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Gaze direction affects visuo-spatial short-term memory

Christophe Carlei, Dirk Kerzel *

Faculté de Psychologie et des Sciences de l'Éducation, Université de Genève, Switzerland

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ABSTRACT

Hemispheric asymmetries were investigated by changing the horizontal position of stimuli that had to be remembered in a visuo-spatial short-term memory task. Observers looked at matrices containing a variable number of filled squares on the left or right side of the screen center. At stimulus offset, participants reproduced the positions of the filled squares in an empty response matrix. Stimulus and response matrices were presented in the same quadrant. We observed that memory performance was better when the matrices were shown on the left side of the screen. We distinguished between recall strategies that relied on visual or non-visual (verbal) cues and found that the effect of gaze position occurred more reliably in participants using visual recall strategies. Overall, the results show that there is a solid enhancement of visuo-spatial short-term memory when observers look to the left. In contrast, vertical position had no influence on performance. We suggest that unilateral gaze to the left activates centers in the right hemisphere contributing to visuo-spatial memory.

1. Introduction

It is generally assumed that the left hemisphere is more involved in verbal processing, whereas the right hemisphere is more involved in visuo-spatial processing (Gazzaniga, 2000). For instance, it has been confirmed that lesions to the right parietal cortex produce stronger perturbations of spatial memory than lesions of the left parietal cortex (e.g., Warrington & Rabin, 1970), which may be related to the frequent occurrence of attentional deficits after lesions of the right hemisphere (Milner & McIntosh, 2005). Interestingly, activity of the right intraparietal sulcus (IPS) reflects the stimulation of both visual hemi-fields in a visual short-term memory (VSTM) task, while the left IPS responded only to stimuli in the contralateral hemi-field (Sheremata, Bettencourt, & Somers, 2010). This asymmetry further underlines the dominance of the right hemisphere in visuo-spatial processing.

Behaviorally, the hemispheric asymmetries can be tested by restricting the presentation of stimuli to one hemi-field, thereby forcing initial processing in the contralateral cortical hemisphere. For instance, Gross (1972) and Samar (1983) demonstrated that responses in categorization or lexical decision tasks were faster when verbal stimuli were presented in the right visual field. Similarly, performance in naming tasks was better when words (vs. non-words) were presented in the right visual field (Jordan & Patching, 2004; Jordan, Patching, & Thomas, 2003). In contrast, spatial stimuli are processed faster when the visual input is initially directed at the right hemisphere. Laeng, Peters, and McCabe (1998) found that pictures were better remembered when they were displayed in the left visual field and Fouty, Otto, Yeo, and Briggs (1992) found higher accuracy and shorter reaction times with left hemi-field presentation when participants were asked to match line orientations to a response set and to make same-different judgments of faces.

Studies using lateralized presentation rely on the fact that the initial processing of the stimuli occurs in the opposite hemisphere. Additionally, there is strong contra-lateral activation when a single hemi-field is stimulated continuously (Schiffer et al., 2004) despite the connections between the two hemispheres. Another method to induce relatively greater activation in one hemisphere than the other relies on spreading activation from motor centers. Harmon-Jones (2006) observed that contraction of one hand increased the activation over contralateral frontal cortices (i.e., alpha suppression). Presumably, the contralateral activation of motor cortex resulting from unilateral hand contraction spread to more frontal areas. At the same time, clenching the right hand (i.e., left hemisphere activation) led to increased approach affect compared to clenching the left hand. In previous work, approach motivated states have been related to activity of the left frontal cortex (Harmon-Jones, Sigelman, Bohlig, & Harmon-Jones, 2003; Jones & Fox, 1992). More relevant to the present paper, it has recently been

* Corresponding author. Address: Faculté de Psychologie et des Sciences de l'Éducation, Université de Genève, 40 Boulevard du Pont d'Arve, CH-1205 Genève, Switzerland.

E-mail address: dirk.kerzel@unige.ch (D. Kerzel).

