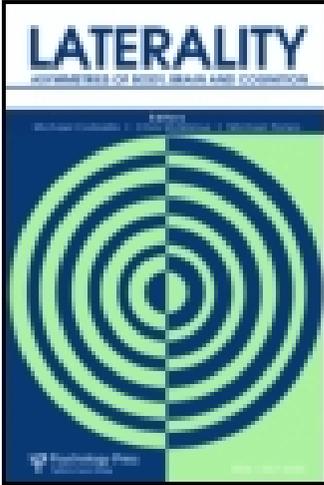


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The effect of gaze direction on the different components of visuo-spatial short-term memory

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The effect of gaze direction on the different components of visuo-spatial short-term memory

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Cerebral asymmetries and cortical regions associated with the upper and lower visual field were investigated using shifts of gaze. Earlier research suggests that gaze shifts to the left or right increase activation of specific areas of the contralateral hemisphere. We asked whether looking at one quadrant of the visual field facilitates the recall in various visuo-spatial tasks. The different components of visuo-spatial memory were investigated by probing memory for a stimulus matrix in each quadrant of the screen. First, memory for visual images or patterns was probed with a matrix of squares that was simultaneously presented and had to be reconstructed by mouse click. Better memory performance was found in the upper left quadrant compared to the three other quadrants indicating that both laterality and elevation are important. Second, positional memory was probed by subsequently presenting squares which prevented the formation of a visual image. Again, we found that gaze to the upper left facilitated performance. Third, memory for object-location binding was probed by asking observers to associate objects to particular locations. Higher performance was found with gaze directed to the lower quadrants irrespective of lateralization, confirming that only some components of visual short-term memory have shared neural substrates.

Keywords: Hemispheric asymmetries; Gaze direction; Unilateral gaze; Object-location binding; Visuo-spatial short-term memory; Positional memory.

Unilateral actions (e.g., looking to the right or contracting the right hand) are thought to activate the contralateral hemisphere. As a result, lateralized cognitive processes associated with the activated hemisphere are facilitated (Carlei & Kerzel,

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2014; Harmon-Jones, 2006; Propper, Brunyé, Christman, & Januszewska, 2012; Propper, McGraw, Brunye, & Weiss, 2013). The present study is concerned with effects of gaze direction on memory. Previously, Propper et al. (2012) concluded that gaze directed to the right facilitated retrieval of verbal and spatial information from semantic memory, which has been associated with left hemisphere functioning (Habib, Nyberg, & Tulving, 2003). Using a different paradigm, Carlei and Kerzel (2014) concluded that looking to the left facilitates visuo-spatial memory because of right-hemisphere activation. In the present study, we investigated the effect of vertical and horizontal gaze direction on different components of visuo-spatial working memory.

Asymmetries between the upper and lower hemifields

As we are interested in differences between upward and downward gaze direction, it is useful to look at differences between the upper and lower visual hemifield. Investigations of gaze direction and visual hemifield have in common that the stimuli are presented in eccentric parts of the screen (above, below, left or right of the centre). To investigate effects of visual hemifield, the eyes are directed at the centre of the screen so that different parts of the retina are stimulated. In studies on gaze direction, however, observers directly look at the eccentric stimuli, which results mostly in foveal stimulation.

Previc (1990) argued that sensory processing of low spatial and high temporal frequencies is best in the lower visual field, whereas higher-level perceptual processing and attention are better in the upper visual field. However, the evaluation of Previc's hypothesis is mixed, in particular with respect to attentional asymmetries. For instance, He, Cavanagh, and Intriligator (1996) claimed that attentional resolution was better in the lower visual field by showing lower visual field advantages in difficult search tasks, but no differences in basic search tasks. In contrast, Carrasco, Talgar, and Cameron (2001) showed that attention, as measured by the effects of exogenous cueing, were similar in the upper and lower visual field, whereas perceptual performance was better in the lower visual field. Further, Rezec and Dobkins (2004) showed that discrimination of basic visual features was better in the lower visual field when search involved the complete visual field, suggesting an attentional bias to the lower visual field, whereas discrimination at cued locations in the upper or lower visual field were equal, suggesting that perceptual performance was about equal. Despite the mixed results for attentional asymmetries, Previc's hypothesis that sensory processing is improved in the lower visual field has been supported by more recent research (Carrasco et al., 2001; Gordon, Shapley, Patel, Pastagia, & Truong, 1997; Levine & McAnany, 2005). In particular, the discrimination of colour is improved in the lower visual field (Gordon et al., 1997; Levine & McAnany, 2005). Finally, there is some evidence that the upper visual field is specialized in conscious perception and object recognition. For instance,

localizing a target among distractors (Feng & Spence, 2014), discrimination between words and non-words (Goldstein & Babkoff, 2001), naming letters in a trigram (Hagenbeek & Van Strien, 2002) or categorical judgements of spatial relationships (i.e., above vs. below, Niebauer & Christman, 1998) were better in the upper visual field.

