Cogn Process (2014) 15:201–207
DOI 10.1007/s10339-013-0591-z

RESEARCH REPORT

Left-ear-driven representational pseudoneglect for mentally represented real-word scenes created from aural–verbal description

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Received: 18 August 2013 / Accepted: 26 November 2013 / Published online: 8 December 2013

Abstract The current research explored pseudoneglect for the mental representation of real-world scenes generated from aural–verbal description in the complete absence of direct visual processing. Healthy participants listened binaurally or monaurally to aural–verbal descriptions of novel real-world scenes with familiar landmarks (e.g. 'shop', 'cafe', 'school') to be imagined on the left- or right-hand side. Participants were asked to mentally represent the street scene using a visuospatial template though it was up to participants how they mentally represented each individual landmark within the street (i.e. in terms of colour and size). There were two main tasks: a relative judgement task (which side of the street contains the most landmarks?) and a recall task (recall the landmarks on the left vs. right side of the street). When stimuli were presented monaurally to the left ear (favouring the activation of the right hemisphere) participants demonstrated representational pseudoneglect and showed a bias towards responding that there were more landmarks on the left compared to the right. However, this did not lead to enhanced recall for left side landmarks. When stimuli were presented binaurally or monaurally to the right ear, there was no evidence of representational pseudoneglect for the relative judgement or recall task. The current study discusses how the use of monaural presentation may boost right hemisphere activation in aural–verbal experimental paradigms designed to explore representational pseudoneglect.

Keywords Pseudoneglect · Spatial attention · Spatial memory · Auditory · Spatial asymmetry

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Introduction

Pseudoneglect (Bowers and Heilman 1980) is a term used to describe a bias towards the left-hand side of space—typically demonstrated when a participant is asked to centrally bisect a visually presented horizontal line under a variety of presentation conditions (for review please see Jewell and McCourt 2000). Visuospatial pseudoneglect has been explained as a result of the right hemisphere preferentially orienting attention to contralateral left space (Reuter Lorenz et al. 1990), a theory well supported by neuroimaging and behavioural studies with healthy participants (Bultitude and Davies 2006; Toba et al. 2011; Fink et al. 2000a, b, 2001). Pseudoneglect may also occur when participants are asked to mentally represent a stimulus. McGeorge et al. (2007) asked healthy participants to imagine the highly familiar scene of the Piazza del Duomo (Cathedral Square) in Italy and to describe the landmarks on each side of the Piazza (see also Bisiach and Luzatti 1978). Participants reported more landmarks from the left side than from the right side of the mental representation, regardless of the imagined viewpoint. Because the bias arose from mental representation, this is suggestive of *representational* rather than visuospatial form of pseudoneglect. Similarly, Bourlon et al. (2011) reported a trend towards participants reporting more elements from the left-hand side of highly familiar scenes in France, and

Friedman et al. (2012) showed a similar tendency for North American cities.

The story becomes even more interesting, however, as it has been demonstrated that healthy participants may have better memory for material that is very briefly presented on the left-hand side of a visual array—here the bias arose from the mental representation of the stimulus after it had been removed from sight (Della Sala et al. 2010; see also Darling et al. 2012). This is an important breakthrough because it suggests that working memory may be susceptible to representational pseudoneglect. An unanswered question, however, is whether this observed effect really originated during mental representation or whether it was due to the activation of a visuospatial bias present at the time of—very brief—stimulus encoding. If so, this may undermine the possibility of an interaction between representational pseudoneglect and working memory.

This question has been addressed by Brooks et al. (2011) who asked participants to mentally represent a novel square matrix that contained either filled-in or empty cells created from aural–verbal description. There was a significant tendency for participants to respond that the left side of the pattern contained the most filled-in cells and to be more certain about judgements for the left-hand side of the pattern; this was enhanced by monaural left ear presentation—a condition that seemed to preferentially favour the activation of the right cerebral hemisphere. Indeed, monaural presentation has been shown in the previous literature to induce contralateral hemispheric activity (Paiement et al. 2008; Schönwiesner et al. 2007). However, the authors found no lateralised memory bias for the mentally represented pattern stimuli. It is possible that mentally representing a completely novel abstract stimulus, like a square pattern, may result in the formation of a less detailed mental representation compared to mentally representing a highly familiar stimulus like a city square (i.e. McGeorge et al. 2007). In addition, mentally representing a completely novel abstract stimulus may lead to the same level of detail for both the left and right side of the stimulus—despite a general orienting of attention towards the left-hand side of the mentally represented stimulus.