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shown that contraction of one hand affects episodic memory of word lists (Propper, McGraw, Brunye, & Weiss, 2013). Consistent with the presumed mode of processing of each hemisphere (Habib, Nyberg, & Tulving, 2003), memory performance improved when participants clenched the right hand before encoding and the left hand before recall. Thus, unilateral motor action activates the contralateral hemisphere and facilitates behavior associated with that hemisphere.

In the present contribution, we will investigate the effect of unilateral gaze on visuo-spatial short-term memory. Up to date, there is no direct evidence showing that looking to one side activates the contralateral hemisphere. However, there is some reason to believe that this is the case. Propper, Brunyé, Christman, and Januszewskia (2012) presented participants with a blank map of the United States and asked them to name the states, point to states when the names were read to them, or to name and point simultaneously. Importantly, participants wore glasses that forced them to look at the map with gaze directed to the left, center, or right. With gaze directed towards the left or center, performance was best in the naming condition, decreased with pointing and even further with both tasks simultaneously. In contrast, the difference between naming and pointing was absent when gaze was directed to the right. The interpretation was that gaze directed to the right improved recall in the pointing task by increasing activation of the left hemisphere. This result is consistent with a specialization of the left hemisphere for retrieval of both spatial and verbal information from semantic memory (Habib et al., 2003). In contrast, it does not support the specialization of the right hemisphere for the retrieval of only spatial information from semantic memory (Belger et al., 1998; Jonides et al., 1993).

In light of these results, we set out to explore the effect of unilateral gaze in a task that involved visuo-spatial information. In contrast to Propper et al. (2012), we do not focus on semantic long-term memory, but on visuo-spatial short-term memory (VSTM). Intuitively, VSTM tasks are closer to the perceptual tasks reviewed above that consistently showed better performance for visuo-spatial information directed at the left hemisphere by right hemi-field presentation. Our basic assumption is that gaze directed to the left or right will increase contralateral cortical activity. As the right hemisphere is more strongly associated with visuo-spatial processing, we expect better performance on VSTM tasks when gaze is directed to the left.

2. Overview of experiments

Our experimental task required observers to memorize the positions of filled squares in a five-by-five matrix (see Fig. 1). Immediately after stimulus presentation, they had to reproduce the positions by mouse click in a response matrix that was shown at the same position as the stimulus matrix. To avoid ceiling or floor effects, the session started by a pre-test of the visual span and the number of filled squares in the experiment was adjusted according to individual performance on the span test.

In all experiments, we compared memory performance with gaze directed to the left to memory performance with gaze directed to the right. In addition, we varied the vertical position of the stimuli by presenting the stimuli in opposite quadrants. We opposed the upper left and lower right quadrant in Experiments 1 and 2, and the lower left and the upper right quadrant in Experiment 3. Consistent with the mixed effects of vertical hemifield in previous studies (cf. Introduction to Experiment 3), we did not observe changes in performance depending on vertical position. Therefore, we will focus our discussion on effects of horizontal gaze direction.

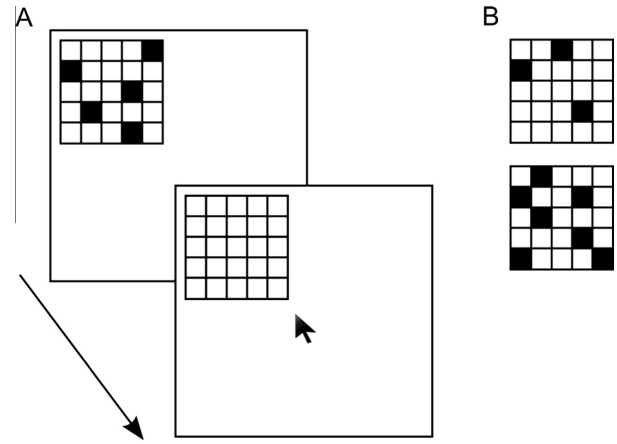

Fig. 1. Illustration of stimuli and procedure. (A) Sample trial with the stimulus matrix in the upper left quadrant of the screen (not drawn to scale). The presentation time was 1 s for each filled square. Then, the response matrix appeared at the same position as the stimulus matrix, together with a mouse cursor in the center. Participants clicked on the remembered cells in the response matrix. Participants using a counting strategy may encode the number of cells from the left edge for each row, resulting in the code 5, 1, 4, 2, 4 from top to bottom. When more than one square was presented per row or rows were empty, this had to be remembered in addition to the square positions. (B) Two sample matrices with three and seven filled squares, respectively.