ASYMMETRIES BETWEEN UPWARD AND DOWNWARD GAZE

The reported differences between the upper and lower visual field may arise from the participation of different brain areas in the processing of stimuli from the upper and lower visual field (Rapcsak, Cimino, & Heilman, 1988; Shelton, Bowers, & Heilman, 1990). Here, our question is whether looking upward or downward activates brain areas that are also involved in treating stimuli from the respective vertical hemifields. We do not expect differences in sensory processing, but differences in higher-level processes, such as attention or object recognition, may occur. However, the advantage of the upper visual field for object recognition mostly concerns letters or words (Goldstein & Babkoff, 2001; Hagenbeek & Van Strien, 2002), whereas we investigate short-term memory for non-verbal stimuli. Thus, the mixed findings on attentional asymmetries and the novel nature of our stimuli make it difficult to derive precise predictions for effects of vertical gaze direction on visuo-spatial memory.

DIFFERENT COMPONENTS OF VISUAL SHORT-TERM MEMORY

In the present study, we will investigate the effects of vertical and horizontal gaze direction on visuo-spatial memory. Visuo-spatial working memory can be subdivided into at least two separable storage systems (Logie, 2003). One for maintaining visual information (such as appearance) and the other for maintaining spatial information (such as the location of objects). Darling, Della Sala, and Logie (2009) provided evidence for these two distinct subsystems in visuo-spatial working memory by selectively disrupting memory in the retention interval. While dynamic noise selectively disrupted visual memory for the appearance of letters, a manual tapping task selectively disrupted location memory for the position of squares.

In our current study, we opted for another technique to selectively investigate visual and positional memory. Pickering, Gathercole, Hall, and Lloyd (2001) asked participants to remember the position of black squares that were either shown simultaneously as a black-and-white pattern or one after the other in an empty matrix. The assumption was that the simultaneously presented squares were stored in the visual subsystem whereas the sequentially presented squares were stored in the positional subsystem.

Finally, Kessels, Kappelle, de Haan, and Postma (2002) argued for a third subsystem of spatial memory with separate brain structures, which they referred to as object-location binding. Based on a study with patients after ischemic stroke, they concluded that the left hemisphere was more involved in binding object identities to known positions, whereas the right hemisphere was critical for positional memory.

PRESENT OBJECTIVES AND OVERVIEW OF EXPERIMENTS

To summarize, our goal is to investigate effects of gaze direction on three distinct types of short-term memory: visual memory, positional memory and object-location binding. Our main prediction is that gaze directed to the left activates centres in the right hemisphere, which improves performance on tasks involving visual and positional memory. In contrast, directing gaze to the right activates centres in the left hemisphere, which improves performance on tasks involving object-location binding (cf. Kessels et al., 2002).

In all our experiments, we compared opposing quadrants in separate groups of participants to disentangle effects of laterality and elevation. We presented the matrices in the upper left or the lower right in one group, and in the lower left or the upper right in the other group.

In the first experiment, we focused on visual memory and attempted to replicate previous results (Carlei & Kerzel, 2014) with improved methods (cf. Discussion). We asked participants to memorize the position of black squares in a matrix that was presented simultaneously and to reproduce the square positions after stimulus offset (see Figure 1A). The main manipulation concerned the position of the matrix on the computer screen and the corresponding gaze direction. The matrix was presented in one of the four quadrants. To prevent verbal coding of the square positions, the phonological loop was blocked (Pelizzon, Brandimonte, & Favretto, 1999). We hope to replicate better performance when participants look to the left, which we attributed to right-hemisphere activation (Carlei & Kerzel, 2014). For elevation, we do not have precise expectations. While categorical judgements of position (i.e., below vs. above) were better in the upper visual field, judgements of distance (i.e., close vs. far) were better in the lower visual field (Niebauer & Christman, 1998). Encoding the matrix positions involves judgements of both categorical spatial relations and distances. Therefore, it is not clear what to expect when gaze is directed upwards or downwards.

In the second experiment, we investigated the positional subcomponent of spatial memory. The squares were presented sequentially instead of simultaneously to prevent subjects from encoding the global shape of the pattern (see Figure 1B). We expect to replicate findings observed for visual memory with better performance when gaze is directed to the left.

