0.001$, ***$p < 0.000$.

were obtained using an Infra-Red (IR) eye-tracker, as described below.

The employed eye-tracking system was developed to detect and track the eye movements at a sampling rate of 25 Hz. In general, the system includes a video camera sensitive to IR, an IR illuminator, a computer for eye data recording, and a subject monitor. In the first step, a 9 point-image was shown on the monitor to the subject as a first visual stimulus for calibration purposes and the anatomic characteristics of the subject were extracted. Data collection followed the calibration procedure. Two separate PCs operated the eye-tracking system and the stimulus administration program, but they were interfaced via a parallel port connection to ensure the accurate timing of stimulus presentation and data collection. The image analysis algorithm computes the location of the pixel points on which the subject focuses on the stimulus (gaze point). For each subject and each line we recorded the scanning time and scanned area in the left and right parts of the transector. The record began with the appearance of the line on the screen and continued until the subject's response. From these computations, the exact location of the pixel that is being focused on is defined as a function of time, and the statistical distribution is plotted in horizontal and vertical directions separately.

Design and analysis

The software records the number of the subject's judgments for stimuli in each experimental session. The mean values of left and right responses were analyzed for responses of correctly bisected lines, to indicate the biases of judgments. LT responses were scored as ***leftward*** when the right side was chosen as being shorter ("near-to-right" response). Behavioral asymmetry scores were calculated by subtracting the number of rightward responses from the number of leftward responses, then dividing by the total number of responses and multiplying by 100.

Scanned area asymmetry scores and scanned area scores were calculated using a similar formula like behavioral data scores: (scanned area in the right – scanned area in the left) / total value of the scanned area * 100 and (scanning time in the right – scanning time in the left) / total value of the scanning time * 100, respectively. All asymmetry scores ranged from −100 (scanning only the left half) to +100 (scanning only the right half).

Results

Behavioral data

One sample t-tests were conducted to compare the asymmetry scores with a score of zero (the theoretical value of the true center) and determine the significance of the biases in performed LT. When analysing the three sessions without considering the different vertical alignments (Figure 2.A), one sample t-test indicated that the leftward judgment bias was significant in the left and central condition ($t(30) = -8.530$, $p = 0.000$; $t(30) = -4.122$, $p = 0.000$, respectively). On the other hand, regardless of the horizontal plane alignments of the stimuli there was an overall significant leftward bias for the whole vertical alignments (for upper $t(30)$

= -5.300, $p = 0.000$; for middle $t(30) = -3.264$, $p = 0.003$ and for lower $t(30) = -5.093$, $p = 0.000$), (see Figure 3.A).

The results of the detailed visuospatial asymmetries for judgment bias are shown in Figure.4 (columns in blue). Examining the data in detail, we found that the leftward judgment bias for the left session exists for the whole vertical conditions (LU, LM, and LL). Although the leftward bias was computed totally for the central horizontal alignment, there was not found a bias after Bonferonni-correction in the upper and middle conditions. Only the central lower (CL) field conducted significantly leftward judgment bias. As expected, the judgment bias was not significant in the whole investigated right spatial fields (RU, RM, and RL). In contrast to other right spatial fields, the judgment tendency in the RM field was rightward (See Suppl. Table 1).

For multiple comparisons, a two way (3x3) repeated–measures analysis of variance was computed for within-subjects, with independent variables of horizontal alignment of lines (left, central, and right) and vertical alignment of lines (upper, middle, and lower), and with the dependent variable being the response asymmetry score on the LT. The main effect of horizontal alignment was significant, $F(2,60) = 19.840$, $p = 0.000$. In particular, *post hoc* Bonferroni analysis revealed that the leftward judgment bias in the left horizontal alignment reached the highest score among the three horizontal positions ($p < 0.05$ in the post hoc comparison with the central alignment and $p < 0.000$ with the right alignment). The difference between the central and the right sessions was also significant ($p < 0.001$, see Figure 2.A).

The main effect of vertical stimulus alignment was significant, $F(2,60) = 4.392$, $p = 0.017$. *Post hoc* Bonferroni analysis revealed that the leftward judgment bias in the lower field is most prominent and different from the middle ($p < 0.05$), but not the upper field. The bias did not differ also between the upper-middle fields (see Figure 3.A).

There was a significant effect of interaction between the judgment biases in horizontal and vertical alignments, $F(4,120) = 4.013$, $p = 0.004$. In particular (see Figure 4), bias differed significantly among vertical alignment at upper field, between the left and right positions ($p < 0.05$), at middle field the overall biases were significantly different (left – central, $p < 0.001$; left-right, $p < 0.000$; central – right, $p < 0.001$), at lower field, between left-right, $p < 0.000$ and central – right, $p < 0.001$. The differences among a horizontal alignment were found significantly different in the right position (see Figure 4), between the upper and middle fields ($p < 0.000$) and the difference between middle and lower fields was close to the margin of statistical significance ($p = 0.057$).