In Experiment 2, we replicated the basic findings from Experiment 1 and additionally measured individual strategies used to solve the task. We distinguished between strategies based on visual images and strategies based on verbal codes. Individual strategies were also measured in Experiment 3.

3. Experiment 1

3.1. Method

3.1.1. Participants

Participants were twenty-one right-handed students (9 female, aged from 18 to 35) at the University of Geneva. Handedness was measured by self-report. It has been reported that memory for verbal material of consistent right-/left-handers improves when they make saccadic eye movements for 30 s before the memory test (Lyle, Hanaver-Torrez, Hacklander, & Edlin, 2012; Lyle, Logan, & Roediger, 2008). Presumably, consistent left-/right-handed individuals benefit from the saccade task because their relatively weaker hemispheric interaction increases when saccades are made. Because we tested visuo-spatial memory and our hypotheses do not relate to the strength of hemispheric interactions, we had no apriori reason to exclude inconsistent left-/right-handers in the current task. If anything, this decision made our study more conservative because the less homogenous sample increased the random error. The data of one participant was lost due to computer failure. At their arrival, subjects participated in a lottery to win 50 Swiss Francs.

3.1.2. Stimuli and apparatus

Observers' head movements were restrained by a chin/forehead rest at 118 cm from the ground. The experiment was controlled by E-Prime (v1.2) and the stimuli were generated by a video-projector. The visual stimulus was a five-by-five matrix of 50 $\times$ 50 cm (or 17.4° $\times$ 17.4° of visual angle, width $\times$ height) shown on a projection screen (170 $\times$ 130 cm, or 46.7° $\times$ 39.1°) at a distance of 160 cm. When the matrix was shown in a quadrant, there was a margin of 2 cm (0.7°) to the edge of the screen. The eyes were approximately at the horizontal and vertical center of the screen.

A variable number of cells in the matrix were filled. The presentation time was 1 s per filled square (e.g., for a matrix with three filled squares, the presentation time was 3 s). The filled squares marked positions that had to be remembered. Fig. 1 shows three sample stimuli. For each number of squares, there were 10 different matrices that were randomly assigned to the experimental conditions. The matrices had been created to avoid patterns that were easy to remember, such as clusters, lines, or geometric figures. Because of the small number of trials, it was important to make sure that all matrices hat the same difficulty. This was confirmed by one-way ANOVAs on the percent correct responses of matrices containing the same number of squares, which did not produce any significant results.

3.1.3. Procedure and span evaluation

In the first part of the experimental session, we determined the visuo-spatial span for each subject (see Lecerf & de Ribaupierre, 2005). The matrix was presented in the center of the screen. Immediately after presentation of the stimulus matrix, the screen went blank for 150 ms. Then, an empty response matrix appeared at the same position as the stimulus matrix. We hoped that the brief flicker introduced by the blank period would erase an iconic image of the stimulus matrix. At the same time as the response matrix, the mouse cursor appeared in the center of the screen. Then, participants indicated the remembered positions by clicking on the cells of the matrix. Response time was unlimited and it was possible to reset the response matrix after response errors. A response was considered correct if all square positions were correctly reproduced.

After seven practice trials, the span evaluation started with two filled squares. There were three consecutive repetitions for each number of squares. When at least one trial of the three repetitions was correct, the number of squares was subsequently increased by one. When the participant failed all three repetitions, the procedure stopped and the previous number of squares with at least two correct responses was considered the participant's memory span. The maximal span was limited to seven because otherwise, it was more likely that participants encoded the empty spaces rather than the filled squares.