One possibility for exploring this further is to ask participants to mentally represent completely novel stimuli (i.e. aural–verbal descriptions of novel scenes) within highly familiar contexts (city streets containing landmarks); this context may result in the formation of a more detailed mental representation from which information can be more easily extracted. It has been recently shown that contextual factors, such as reading direction, can influence how participants reproduce aural–verbal arrays (Roman et al. 2013) and, more generally, contextual elements like the spatial representation of one's body can influence the judgement of stimuli orientation (Barnett-Cowan et al. 2013).

The current study followed the experimental design of Brooks et al. (2011) but used aural–verbal descriptions of fictitious real-world city street scenes with familiar landmarks ('shop', 'market', 'cafe') that were to be imagined on either the left or right side of the street, starting on the imagined left or right. The task for participants was to decide which side of the street, left versus right, contained the most landmarks, provide a certainty score for this judgement (relative judgement task) and recall specific landmarks for the side of the street that was perceived to have the most landmarks (recall task). The stimuli were presented monaurally or binaurally. Participants built a mental representation for each description using a visuospatial template that was provided to them at the beginning of the study; participants were free to mentally represent the individual landmarks in whichever way they choose (in terms of colour, size, dimension). The blended option of providing a template and then some freedom within the template was to ensure that participants could still have the option of using a strategy that worked best for them while completing the tasks above (i.e. Varnava and Halligan 2009).

If participants show a bias towards responding that the left side of the street has the most landmarks as well as superior memory recall for landmarks located on the left, then this may suggest that the contextual familiarity of stimuli is an important factor when exploring the interaction between memory and representational forms of pseudoneglect. The current study thus adds to our understanding of representational pseudoneglect as well as research that has explored how people mentally represent spatial layouts (i.e. Bruyné and Taylor 2008; Deyzac et al. 2006).

Method

Participants

There were 96 right-handed native English-speaking participants from the University of Edinburgh aged between 18 and 38 years. Handedness was assessed with the Edinburgh Handedness Inventory (Oldfield 1970). Vision was reported by participants on a participant information sheet to be normal or corrected-to-normal. Participants confirmed that they had normal or corrected-to-normal hearing and performed a sound check at the beginning of the experiment in order to confirm they could hear a stimulus in each individual ear (monaurally) as well as both ears (binaurally). Participants were paid a £6 honorarium for their time.

Stimuli

There were 32 pre-recorded aural–verbal descriptions of fictitious 'city streets' scenes containing a mixture of

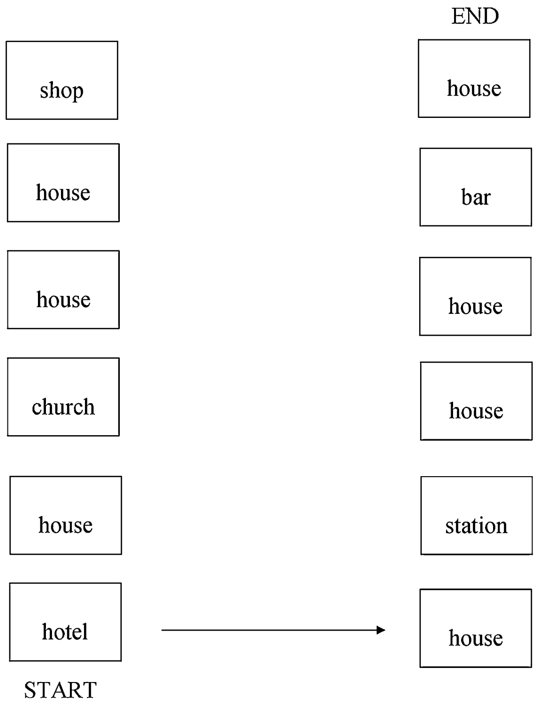

Fig. 1 Illustration of the visuospatial template and example experimental stimulus. *Note* The *left side* of the street has more landmarks than the *right*