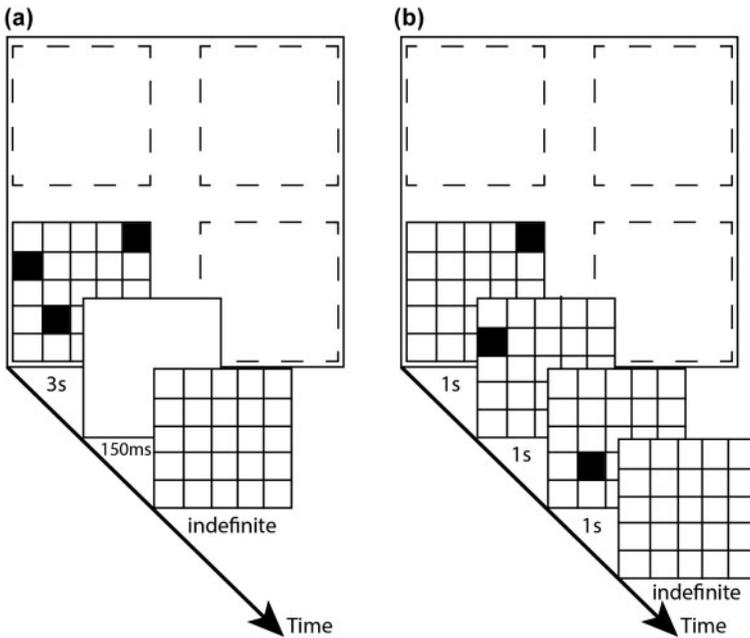


Figure 1. Simultaneous and sequential presentation modes in Experiments 1 and 2 are illustrated in panels A and B, respectively. With simultaneous presentation, presentation time was increased by one second for each square. With sequential presentation, each square was shown for one second. At the end of stimulus presentation, a response matrix appeared in the same location. Participants clicked on the cells to respond. There was no time constraint.

In the third experiment, we investigated object-location binding in a variant of our matrix task that was similar to Kessels et al. (2002). Participants were asked to memorize Japanese symbols at their respective locations. Subsequently, blue dots replaced the Japanese symbols and participants had to recall the Japanese symbol at each dot location. Given that the selected Japanese symbols are visually complex, the capacity to discriminate may play a significant role. As there is some evidence that visual discrimination, as well as attentional and spatial resolution, are better in the lower visual field, we expect better performance when gaze is directed to the lower quadrants.

EXPERIMENT 1

Methods

Participants. Participants were 35 right-handed female students (aged from 17 to 35) at the University of Geneva. All participated for course credit. Handedness of all students was assessed by the Edinburgh Handedness Inventory (Oldfield,

1971), but only strongly right-handed participants with a score equal or above 80 on a scale of 100 participated in the present experiment (see Christman, Propper, & Dion, 2004). We chose to restrict our sample to right-handed women because gender and laterality influence cerebral specialization (Grabowska, Herman, Nowicka, Szatkowska, & Szelag, 1994; Tzourio-Mazoyer et al., 2010). Furthermore, we also chose strongly right-handed participants because we know that their memory performance is more affected by eye movements (Lyle, Logan, & Roediger, 2008). By doing so, we hope to create a more uniform sample and increase our chances of finding reliable differences. Following consent, participants were randomly assigned to one of the two groups. We had 17 participants for the first and 18 participants in the second group.

Stimuli and apparatus. Participants' head position was stabilized with a chin rest at 40 cm from the screen centre in a dimly lit room. The experiment was controlled by E-Prime 2.0 software (Psychology Software Tools, Pittsburgh, PA). Eye movements were monitored by the experimenter from outside the experimental booth with the help of the image of the eye provided by an EyeLink 1000 eye-tracker (SR-Research, Ontario, Canada). Eye movements were not recorded or analysed, but the experimenter assured that participants followed the instructions to look at the stimulus matrix. No deviations from the instructions were noted, probably because it was very difficult to perform the task in peripheral vision.

The visual stimulus was a five-by-five matrix of 8×8 cm (or $11.3^\circ \times 11.3^\circ$ of visual angle, width \times height) shown on a computer screen (30×39 cm, or $36.9^\circ \times 44.3^\circ$). When the matrix was shown in a quadrant, there was a margin of 0.4 cm (0.6°) to the edge of the screen. A variable number of cells in the matrix were filled depending on the visual span of each participant.

The filled squares marked positions that had to be remembered. In order to avoid patterns that were easy to remember such as clusters, lines or geometric figures, matrices had been created and selected previously. The same 20 matrices were used for all participants, but their assignment to the experimental conditions was random.