<u>*Eye-tracking data*</u>

Due to the technical difficulties of recording eye movement parameters from some individuals, eye-tracking data from only 10 participants in all three sessions was usable. Partial results were obtained for the separate

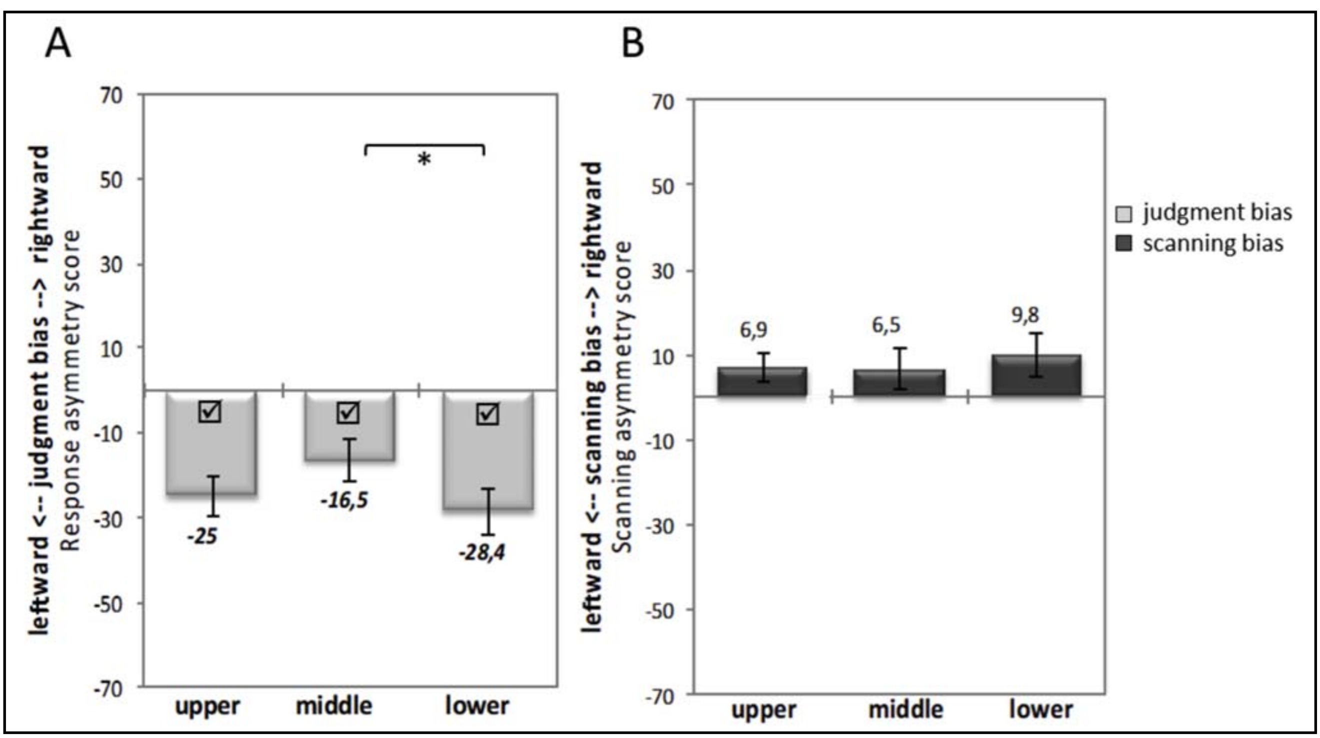

Fig. 3A. Mean response asymmetry scores (M ± S.E.) for the three vertical alignments. B – Mean scanning asymmetry scores for the three vertical alignments.
☑ indicates bias significantly different from zero.)
*$p < 0.05$