landmarks on either street side (depicted in Fig. 1). The stimuli were recorded by a native English-speaking female in a sound-attenuated recording booth. The landmarks were generated using the MRC psycholinguistic database and chosen on the basis of having high imageability scores (>550). The original landmarks were 'bank', 'bar', 'café', 'church', 'college', 'garden', 'hotel', 'market', 'office', 'school', 'shop', 'station'. In a pilot study, 13 native English right-handed participants were asked to decide if each landmark could be easily visually imaged on a city street using a sliding scale of certainty [1 2 3 4 5 6 7]. For this scale, the number '1' represented 'very difficult to conjure up a visual image' and '7' represented 'very easy to conjure up a visual image'. Participants responded towards the low end of the scale (<3) for 'office' and 'college', so these were removed from the cohort. The remaining ten landmarks (with scores >3) were used for the experimental stimuli. For each stimulus, one side of the street was always 'fuller' with more landmarks on one side than the other. There were 8 'left fuller' street scenes with either two, three, four or five landmarks interspersed with the spoken word 'house' on the left side of the street along with one, two, three or four landmarks interspersed with the spoken word 'house' on the right side of the street. There were also 8 'right fuller' street scenes designed in exactly the same way. There were always 6 items (a mixture of landmarks and houses) on each side of the street; 12 items in total. The landmarks were randomly distributed, but the same landmark was not presented at the last/first position of the description on every trial. There were 16 descriptions that started on the left side of the street and 16 descriptions that started on the right side of the street; the description switched back and forth between each side of the street (e.g. on the left is a house, on the right is a bank, on the left is a garden, on the right is a house and so on). The ten original landmarks were split into two matching groups of five stimuli based on their imageability scores. The landmarks for each street side were randomly picked from a pool of 'left side landmarks' and a pool of 'right side landmarks' which allowed the imageability for each street side to be matched on every trial (counterbalanced so that the left side landmarks were presented on the right and vice versa for the right side landmarks).

Procedure

There were 48 participants in a binaural listening condition and a separate group of 48 participants in a monaural listening condition. Participants were given written task instructions and a top-down visuospatial template of a fictitious city street (Fig. 1). Participants were asked to create a mental representation of the street when listening to the description in terms of landmarks on the left and landmarks on the right using the visuospatial template. It was up to participants how they mentally represented each individual landmark in terms of size, colour and dimension (i.e. two or three dimensional)—as long as the landmarks were clearly imagined to be on the left- and right-hand side of the street. Before commencing the experiment, participants were played an aural–verbal example description (this was not included in the main experiment) binaurally and monaurally in each ear in order to ensure that they could hear the stimulus and that the volume of the description was adequate. During the playing of the example stimulus participants were asked to mentally represent the stimulus following the instructions above (using the template), so this was a practice trial. Participants were fitted with a pair of Sony noise-cancelling headphones and closed their eyes and clasped their hands (in order to prevent counting) and were ready to begin. The experiment started when the space bar was pressed by the experimenter. A pre-recorded aural–verbal description of a street scene was played either binaurally or monaurally over the headphones. When the description was completely finished, participants opened their eyes and conducted a relative judgement task with a certainty judgement. The right index finger was always used to respond because participants were all right handed and to keep the response method simple and consistent across the experiment and across participants. Participants reported which side of the street, left or right, had the most landmarks by pressing a key on a response scale consisting of nine keys [4 3 2 1 0 1 2 3 4] which was centrally positioned so that the '0' aligned with the participant's body mid-line. To this end, the left side of the scale was positioned within the participant's left hemispace and the right side of the scale in right hemispace. If the left side of the street was perceived to have the most landmarks, they were asked to select a number on the left side of the scale [4 3 2 1] and rate their certainty about this judgement: '4' on the far left side of the keyboard indicated 'very certain', '3' indicated quite certain, '2' indicated somewhat certain, '1' indicated a little certain. If participants were completely uncertain about which side of the street had the most landmarks, or thought that both sides had the same number, they were asked to press '0' on the scale. If the right side of the street was perceived to have the most landmarks, they were asked to select a number on the right side of the scale [1 2 3 4] and rate their certainty about this judgement. Half the participants (24 binaural and 24 monaural) in each listening condition were also asked to perform an additional task: to recall the landmarks for the side of the street, they reported to have the most landmarks. If they had responded that the left side of the street had the most landmarks, by responding on the left side of the scale, they were asked to recall the landmarks on the left and vice versa for the right side of the street. Participants verbally responded into a centrally positioned microphone with all the landmarks that they remembered—there was no time limit for recall. When recall was complete, participants pressed the space bar for the next trial. Imagined starting side (start on the left side of the street vs. start on the right side of the street) was a within-subject variable and trials were blocked by imagined starting side and counterbalanced across participants. For the monaural listening condition, ear was a within-subject variable and trials were also blocked by ear (counterbalanced across participants). Trial order was randomly shuffled.