3.1.4. Experimental task

The procedure was as in the span evaluation with the following exceptions. Participants worked through ten trials with a number of squares corresponding to the memory span, followed by ten trials with an additional square (span + 1). In both blocks, stimulus matrices were presented randomly either in the upper left or in the lower right quadrant. On each trial, the response matrix was presented at the same position as the stimulus matrix. Presentation times and response acquisition were as in the span test. Overall, there were 20 experimental trials resulting from the combination of the two numbers of squares (span, span + 1), two stimulus positions (upper left, lower right), and five repetitions. A new pattern of filled squares was presented on each trial. It took about 20 min to complete the experiment (including practice trials and span procedure).

3.2. Results and discussion

The mean memory span, the range of the span, and memory performance as a function of gaze direction (Experiments 1–3) and strategy (Experiments 2 and 3) are shown in Table 1. A response was counted as correct if the positions of all filled squares in the matrix were reproduced correctly. As presentation of the squares was simultaneous, the order of mouse clicks in the matrix was not taken into account. We calculated the mean percentage of correct responses for each location and number of squares. A

Table 1
Results from Experiments 1 to 3. The span refers to the number of squares participants were able to memorize (see text). In Experiment 1, individual strategies were not measured. In Experiment 3, the interaction between strategy and gaze direction was not significant, but we nonetheless report the means as a function of gaze direction and strategy.

Experiment	Span		Memory performance gaze left vs. right		
	Mean	Range	Overall	Visual strategy	Verbal strategy
1	5.55	4–7	64% vs. 53%	–	–
2	5.29	3–7	63% vs. 58%	82% vs. 50%	45% vs. 62%
3	5.57	3–7	59% vs. 49%	66% vs. 61%	60% vs. 38%

repeated-measures ANOVA (2 matrix positions: upper left, lower right; 2 number of squares: span and span + 1) showed that the percentage of correct responses was higher when the number of squares corresponded to the memory span than when one square was added (64% vs. 53%), $F(1,19) = 8.88$, $p = .008$, $\eta^2_P = .32$. We were surprised by the very good performance on trials with span + 1 squares (53% correct responses). Apparently, our procedure underestimated the span in the experimental trials. While the term "span" seems inappropriate with such a high level of performance, we nonetheless keep it for lack of a better term. When the matrix was shown in the upper left corner, performance was better than when it was shown in the lower right corner (63% vs. 54%), $F(1,19) = 5.52$, $p = .029$, $\eta^2_P = .23$. The effect of stimulus position is consistent with our hypothesis that looking to the left activates the right hemisphere, which is experienced as facilitation of the respective lateralized cognitive function (i.e., visuo-spatial memory). The interaction of matrix position and number of squares was not significant, $p = .150$.

4. Experiment 2

In order to explain the inter-individual variability in the effect of gaze direction, we examined the modulating effect of strategies used to solve the task. After informal questioning of the participants, we discerned two main strategies. The visual strategy involved remembering the complete image or the shape created by the squares. The counting strategy involved remembering the position of individual squares by counting the number of empty cells relative to some reference point. For instance, participants may recall the number of empty cells from the left edge for each row containing a filled square (cf. Fig. 1).

We expected that participants relying on the counting strategy would be differently influenced by gaze direction. Looking to the left is expected to facilitate performance when a visual strategy is used because of the right hemisphere's greater involvement in visuo-spatial memory. In contrast, the counting strategy involves mental repetition of words or numbers, which depends on verbal rather than visuo-spatial memory. Therefore, looking to the right may facilitate performance when a counting strategy is used because of the left hemisphere's specialization for verbal stimuli.

4.1. Method

Thirty-five students at the University of Geneva (25 female, 4 left-handed, aged from 20 to 35 years) participated in this experiment. The experimental procedure was the same as in Experiment 1 with the following exceptions. Trials with a number of squares corresponding to the span and trials with span + 1 squares were presented in random order. Further, the position of the subject relative to the screen was slightly changed. The screen was closer to the participant (144 cm instead of 160 cm). Therefore, the visual angle subtended by the matrix increased from 17.4° to 20.9°. The height of the chin rest was raised by 4 cm (now at 122 cm from the ground), which brought the eyes closer to the center of the screen.

In order to determine the strategy, we asked participants at the end of the experiment to describe their strategy. Participants were classified according to their reports during debriefing. Individuals who reported having counted the black squares on every trial in order to remember the position of squares were classified into the counting strategy. Individuals who reported having tried to remember matrices as a whole were classified into the visual strategy. Participants who reported having used both strategies depending on the pattern of filled squares were classified into the mixed strategy.