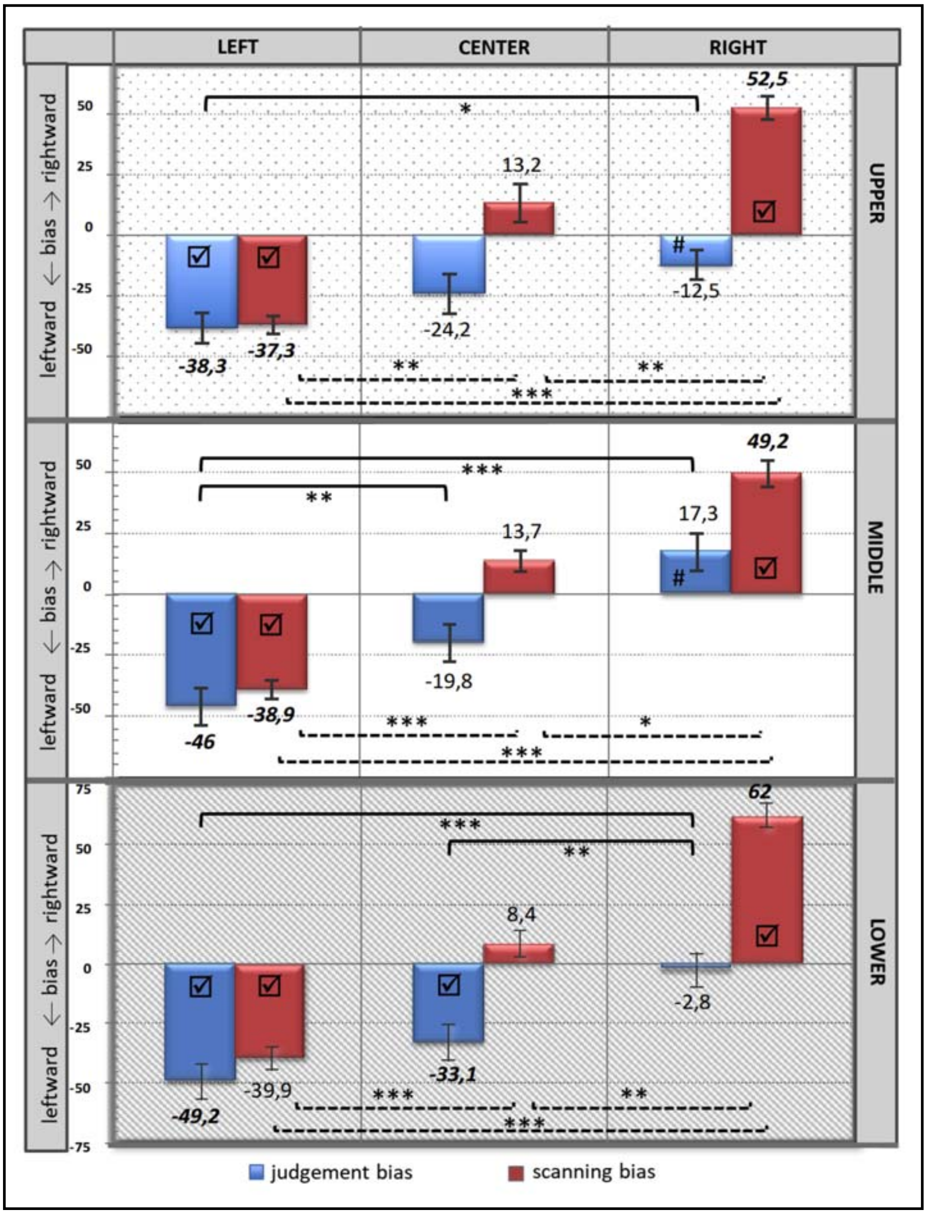

Fig. 4. Mean response asymmetry scores (M ± S.E.) and mean scanning asymmetry scores (M ± S.E.) for the whole screen alignments. Dashed marks indicates significant difference between scanning biases among a vertical alignment. # indicates significant difference between judgment biases among the right session ☑ indicates bias significantly different from zero. *$p < 0.05$, **$p < 0.001$, ***$p < 0.000$.

sessions: 13 for the *Left*, 15 for the *Central*, and 12 for the *Right session*.

Firstly, the eye-scanning parameters of each session were analyzed separately to reduce the effect of missing data. Depend on horizontal alignment, one sample *t*-test revealed that the scanned area asymmetry scores and scanning time asymmetry scores were ***leftward*** and significantly different compared with a score of zero in the left condition; $t(12) = -11.375$, $p = 0.000$, $t(12) = -8.096$, $p = 0.000$, respectively.

Scanned area asymmetry scores and scanning time asymmetry scores were significantly rightward in the right condition; $t(11) = 9.199$, $p = 0.000$, $t(11) = 12.748$, $p = 0.000$, respectively. Analyzing the vertical alignments without considering the different horizontal conditions, the scanned area asymmetry score was ***rightward*** and significantly different compared with a score of zero in the lower alignment, $t(9) = 3.899$, $p = 0.004$. Scanning time asymmetry scores were not significantly different, but only the score in the lower field ($t(9) = 2.818$, $p = 0.02$) was found in tendency to be significantly rightward after Bonferroni correction ($p = 0.017$), see Suppl.Table 2.

Because of the similarity of the pattern for the eye scanning variables, we computed a combined scanning bias variable according to the following formula: scanning bias score = (scanning area + scanning time)/2.

The results of the detailed visuospatial asymmetries for scanning bias are shown in Figure 4 (columns in red):

<u>*Left session analyses*</u>

Similar to the judgment bias, one sample *t*-test revealed that the leftward scanning bias exists for the whole vertical conditions in the left session (LU, LM, LL). No significant main effect of the vertical position of lines

Tab. 1. Mean asymmetry scores of behavioral responses for the lines at the vertical and horizontal peresentation and comparisons to 0 for the whole screen alignments.

	Left			**Center**			**Right**						
Upper	*mean*	*sd*	*n*	*mean*	*sd*	*n*	*mean*	*sd*	*n*	*Avg. Upper*	*mean*	*sd*	*n*
	-38.3	35.3	31	-24.2	46.8	31	-12.5	32.9	31		-25.0	26.3	31
	t	*p*	*se*	*t*	*p*	*se*	*t*	*p*	*se*		*t*	*p*	*se*
	-6.034	**0.000**	6.348	-2.881	0.007	8.399	-2.115	0.043	5.912		-5.300	**0.000**	4.717
Middle	*mean*	*sd*	*n*	*mean*	*sd*	*n*	*mean*	*sd*	*n*	*Avg. Middle*	*mean*	*sd*	*n*
	-46	43.2	31	-19.8	42.9	31	17.3	42.2	31		-16.5	28.1	31
	t	*p*	*se*	*t*	*p*	*se*	*t*	*p*	*se*		*t*	*p*	*se*
	-5.921	**0.000**	7.764	-2.564	0.016	7.707	2.283	0.030	7.573		-3.269	**0.003**	5.048
Lower	*mean*	*sd*	*n*	*mean*	*sd*	*n*	*mean*	*sd*	*n*	*Avg. Lower*	*mean*	*sd*	*n*
	-49.2	42	31	-33.1	41.4	31	-2.82	39.5	31		-28.4	31	31
	t	*p*	*se*	*t*	*p*	*se*	*t*	*p*	*se*		*t*	*p*	*se*
	-6.510	**0.000**	7.557	-4.447	**0.000**	7.436	-0.397	0.694	7.092		-5.093	**0.000**	5.568
	Avg. Left			*Avg. Center*			*Avg. Right*						
	mean	*sd*	*n*	*mean*	*sd*	*n*	*mean*	*sd*	*n*				
	-45.5	29.7	31	-28.5	38.5	31	-2.3	33	31		in red: right-bias tendency **in bold: significant** *after Bonferonni- correction*		
	t	*p*	*se*	*t*	*p*	*se*	*t*	*p*	*se*				
	-8.530	**0.000**	5.334	-4.122	**0.000**	6.915	-0.388	0.701	5.927				

*indicates bias significantly different from zero (one-sample *t*-test).
Significance level is $p < 0.006$, Bonferonni-corrected.

was found according to repeated–measures ANOVA, $F(2,24) = 0.044$, $p = 0.957$.