Results

Relative judgement

For the relative judgement task, the total number of 'left' responses for each of the 96 (binaural and monaural) participants was subtracted from the total number of 'right' responses and then divided by the overall number of responses to yield a measure of 'proportional bias'. A negative proportional bias indicated a tendency to respond that the left side of the street had more landmarks—a positive value reflected the opposite tendency (Brooks et al. 2011). Both correct and incorrect responses were amalgamated here because a tendency to report that there were more landmarks on the left side of the street should occur regardless of whether or not participants were correct or incorrect in their responses. Across listening conditions there was no significant difference in mean proportional bias between participants who completed relative judgement plus certainty task ($M = -.01$, $SD = .13$) compared to relative judgement plus certainty plus recall ($M = .00$, $SD = .13$) ($F(2,141) = .356$, $p = .552$), so for the purpose of analysing proportional bias the data were collapsed across task type. Figure 2 displays mean proportional bias for participants overall in the binaural and separate monaural listening conditions. Proportional bias was significantly different across the three listening conditions ($F(2,141) = 4.235$, $p = .016$). There was a significant difference between the left and right ear ($p = .014$), no significant difference between the binaural and left ear ($p = .608$) or the binaural and right ear ($p = .141$). For the left ear, proportional bias was significantly different from zero ($t(47) = -2.722$, $p = .009$), but not for the binaural condition ($t(47) = -.713$, $p = .480$) nor for the right ear ($t(47) = 1.704$, $p = .095$) (Table 1).

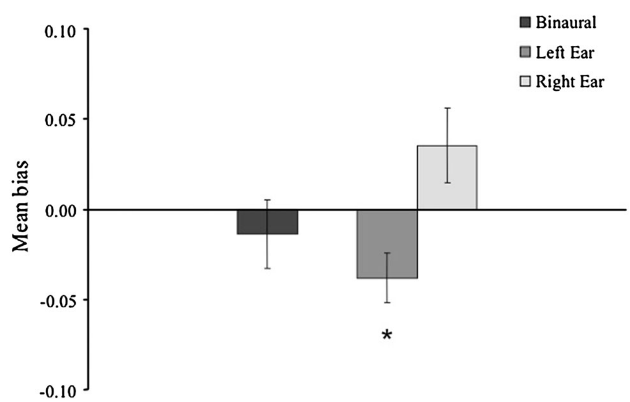

Fig. 2 Proportional bias for the separate binaural and monaural listening conditions. *Note Asterisk* indicates significance. *Error bars* indicate standard error of the mean

Table 1 Summary of responses for the question 'which side had more landmarks?' for each listening condition

Listening condition	Left side *N*	Right side
Binaural	683	662
Left ear	715	657
Right ear	656	710

'Left side' refers to the response 'left side has more landmarks' and vice versa for 'Right side'

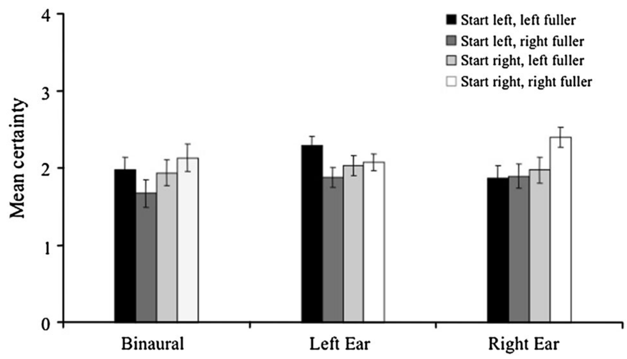

Fig. 3 Mean certainty responses as a function of start side. *Note* Values represent mean certainty on a 4-point scale (4 = maximum certainty, 1 = minimum certainty) for *left fuller* and *right fuller* stimuli. *Error bars* indicate standard error of the mean