4.2. Results

The results are presented in Fig. 2. There were 10 participants using the visual strategy, 13 participants using counting, and 12 participants alternating between the two. Because the number of squares had not interacted with the effect of gaze direction in Experiment 1, we collapsed across this factor. A mixed-factors ANOVA (2 gaze directions: upper left, lower right; 3 strategies: visual, counting, mixed) confirmed better performance when participants looked at the upper left compared to the lower right (63% vs. 58%), $F(1,32) = 7.95$, $p = .008$, $\eta^2_P = .20$. There was no main effect of strategy, $F(2,32) = 1.07$, $p = .353$, but an interaction between gaze direction and strategy, $F(2,32) = 37.79$, $p < .001$, $\eta^2_P = .70$ (see Fig. 2). To follow up on this interaction, we compared the upper left and the lower right for the three groups. A *t*-test showed that there were more correct answers for matrices in the upper left than in the lower right quadrant for participants with a visual strategy (82% vs. 50%), $t(9) = 7.69$ $p < .001$, confirming the results of the first experiment. On the other hand, there was an opposite effect with the counting strategy (45% vs. 62%), $t(12) = 16.01$, $p = .002$, and no effect with a mixed strategy, (65% vs. 61%), $t(11) = 1.45$, $p = .175$.

4.3. Discussion

We replicated the effect of gaze direction with a larger sample and found a strong modulation by strategy. Participants using a visual strategy showed better performance with gaze directed at the upper left quadrant. We suggest that the visual strategy relies on visuo-spatial memory, which improves when the right hemisphere is activated by directing gaze to the left. The results from the group using the counting strategy are also interesting. Under the assumption that these participants transformed the visual stimulus into a verbal code, activation of the left hemisphere would have been beneficial. Consistent with this idea, better performance was observed when gaze was directed to the right. Participants using a mixed strategy showed no effect of gaze direction, which makes sense when considering that a given gaze direction either facilitates or degrades performance depending on the strategy.

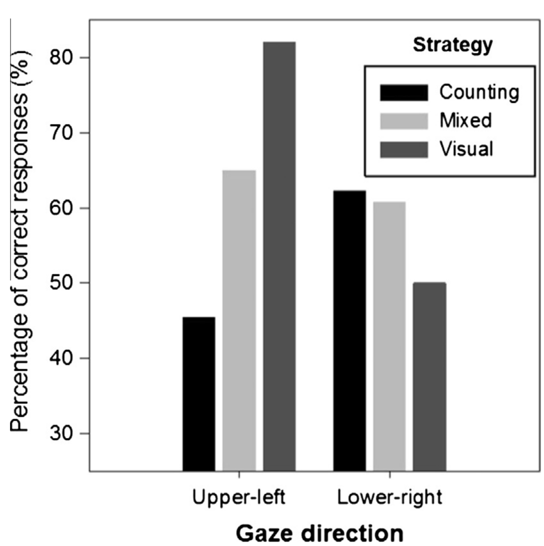

Fig. 2. Results from Experiment 2. Percentage of correct responses is shown as a function of gaze direction and strategy.

5. Experiment 3

In Experiments 1 and 2, a difference was observed between gaze directed at the upper left quadrant and gaze directed at the lower right quadrant, which we attributed to activation of the contralateral hemisphere. However, the two gaze directions examined so far confound laterality (left, right) and elevation (up, down). Beyond the dichotomy between left and right, there are also studies focusing on differences between the upper and lower visual field. For example, attentional resolution was found to be enhanced in the lower visual field (He, Cavanagh, & Intriligator, 1996), which may be explained by enhanced visual discrimination (Carrasco, Talgar, & Cameron, 2001). Similarly, the segmentation of an image into figure and background (Rubin, Nakayama, & Shapley, 1996) and goal-directed actions (Danckert & Goodale, 2001; Khan & Lawrence, 2005; Krigolson & Heath, 2006) are performed better in the lower than the upper visual field. While most studies point to an advantage of processing in the lower visual field (overview in Danckert and Goodale (2003)), visual search (Previc & Naegele, 2001), letter naming (Hagenbeek & Van Strien, 2002), and distance judgments (Niebauer & Christman, 1998) were found to be better in the upper visual field. Given the complexity of the literature on this topic, it is difficult to predict whether there would be an advantage of the upper or lower visual field for the VSTM task of Experiments 1 and 2. Therefore, we do not have any predictions about whether looking upwards or downwards would facilitate performance.