Right session analyses

Again, the significantly rightward scanning bias exists for the whole vertical positions in the right session (RU, RM, RL). The main effect of the vertical position of lines was also not significant for scanning bias in this session, $F(1,14) = 2.828$, $p = 0.081$.

Central session analyses

Neither significant scanning bias was found in the central session's vertical positions. The main effect of vertical alignment was not significant also for the scanning bias in the central condition, $F(1,14) = 0.632$, $p = 0.44$.

For multiple comparisons a two way 3x3 repeated–measures ANOVA was computed for within-subjects, with independent variables of horizontal alignment of lines (left, central, and right) and vertical alignment of lines (upper, middle, and lower), and with the dependent variable being the scanning bias score during the LT.

The main effect of horizontal position of lines was significant, $F(2,18) = 108.374$, $p = 0.000$. *Post hoc* Bonferroni analysis indicated that scanning bias scores were significantly different between the leftward scanning bias in the left session and the biases in the central and right sessions ($p < 0.000$ for both). The rightward scanning biases in the central and right conditions differed also significantly ($p < 0.001$), see Figure 2.B.

No significant main effect of vertical position of lines was found, $F(2,18) = 0.531$, $p = 0.6$.

The interaction between horizontal and vertical alignment was not significant for eye scanning bias scores, $F(4, 36) = 1.687$, $p = 0.174$.

Discussion

Using the LT, we examined the effect of different visuospatial conditions on pseudoneglect regarding visual exploration research. Behaviourally, we found that pseudoneglect exists in the overall left session and central session, whereas no significant judgment bias was observed during the performance of the task in the right session. In the left session, a stronger pseudoneglect was found in the lower (LL) field, but the difference between the vertical fields was not significant. In the central session, pseudoneglect was found only in the lower field (CL). The judgment bias in the LL was more leftward than CL, but the difference was also not significant. In summary, for overall vertical conditions in the left session and central-lower condition, participants perceived the transector as being located to the right, consistent with a relative over-estimation of the left-sided stimuli half. In hence our findings suggest that the allocation of spatial attention in the left-lower field modified robustly the size of the pseudoneglect.

Tab. 2A. Mean scanned area scores for the whole screen alignments.

Eye area	Left			Center			Right						
Upper	*mean*	*sd*	*n*	*mean*	*sd*	*n*	*mean*	*sd*	*n*	*Avg. Upper*	*mean*	*sd*	*n*
	-38.5	13.7	13	14.9	31.6	15	52.9	18.8	12		6	13.9	10
	t	*p*	*se*	*t*	*p*	*se*	*t*	*p*	*se*		*t*	*p*	*se*
	-10.129	**0.000**	3.802	1.824	0.089	8.169	9.749	**0.000**	5.431		1.376	0.205	4.396
Middle	*mean*	*sd*	*n*	*mean*	*sd*	*n*	*mean*	*sd*	*n*	*Avg. Middle*	*mean*	*sd*	*n*
	-39	14.4	13	13.3	16.4	15	47.7	33.6	12		6.2	16.4	10
	t	*p*	*se*	*t*	*p*	*se*	*t*	*p*	*se*		*t*	*p*	*se*
	-5.921	**0.000**	7.764	3.135	**0.007**	4.246	4.920	**0.000**	7.573		1.197	0.262	5.187
Lower	*mean*	*sd*	*n*	*mean*	*sd*	*n*	*mean*	*sd*	*n*	*Avg. Lower*	*mean*	*sd*	*n*
	-41.7	17.1	13	9	18.2	15	66.2	18.2	12		17.3	14	10
	t	*p*	*se*	*t*	*p*	*se*	*t*	*p*	*se*		*t*	*p*	*se*
	-8.807	**0.000**	4.740	1.910	0.076	4.712	12.620	**0.000**	5.248		3.908	**0.004**	4.437
	Avg. Left			*Avg. Center*			*Avg. Right*						
	mean	*sd*	*n*	*mean*	*sd*	*n*	*mean*	*sd*	*n*				
	-39.9	12.6	13	11.8	17.6	15	53.8	20.2	12		in red: right-bias		
	t	*p*	*se*	*t*	*p*	*se*	*t*	*p*	*se*		**in bold: significant** *after Bonferonni- correction*		
	-11.375	**0.000**	3.504	-4.122	**0.000**	6.915	9.199	**0.000**	5.844				

Reuter-Lorenz *et al.* (1990) observed that presentation of lines in the left visual field induced pseudoneglect, while the presentation of lines in the right visual field attenuated or reversed this bias, supporting the notion that pseudoneglect was a product of contralateral distribution of attention by the right hemisphere. Visual field presentation modulates the magnitude of the bias. Cavezian *et al.* (2012) found that the magnitude of the leftward bias was modulated by the lateral position of the stimulus. Right hemisphere attentional dominance may lead to a propensity for leftward bias. However, the right hemispace is the contralateral side mainly controlled by the left hemisphere, which is less specialized for spatial attention.