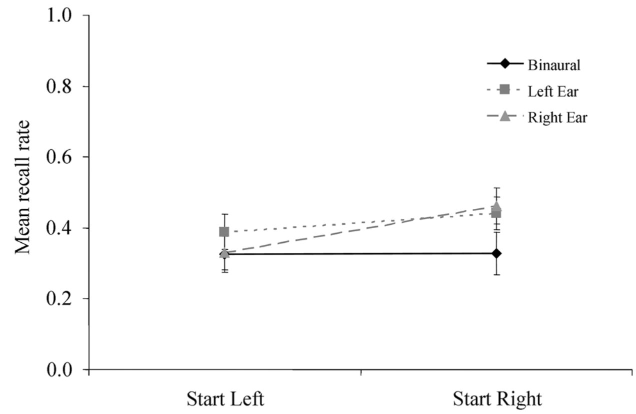

Fig. 4 Mean recall rate as a function of start side. *Note* Values represent mean recall rate for start *left* and start *right*. *Error bars* indicate standard error of the mean

Certainty

A certainty index was created by coding correct judgements (e.g. participants responded 'left side has more landmarks' when the left side did have more landmarks) as positive in value and incorrect judgements (e.g. participants responded 'left side has more landmarks' when the right side had more landmarks) as negative in value (i.e. Brooks et al. 2011). The certainty analysis for participants in the binaural condition and monaural condition was then conducted overall (correct and incorrect trials combined) because, like the measure of proportional bias overleaf, a tendency to be more certain about the landmarks on the left side of the street should occur regardless of whether or not participants were correct or incorrect in their responses. Figure 3 displays mean certainty for the binaural and monaural conditions. For the monaural listening condition, there was a significant interaction between ear and side ($F(1,47) = 7.277$, MSE = .556, $p = .010$) and start side and side ($F(1,47) = 5.541$, MSE = .786, $p = .023$). When presentation was to the left ear, participants' certainty was greater when judging that the left side of the street contained more landmarks than the right—especially when the aural–verbal description was imagined to start on the left-hand side of the mentally represented street.

There was no significant main effect of ear ($F(1,47) = .124$, MSE = .951, $p = .726$), side ($F(1,47) = .086$, MSE = .517, $p = .770$), or start side ($F(1,47) = 2.195$, MSE = .813, $p = .145$), and no interaction between ear and start side ($F(1,47) = 3.435$, MSE = .799, $p = .070$), or ear, start side and side ($F(1,47) = .033$, MSE = .476, $p = .856$). For the binaural condition, there was no significant main effect of side ($F(1,47) = .255$, MSE = .565, $p = .616$) or start side ($F(1,47) = 3.055$, MSE = .679, $p = .087$) nor start side and side ($F(1,47) = 3.929$, MSE = .782, $p = .053$). There was a significant interaction between side and listening condition ($F(2,141) = 3.878$, $p = .023$).

Recall

Recall accuracy was analysed for participants in the binaural condition ($N = 24$) and monaural condition ($N = 24$) in terms of the rate of hits (landmarks correctly recalled), false alarms (landmarks incorrectly recalled), correct rejections (landmarks correctly not recalled), and misses (landmarks not recalled but missed). The calculation of hit rate (HR) is given in Eq. (1) and false alarm rate (FAR) in Eq. (2):

$$\text{Hits}/(\text{Hits} + \text{Misses}) \tag{1}$$

$$\text{False alarms}/(\text{Hits} + \text{False alarms}) \tag{2}$$

Recall rate was then calculated as (HR–FAR) where higher values indicate more accurate recall of landmarks. Figure 4 displays mean recall rate for the binaural and monaural listening conditions.

For the monaural condition, there was a significant main effect of start side ($F(1,23) = 9.964$, MSE = .041, $p = .004$) with recall rate being better for the imagined start right condition (description moved from right to left and finished on the left) compared to the start left condition (description moved from left to right and finished on the right). There was no significant main effect of ear ($F(1,23) = .276$, MSE = 0.67, $p = .605$) or side ($F(1,23) = 1.670$, MSE = .067, $p = .209$), and no interaction between ear and start side ($F(1,23) = 1.982$, MSE = .038, $p = .173$) or ear and side ($F(1,23) = .001$, MSE = .040, $p = .971$) or ear, start side and side ($F(1,23) = 0.62$, MSE = .030, $p = .805$).

For the binaural condition, there was no significant main effect of side ($F(1,23) = .082$, MSE = .043, $p = .777$) or start side ($F(1,23) = .002$, MSE = .022, $p = .968$) and no interaction between start side and side ($F(1,23) = .657$, MSE = .128, $p = .426$). When listening condition was added as a between-group variable, there were no significant effects.