To examine whether laterality or elevation caused the asymmetry observed in Experiments 1 and 2, we examined the lower left and the upper right quadrant (instead of the upper left and lower right). If presentation above and not presentation to the left explained the facilitation in Experiments 1–2, we should find better performance for the upper right than for the lower left quadrant in the current experiment. In addition, we developed questions to allow for a more objective classification of participants. As in the previous experiment, the visual and counting strategies should lead to opposite effects, because they rely on different hemispheres.

5.1. Method

Thirty students at the University of Geneva (25 female, 2 left-handed, aged from 19 to 27), participated. All subjects received a voucher for a lunch at MacDonald's worth 11.30 Swiss Francs.

The same procedure was used as in the second experiment with the following exceptions. The matrices were shown in the upper right quadrant of the screen or in the lower left quadrant (i.e., vertical positions were inverted relative to Experiment 1). Further, participants filled in a questionnaire at the end of the session in order to determine the strategy. Participants rated how often they used each strategy on a scale from zero to three: 0 = never, 1 = sometimes, 2 = often, 3 = every time. Four questions were administered in French. Here, we report the English translation.

For the visual strategy, we asked "I imagined a global shape to better remember the position of squares" and "I imagined isolated shapes to better remember the position of certain squares". For the counting strategy, we asked "I counted the total number of squares displayed in the grid" and "I mentally repeated numbers corresponding to positions of squares (lines and/or columns)". If a participant had a score equal or superior to four on two questions of the same strategy, the participant was categorized into the respective strategy, except if his score on the other strategy was equal or superior to three. In this case, the participant was categorized into the "mixed" strategy. A participant having scores inferior to four on both sets of questions was also categorized into "mixed". The criterion of four was selected *apriori* because it indicated that the participant had indicated at least "often" (score of 2) on both questions or "every time" (score of 3) on one question. Therefore, a total score of 4 indicated that the participant had used the respective strategy frequently. Unless the participant obtained a similar score on the other strategy, we think it was justified to classify the participant into the respective strategy. Some additional questions unrelated to strategies were administered but these are not reported.

5.2. Results

A mixed-factors ANOVA (2 gaze directions: lower left, upper right; strategy: visual $n = 14$, counting $n = 4$, mixed $n = 12$) confirmed a significant effect of gaze direction with better performance when gaze was directed at the lower left than at the upper right quadrant (59% vs. 49%), $F(1,27) = 6.74$, $p = .015$, $\eta^2_P = .20$. Performance depended also on strategy and was better with the visual (63%) than with the counting or mixed strategies (49% and 45%, respectively), $F(2,27) = 3.65$, $p = .039$, $\eta^2_P = .21$. The interaction was not significant, $p = .420$.

5.3. Discussion

Performance was better when gaze was directed at the lower left vs. upper right quadrant. This result confirms our hypothesis that looking to the left increases activation of the right hemisphere, which facilitates performance on VSTM tasks. Comparison of Experiment 3 with Experiments 1–2 suggests that the elevation of the stimuli does not play a role. Further, there was no interaction with strategy. Rather, the advantage of the lower left position was independent of strategy, which may be due to the small number of participants using a counting strategy (only 4).