Researchers have assumed that neglect and pseudoneglect arise mostly as a result of the right hemisphere dominance for visuospatial functions. An influential model of the neural processes involved in attentional bias was proposed by Kinsbourne (1970). Kinsbourne has suggested that the bias toward the left hemispace exists as a result of this dominance and well-known contralateral innervation. According to this model, the spatial distribution of attention is biased in the direction contralateral to the more activated hemisphere (Reuter-Lorenz *et al.* 1990). In addition, neuroimaging data indicate that the brain regions associated with spatial attention in the right hemisphere are preferentially activated during visuospatial tasks (Bjoertomt *et al.* 2002; Cicek *et al.* 2009; Fink *et al.* 2000; Fink *et al.* 2001; Foxe *et al.* 2003). Also, according to research by Seydell-Greenwald *et al.* (2019) LT activation is strongly right-lateralized among different spatial tasks. They also indicate that especially the LT requires the spatial attention and spatial representation together. Using spatial attention one has to shift the attention between the left and the right line segment and compare both line segments in content with spatial representation.

Moreover, stimuli in the left visual field have greater potential to activate visuospatial attention networks in the right hemisphere (Siman-Tov *et al.* 2007). This, in turn, supports the suggestion that pseudoneglect occurs as a result of the right hemisphere's overactivation, which causes the distribution of attention to be strongly directed to the left side. Models of neural connectivity have been proposed which suggest increased connectivity within the right hemisphere and/or connectivity from the right- to the left hemisphere. This asymmetry in connectivity results in enhanced recruitment of both hemispheres for the processing of stimuli located in the left hemispace (Siman-Tov *et al.* 2007). In healthy right-handers, the left hemisphere's rightward vector prevails over the right hemisphere's leftward vector. This difference may explain the opposite pseudoneglect in the right hemispace.

Our results showed that subjects' judgments differed without an obvious difference among extreme upper-lower vertical positions. Without considering the horizontal alignment, the difference was found between upper-middle fields. The only significant difference among distinct sessions was in the right session,

Tab. 2B. Mean scanning time scores for the whole screen alignments.

Eye time	Left			Center			Right						
Upper	*mean*	*sd*	*n*	*mean*	*sd*	*n*	*mean*	*sd*	*n*	*Avg. Upper*	*mean*	*sd*	*n*
	-37.1	16.2	13	11.5	33.6	15	52	16.1	12		6.6	12.2	10
	t	*p*	*se*	*t*	*p*	*se*	*t*	*p*	*se*		*t*	*p*	*se*
	8.253	**0.000**	4.501	1.331	0.209	8.671	11.182	**0.000**	4.652		1.702	0.121	3.886
Middle	*mean*	*sd*	*n*	*mean*	*sd*	*n*	*mean*	*sd*	*n*	*Avg. Middle*	*mean*	*sd*	*n*
	-38.3	18.1	13	14	23.9	15	50.6	15.4	12		9.6	15.2	10
	t	*p*	*se*	*t*	*p*	*se*	*t*	*p*	*se*		*t*	*p*	*se*
	-7.726	**0.000**	5.014	2.283	0.040	6.167	11.367	**0.000**	4.455		1.988	0.077	4.811
Lower	*mean*	*sd*	*n*	*mean*	*sd*	*n*	*mean*	*sd*	*n*	*Avg. Lower*	*mean*	*sd*	*n*
	-36	21.2	13	7.7	26.5	15	57.2	16.6	12		14.1	15.8	10
	t	*p*	*se*	*t*	*p*	*se*	*t*	*p*	*se*		*t*	*p*	*se*
	-6.150	**0.000**	5.850	1.129	0.276	6.841	12.040	**0.000**	4.792		2.818	0.020	5.008
	Avg. Left			*Avg. Center*			*Avg. Right*						
	mean	*sd*	*n*	*mean*	*sd*	*n*	*mean*	*sd*	*n*				
	-37.3	16.6	13	11.8	17.6	15	53.1	14.4	12		in red: right-bias		
	t	*p*	*se*	*t*	*p*	*se*	*t*	*p*	*se*		**in bold: significant** *after Bonferonni- correction*		
	-8.096	**0.000**	4.605	-4.122	**0.000**	6.915	12.748	**0.000**	4.167				

between the fields with opposite pseudoneglect bias (RU – RM). As the bias wasn't found significant for the abovementioned right fields, we cannot conclude that the result indicates an important spatial influence.

A small number of studies have measured visuospatial asymmetries as a function of vertical stimulus location, and these have reported a leftward bias for stimuli appearing in the lower visual field, but results for the upper fields have been inconsistent (Drago *et al.* 2006; Thomas & Elias, 2010, 2011; Nicholls et. al., 2012). The lower visual field is predominantly represented along the dorsal visual pathway, important for visually guided actions; the upper visual field is predominantly represented in the ventral pathway, necessary for perceptual identification of objects (Goodale & Milner, 1992). Kraft *et al.* (2011) showed a lower field preference during stationary spatial orienting and an upper field preference during visual searching, using fMRI. Loughnane *et al.* (2014) used stimuli in the vertical plane and found that reaction times were faster to left hemifield targets in the lower visual field, but the opposite trend was observed for targets in the upper field. Recently, Zhou *et al.* (2017) obtained evidence that supports that the upper and lower visual fields were primarily represented in the allocentric and egocentric references, respectively.