Discussion

The current study explored representational pseudoneglect for the mental representation of completely novel material presented in highly familiar contexts. Healthy participants listened binaurally or monaurally to aural–verbal descriptions of novel city street scenes which contained familiar landmarks (e.g. 'shop', 'market', 'school') and were asked to create a mental representation of the street as it was described using a visuospatial template. Participants were then asked to decide which side of the street contained the most landmarks, provide a certainty score for this judgement and recall the landmarks on the side of the street that was perceived to contain the most landmarks.

The results showed a significant effect of listening condition: when presentation was monaural to the left ear, judgements were significantly biased towards the left side of the street (i.e. 'the left side of the street has the most landmarks') and participants were more certain; but when presentation was binaural or monaural to the right ear, there was no bias. Despite the significant leftward bias for the left ear condition recall accuracy was not biased, with no difference in recall accuracy between the left and right side of the mentally represented street.

In the current study, representational pseudoneglect for the left ear monaural condition is arguably robust. Firstly, it replicates the previous research in the field (Brooks et al. 2011), and secondly, when the stimulus description started on the imagined left side of the street, the bias was enhanced for the certainty judgement. The effect of start side supports the notion that participant responses were driven by attentional mechanisms rather than by chance—otherwise, a start side effect would have been unlikely. However, the results cannot be wholly interpreted within the theoretical framework of the activation–orientation hypothesis (Reuter Lorenz et al. 1990) because representational pseudoneglect was not present for the binaural listening condition. Following the activation–orientation hypothesis, and the notion that monaural presentation induces contralateral hemispheric activity (Paiement et al. 2008; Schönwiesner et al. 2007), representational pseudoneglect should have been present for the binaural listening condition and *enhanced* for the left ear condition due to boosted activation of the right hemisphere. One possibility is that there were two (unforeseen) activational elements at play during this task. Because of the spatial nature of the task, the right hemisphere may have been preferentially activated (i.e. Fink et al. 2000a, b, 2001), and thus, attention was oriented preferentially leftward. But in parallel the left hemisphere may also have been favourably activated due to the processing of spoken words and the left hemisphere's dominant role in language processing. To this end, the activation of each hemisphere may have resulted in a 'cancellation effect' effect, leading to no observation of representational pseudoneglect for the binaural condition. For the right ear listening condition, the current study supports the findings of Brooks et al. (2011) who noted that presentation to the right ear resulted in reduced sensitivity to representational pseudoneglect compared to monaural left ear or binaural presentation.

Unlike the previous research which has demonstrated lateralised memory biases (i.e. McGeorge et al. 2007), the results of the recall task in the current study show that even when there was representational pseudoneglect for left ear presentation, there was no clear lateralised recall bias under this condition. This suggests that the street scene stimulus was mentally represented in equal detail on both the left and right sides (or equally impoverished) despite the bias when participants made a relative judgement. In the current study, the recall rate was higher when participants imagined starting on the right-hand side of the street and finishing on the left; it is possible that this finding was a signature of an underlying effect that could lead to a more marked asymmetry in recall given a developed experimental paradigm.

The results of the current study add to our existing understanding of how different factors may influence the cognitive processing of aural–verbal arrays (i.e. Roman et al. 2013) and indicate that highly familiar context alone is not enough to generate an interaction between memory and representational pseudoneglect.

Future research should ideally focus on exploring the cancellation effect that we mention here—this is highly relevant for the exploration of whether memory is susceptible to representational pseudoneglect using aural–verbal paradigms. It would also be highly relevant for future research to explore the strategies that people use when mentally representing stimuli of an abstract or highly familiar nature. In the current study, while participants were asked to follow the instruction to create a mental representation using a visuospatial template (Fig. 1), the individual mental representation of landmarks may have been markedly different between participants. Of relevance here is a study by Varnava and Halligan (2009) asked over one hundred participants to conduct a visuospatial line bisection task and then report the strategies they used while doing so. Regardless of the strategy used, such as 'extracting the centre of the line' or 'making a comparison between two portions of the line' 'participants deviated towards the left-hand side. While strategy may not directly affect the outcome of visuospatial line bisection, it could well affect the outcome of mental representation.

In conclusion, the current study points towards a dynamic attentional orienting system in the right hemisphere with activation levels that can be potentially boosted by conditions that favour it. The current study emphasises the need for future research in the field of memory and representational pseudoneglect.

Acknowledgments This research was supported by a Ph.D. studentship from The Universita' Suor Orsola Benincasa awarded to JB.

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