6. General discussion

Our results show that in a task involving maintenance of information in visuo-spatial short-term memory, it mattered where gaze was directed. Across Experiments 1–3, better performance was observed when gaze was directed to the left than to the right. This finding is in line with the hypothesis that unilateral gaze increases contralateral hemispheric activation (cf. Propper et al., 2012). Accordingly, looking to the left increases activation of the right hemisphere. As the right hemisphere is specialized in spatial memory, performance on the visuo-spatial memory task improved. In contrast, Propper et al. (2012) had concluded that gaze directed to the right (i.e., left hemisphere activation) improves performance in a spatial relative to a verbal task. Their results are consistent with the lateralization of retrieval from semantic memory to the left hemisphere, but not with the lateralization of visuo-spatial processing to the right hemisphere. Thus, unilateral gaze affects short-term and long-term memory differently, which is not surprising given the distinct neural substrates (Tulving, Kapur, Craik, Moscovitch, & Houle, 1994).

Further, there was some evidence in Experiment 2 that performance improves with gaze directed at the lower right when participants use a verbal strategy. This would be consistent with activation of the left hemisphere, which is specialized in the processing and production of language. However, this result was not replicated in Experiment 3, possibly because of the small number of participants using the verbal strategy. In addition, it is possible that strategy and the consistency of handedness were confounded. We did not measure the consistency of handedness and the sample size for verbal strategy was very small ($n = 4$). Thus, it may have been possible that among the few individuals who were using the verbal strategy there were more inconsistent than consistent right-handers. However, only consistent right-handers show improvement of memory performance after the execution of saccades (Lyle et al., 2012; Lyle et al., 2008). Consequently, future studies would need to better distinguish between effects of handedness and encoding strategy.

While our results show a robust advantage in a VSTM task when gaze was directed to the left, we would nonetheless like to mention some limitations of the present study. For example, we did not monitor the direction of gaze by means of an eyetracker. We assumed that participants would look at the stimuli in order to perform the task properly. Actually, we think it is very unlikely that participants would encode the stimuli extrafoveally, for instance by keeping their eyes directed at the empty center of the screen. Moreover, the unequal distribution of subjects in the different strategy groups reduced statistical significance in the last experiment. In future experiments, it would be preferable to identify experimental tasks that exclusively tap into one type of memory.

Further, more research is needed to confirm that directing gaze at one quadrant actually does produce more activation in the respective contralateral cortical centers. Recent research suggests that links between asymmetric hemispheric activation and behavior are strong. For instance, temperature in the ear is correlated with activation in the ipsilateral hemisphere and it has been shown that higher temperature in the left ear is associated with more impulsive behavior in a go-nogo task (Helton, 2010), which is consistent with theories about the lateralization of approach and avoidance (Gray, 1990). Similarly, our research suggests a link between asymmetric brain activation and behavior, but our research remains inconclusive with respect to the underlying neurophysiology. If the effect was mediated by cortical centers of oculomotor control, such as the frontal eye fields, it may be possible to measure differences in the distribution of alpha power between the left and right frontal cortices (cf. Harmon-Jones, 2006). Moreover, our task involves only one component of working memory, the maintenance of information. Future studies should investigate tasks that also require the manipulation of information (reviewed in Barrouillet and Camos (2012)).

Further, it remains unclear whether there is a link between effects of unilateral gaze that we observed in the current study and "non-visual eye movements". Until now, the literature on non-visual eye movements focused on the frequency of saccadic eye movements, but similar to our research, it was also interested in the link between eye movements and memory (e.g. Ehrlichman & Micic, 2012; Ehrlichman, Micic, Sousa, & Zhu, 2007). In contrast to our research, however, there was no systematic investigation of directional patterns. The main finding of these studies was that looking for information in long-term memory increases, whereas maintenance of information in working memory decreases eye movement rate. We also know that the frequency of saccadic eye movements depended on the task. They are more frequent for verbal than for spatial tasks, regardless of visual stimulation (Ehrlichman & Barrett, 1983).

We speculate that we unconsciously make non-visual saccades at a certain frequency in order to activate specific areas in the brain to facilitate the recruitment of some cognitive abilities. For instance, in a task involving visuo-spatial memory in which people can freely move their eyes, the best performance will result when participants make non-visual saccadic eye movements oriented to the left at a certain frequency. However, another direction may be beneficial for verbal tasks and the frequency may be different.

In sum, we find that gaze direction may play a functional role in cognitive processing. Looking to the left increases performance in a task involving visuo-spatial short-term memory.

However, the exact neural causes remain to be investigated.

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