Thomas & Elias (2010) found a greater leftward bias in the lower field using a free viewing grayscale task paradigm. Their subsequent research (Tomas & Elias, 2011) indicated that the leftward bias in the lower field is stronger during the prolonged presentation, which allows eye movements, but the brief presentation without saccadic eye movements induces a stronger left bias in the upper field. Additionally, tasks observing the lower field advantage have shown left hemispatial field advantage whereas those showing an upper field advantage find a right hemispatial field advantage. Furthermore, tasks demonstrating the lower field advantage also observed a left hemispatial field advantage, whereas those finding an upper field advantage observe a stronger left bias in the right hemispatial field (Christman & Niebauer, 1997). The same relationship has been observed in visuospatial attention as hemispatial neglect is most pronounced in the left and lower visual fields (Rubens, 1985).

As our study also involves saccadic eye movements and the stronger pseudoneglect was found in the LL field, our results have been found in line with the previous investigations that have reported a lower field advantage during prolonged free viewing tasks in the left spatial conditions. Although the pronounced leftward judgment bias score was found in the LL field, the difference between lower and upper fields was not significant. Even using the middle alignment reduced the number of gaze gaps between both extreme stimuli positions. One possible reason is that in our experiment, the difference between the upper and lower alignments is not large enough to induce different eccentric spatial conditions such as allocentric and egocentric. Moreover, the use of the middle vertical alignment reduced the number of gazes between the locations of the two extreme stimuli.

Asymmetry of visual scanning and pseudoneglect on LT

Eye movements have the potential to play an essential role in pseudoneglect. Initial saccades to the left side of a stimulus (Dickinson & Intraub, 2009) or more time spent inspecting the left side (Nuthmann & Matthias, 2014) could lead to an overrepresentation of the leftward features compared to the right.

Stimuli presentation is centrally located in most line bisection research; in our experiment, this condition is similar to the central session presentation of lines in the task used by Kim *et al.* (1997). In their study, number 5 appears as located in different randomized positions before the presentation of each central line. The aim is to initiate the subject's search from different spatial portions and alter the initial eye position. Subjects scan the lines significantly more from the left to right direction ($p < 0.000$), and the scan pattern is not influenced by the initial eye position.

The data obtained by eye scanning during LT provided additional information for asymmetric visuospatial perception. In the left session, ***leftward*** bias was found to be related to asymmetric scanning bias for each half of the lines. The left half of the lines was scanned longer in comparison to the right half in the left session, which is controlled mainly by the right hemisphere. Contrary to the left session, in the right session ***rightward*** bias was usually found to be consistent with scanning bias for the right half of the lines.

In our case, the scanning bias results for vertical alignment differ from the judgment bias findings. One of the main limitations of this research is the lack of eye scanning records for certain subjects. This limitation makes the interpretation difficult. Keeping this in mind, we should indicate that the consistency of the findings in the left session is significant evidence of the right hemisphere advantage in visuospatial attention.

These findings suggest that, in addition to asymmetric attention in space, pseudoneglect is due to the asymmetric representation of the lines in the brain.

Conslusion

The results obtained by presenting the lines in horizontal and vertical alignments in LT suggested that the pseudoneglect observed during the LT was produced by asymmetric activation of the hemispheres and the asymmetric representation of the lines in the brain as well.

Acknowledgment

This research has been supported by Ankara University Scientific Research Projects Coordination Unit (2003.08.09.095) and Ankara University Ethical Committee. We are also grateful to the participants for their help and patience.

Conflict of interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

REFERENCES

1 Adair JC, Barrett AM (2008). Spatial neglect: clinical and neuroscience review: a wealth of information on the poverty of spatial attention. *Ann. NY. Acad. Sci.* **1142**: 21–43. doi: 10.1196/annals.1444.008

2 Barrett AM, Crosson JB, Crucian GP, Heilman KM (2000). Horizontal line bisections in upper and lower body space. *J. Int. Neuropsychol. Soc.* **6**: 455–459. doi: 10.1017/s135561770064403x

3 Bjoertomt O, Cowey A, Walsh V (2002). Spatial neglect in near and far space investigated by repetitive transcranial magnetic stimulation. *Brain.* **125**: 2012–2022. doi:10.1093/brain/awf211

4 Bowers D, Heilman KM (1980). Pseudoneglect effects of hemispace on a tactile line bisection task. *Neuropsychologia.* **18**: 491–498. doi: 10.1016/0028-3932(80)90151-7

5 Broman AT, West SK, Muñoz B, Bandeen-Roche K, Rubin GS, Turano KA (2004). Divided visual attention as a predictor of bumping while walking: the Salisbury Eye Evaluation. *Invest. Ophthalmol. Vis. Sci.* **45**: 2955–2960. doi: 10.1167/iovs.04-0219

6 Bultitude JH, Aimola Davies AM (2006). Putting attention on the line: investigating the activation-orientation hypothesis of pseudoneglect. *Neuropsychologia.* **44**: 1849–1858. doi: 10.1016/j.neuropsychologia.2006.03.001

7 Buxbaum LJ, Ferraro MK, Veramonti T, Farne A, Whyte J, Ladavas E, Frassinetti F, Coslett HB (2004). Hemispatial neglect: Subtypes, neuroanatomy, and disability. *Neurology.* **62**: 749–756. doi: 10.1212/01.wnl.0000113730.73031.f4

8 Chapman LJ, Chapman JP (1987). The measurement of handedness. *Brain Cogn.* **6**: 175–183. doi: 10.1016/0278-2626(87)90118-7

9 Cavézian C, Valadao D, Hurwitz M, Saoud M, Danckert J (2012). Finding centre: ocular and fMRI investigations of bisection and landmark task performance. *Brain Res.* **1437**: 89–103. doi: 10.1016/j.brainres.2011.12.002

10 Christman SD, Niebauer CL (1997). The relation between left-right and upper-lower visual field asymmetries (or: what goes up goes right, while what's left lays low). In: Christman SD, editor. Cerebral Asymmetries in Sensory and Perceptual Processing. Elsevier Science B. V, Amsterdam, The Netherlands, p. 263–296.

11 Cicek M, Deouell LY, Knight RT (2009). Brain activity during landmark and line bisection tasks. *Front. Hum. Neurosci.* **8**: 3–7. doi: 10.3389/neuro.09.007.2009

12 Clay OJ, Wadley VG, Edwards JD, Roth DL, Roenker DL, Ball KK (2005). Cumulative meta-analysis of the relationship between useful field of view and driving performance in older adults: current and future implications. *Optom. Vis. Sci.* **82**: 724–731.

13 Corbetta M, Akbudak E, Conturo TE, Snyder AZ, Ollinger JM, Drury HA et al (1998) A common network of functional areas for attention and eye movements. *Neuron.* **21**: 761–773. doi: 10.1016/s0896-6273(00)80593-0.

14 Dickinson CA, Intraub H (2009). Spatial asymmetries in viewing and remembering scenes: consequences of an attentional bias? *Atten. Percept. Psycho.* **71**: 1251–1262. doi: 10.3758/APP.71.6.1251

15 Drago V, Crucian CP, Pisani F, Heilman KM (2006). Distribution of attention in normal people as a function of spatial location: right-left, up-down. *J. Int. Neuropsychol. Soc.* **12**: 532–537. doi: 10.1017/S1355617706060681

16 Edgar GK, Smith AT (1990). Hemifield Differences in Perceived Spatial Frequency. *Perception.* **19**: 759–766. doi: 10.1068/p190759

17 Fink GR, Marshall JC, Shah NJ, Weiss PH, Halligan PW, Grosse-Ruyken M et al (2000). Line bisection judgments implicate right parietal cortex and cerebellum as assessed by fMRI. *Neurology.* **54**: 1324–1331. doi:10.1212/wnl.54.6.1324

18 Fink GR, Marshall JC, Weiss PH, Zilles K (2001). The neural basis of vertical and horizontal line bisection judgments: an fMRI study of normal volunteers. *Neuroimage.* **14**: 59–67. doi: 10.1006/nimg.2001.0819

19 Foxe JJ, McCourt ME, Javitt DC (2003). Right hemisphere control of visuospatial attention: line-bisection judgments evaluated with high-density electrical mapping and source analysis. *Neuroimage.* **19**: 710–726. doi: 10.1016/S1053-8119(03)00057-0
20 Fukatsu R, Fujii T, Kimura I, Saso S, Kogure K (1990). Effects of hand and spatial conditions on visual line bisection. *Tohoku J. Exp. Med.* **161**: 329–333. doi: 10.1620/tjem.161.329
21 Goodale MA, Milner AD (1992). Separate visual pathways for perception and action. *Trends Neurosci.* **15**: 20–25. doi: 10.1016/0166-2236(92)90344-8
22 Greene CM, Robertson IH, Gill M, Bellgrove MA (2010). Dopaminergic genotype influences spatial bias in healthy adults. *Neuropsychologia.* **48**: 2458–2464. doi: 10.1016/j.neuropsychologia.2010.04.019
23 Harvey M, Milner AD, Roberts RC (1995). An investigation of hemispatial neglect using the Landmark Task. *Brain Cogn.* **27**: 59–78. doi: 10.1006/brcg.1995.1004
24 Heilman KM, Valenstein E (1979). Mechanisms underlying hemispatial neglect. *Ann. Neurol.* **5**: 166–170. doi: 10.1002/ana.410050210
25 Jewell G, McCourt ME (2000). Pseudoneglect: a review and meta-analysis of performance factors in line bisection tasks. *Neuropsychologia.* **38**: 93–110. doi: 10.1002/ana.410050210
26 Kim M, Anderson JM, Heilman KM (1997). Search patterns using the line bisection test for neglect. *Neurology.* **49**: 936–940. doi: 10.1212/wnl.49.4.936
27 Kinsbourne M (1970). A model for the mechanism of unilateral neglect of space. *Trans. Am. Neurol. Assoc.* **95**: 143–146.
28 Kraft A, Sommer WH, Schmidt S, Brandt SA (2011). Dynamic upper and lower visual field preferences within the human dorsal frontoparietal attention network. *Hum. Brain Mapp.* **32**: 1036–1049. doi: 10.1002/hbm.21087
29 Loughnane GM, Shanley JP, Lalor EC, O'Connell RG (2015). Behavioral and electrophysiological evidence of opposing lateral visuospatial asymmetries in the upper and lower visual fields. *Cortex.* **63**: 220–231. doi: 10.1016/j.cortex.2014.09.003
30 McCourt ME, Garlinghouse M (2000). Asymmetries of visuospatial attention are modulated by viewing distance and visual field elevation: pseudoneglect in peripersonal and extrapersonal space. *Cortex.* **36**: 715–731. doi:10.1016/s0010-9452(08)70548-3
31 McCourt ME, Garlinghouse M, Slater J (2000). Centripetal versus centrifugal bias in visual line bisection: focusing attention on two hypotheses. *Front Biosci.* **1**: 58–71.
32 McCourt ME, Jewell G (1999). Visuospatial attention in line bisection: Stimulus modulation of pseudoneglect. *Neuropsychologia.* **37**: 843–855. doi: 10.1016/s0028-3932(98)00140-7
33 McCourt ME, Freeman P, Tahmahkera-Stevens C, Chaussee M (2001). The influence of unimanual response on pseudoneglect magnitude. *Brain Cogn.* **45**: 52–63. doi: 10.1006/brcg.2000.1255
34 Mesulam M (1981). A cortical network for directed attention and unilateral neglect. *Ann. Neurol.* **10**: 309–325. doi: 10.1002/ana.410100402
35 Milner AD, Brechmann M, Pagliarini L (1992). To halve and to halve not: an analysis of line bisection judgments in normal subjects. *Neuropsychologia.* **30**: 515–526. doi: 10.1016/0028-3932(93)90079-f
36 Nalçaci E, Kalaycıoğlu C, Güneş E, Çiçek M (2002). Reliability and validity of Handedness Questionnaire. *Turkish J. Psych.* **13**: 99–106.
37 Nicholls ME, Roberts GR (2002). Can free-viewing perceptual asymmetries be explained by scanning, pre-motor or attentional biases? *Cortex.* **38**: 113–136. doi: 10.1016/s0010-9452(08)70645-2
38 Nicholls ME, Thomas NA, Loetscher T, Wignall S, Yates MJ, Forte J et al (2012). The relationship between vertical stimulation and horizontal asymmetries. *Q. J. Exp. Psychol.* **65**: 2384–2396. doi: 10.1080/17470218.2012.688979
39 Nicholls ME, Hobson A, Petty J, Owen C, Thomas NA (2017). The effect of cerebral asymmetries and eye scanning on pseudoneglect for a visual search task. *Brain Cogn.* **111**: 134–143. doi: 10.1016/j.bandc.2016.11.006
40 Niebauer CL, Christman SD (1998). Upper and lower visual field differences in categorical and coordinate judgments. *Psychon. Bull. Rev.* **5**: 147–151.
41 Nuthmann A, Matthias E (2014). Time course of pseudoneglect in scene viewing. *Cortex.* **52**: 113–119. doi: 10.1016/j.cortex.2013.11.007
42 Olk B, Harvey M (2002). Effects of visible and invisible cueing on line bisection and Landmark performance in hemispatial neglect. *Neuropsychologia.* **40**: 282–290. doi: 10.1016/S0028-3932(01)00095-1
43 Previc FH (1990). Functional specialization in the lower and upper visual fields in humans: its ecological origins and neurophysiological implications. *Behav. Brain Sci.* **13**: 519–542. doi: 10.1017/SO140525X0080018
44 Rezec AA, Dobkins KR (2004). Attentional weighting: A possible account of visual field asymmetries in visual search? *Spat. Vision.* **17**: 269–293. https://doi.org/10.1163/1568568041920203
45 Reuter-Lorenz PA, Kinsbourne M, Moscovitch M (1990). Hemispheric control of spatial attention. *Brain Cogn.* **12**: 240–266. doi: 10.1016/0278-2626(90)90018-j
46 Roselli M, Roselli A, Vergara I, Ardila A (1985). Topography of the hemi-inattention syndrome. *Int. J. Neurosci.* **27**: 165–172. doi: 10.3109/00207458509149764
47 Rubens AB (1985). Caloric stimulation and unilateral visual neglect. *Neurology.* **35**: 1019–1024. doi: 10.1212/wnl.35.7.1019.
48 Rueckert L, McFadden HG (2004). Context effects in pseudoneglect measured with a free vision Landmark task. *Laterality.* **9**: 421–432. doi: 10.1080/13576500342000257
49 Schuster V, Herholz P, Zimmermann KM, Westermann S, Frässle S, Jansen A (2017). Comparison of fMRI paradigms assessing visuospatial processing: Robustness and reproducibility. *PLoS One.* **12**: e0186344. doi: 10.1371/journal.pone.0186344
50 Seydell-Greenwald A, Pu SF, Ferrara K, Chambers CE, Newport EL, Landau B (2019). Revisiting the Landmark Task as a tool for studying hemispheric specialization: What's really right? *Neuropsychologia.* **127**: 57–65. doi: 10.1016/j.neuropsychologia.2019.01.022
51 Skrandies W (1987). The upper and lower visual field of man: Electro-physiological and functional differences. *Prog. Sens. Physiol.* **8**: 1–93.
52 Siman-Tov T, Mendelsohn A, Schonberg T, Avidan G, Podlipsky I, Pessoa L et al (2007). Bihemispheric leftward bias in a visuospatial attention-related network. *J. Neurosci.* **27**: 11271–11278. doi: 10.1523/jneurosci.0599-07.2007
53 Thomas NA, Elias LJ (2010). Do perceptual asymmetries differ in peripersonal and extrapersonal space? *J. Int. Neuropsychol. Soc.* **16**: 210–214. doi: 10.1017/S135561770999097X
54 Thomas NA, Elias LJ (2011). Upper and lower visual field differences in perceptual asymmetries. *Brain Res.* **1382**: 108–115. doi: 10.1016/j.brainres.2011.02.063
55 Zhou Y, Yu G, Yu X, Wu S, Zhang M (2017). Asymmetric representation of upper and lower visual fields in egocentric and allocentric references. *J. Vis.* **17**: 1–11. doi: 10.1167/17.1.9