Procedure and span evaluation. The procedure was almost the same as the one we used in a recent paper (Carlei & Kerzel, 2014), but this time the phonological loop was blocked in order to force visual encoding. Participants had to repeat two nonsense syllables throughout the experiment (e.g., badabada), which prevented participants from re-coding the matrices as a series of numbers (e.g., one number for each column containing a square). The syllables were presented via headphones and participants had to repeat the syllables at the same tempo (1 syllable/second) and approximate volume. Compliance in the articulatory suppression task was monitored by the experimenter. A failure to comply was

to miss a syllable, to not respect the tempo or to be inaudible to the experimenter. All our participants managed to follow this instruction.

In the first part of the experimental session, we determined the visual span for each participant (see Lecerf & de Ribaupierre, 2005). For the span evaluation, matrices were always displayed at the centre of the screen. The presentation time was one second per filled square (e.g., for a matrix with three filled squares, the presentation time was three seconds). Subsequently, the screen went blank for 150 ms and finally, an empty response matrix was displayed. The blank period between the stimulus and the response matrix created a flicker that erased the iconic image of the stimulus matrix. When the response matrix was shown, the mouse cursor was available, so that the participant could indicate the remembered positions by clicking on the respective squares. There was no time limit during the response period. Once the participant was satisfied with the response, she confirmed it by clicking on a separate button. A trial was considered correct if all square positions were correctly reproduced. At the beginning of the experiment, participants went through seven practice trials followed by immediate performance feedback. Then, the span evaluation started with two filled squares. For each number of squares, three consecutive repetitions were performed. When at least one trial of the three repetitions was correct, the number of squares on the next trial was 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.

Experimental task. The procedure was as in the span evaluation with the following exceptions. Stimulus and response matrix were not shown in the centre, but in one of the quadrants. Before presentation of the stimulus matrix, the fixation cross was replaced for 250 ms by an arrow guiding participants to the quadrant of the upcoming matrix. No feedback was given. The duration of the experiment was about 20 minutes (including practice trials and span procedure).

Participants worked through 20 trials following from a 2 (number of squares: span, span + 1) \times 2 (diagonally opposed quadrants) \times 5 (repetitions) design. Participants in the first group saw matrices in the upper left and in the lower right quadrants, whereas participants in the second group saw matrices in the lower left and the upper right quadrants of the screen.

Results and discussion

The mean memory span and the range of the span for Experiments 1–3 are shown in Table 1. The mean percentage of correct responses for each condition collapsed across span and span + 1 is shown in Figure 2A. For the first group, the percentage of correct responses was higher in the upper left corner than in the lower right corner (68% vs. 53%), $F(1, 16) = 24.27$, $p < .001$, $\eta_p^2 = .60$. This result confirms that activation of the right hemisphere by looking towards the left

TABLE 1
Results from Experiments 1–3

<i>Experiment</i>	<i>Span</i>	
	<i>Mean</i>	<i>Range</i>
1	5.4	3–7
2	4.6	3–7
3	4.6	3–7

The span refers to the number of squares participants were able to memorize.

improves visuo-spatial short-term memory (Carlei & Kerzel, 2014). For the second group, there was no difference between the lower left and the upper right corner (50% vs. 50%), $F(1, 17) = 0$, $p = 1$. Further, we performed a mixed-design analysis of variance (ANOVA) with one within-subjects (2 matrix positions: left, right) and one between-subjects factor (2 vertical positions: upper left/lower right, lower left/upper right). We found a main effect of matrix position, $F(1, 33) = 5.99$, $p = .020$, $\eta_p^2 = .154$, and an interaction effect, $F(1, 33) = 5.99$, $p = .020$, $\eta_p^2 = .154$, showing that only the upper left was better than the remaining conditions.

Thus, the advantage of stimuli on the left, which we had observed previously (Carlei & Kerzel, 2014), only occurred when the stimuli were presented in the upper left corner. This discrepancy may be explained by differences in the procedure and sample. In our previous research (Carlei & Kerzel, 2014), we separated participants according to the strategy they used to perform the task. We suspected that participants who transformed the visual stimulus into a visual code (i.e., a mental image) relied on visual memory, whereas participants who transformed the visual stimulus into a verbal code (i.e., numbers representing positions) relied on verbal memory. However, the classification of participants was post hoc and possibly unreliable because there was no way of knowing whether a certain coding strategy had been consistently applied. Blocking the phonological loop is a more reliable way to disengage verbal memory. Also, the sample size for either strategy was small in our previous study, which may have prevented a significant interaction to emerge. Further, the current sample was selected with respect to gender (only women) and laterality (only strongly right-handed), whereas the previous sample was completely random. Thus, our present methods reduced the measurement error, which may explain why the effect of gaze direction was confined to a smaller area of space (upper left quadrant vs. entire left side).

EXPERIMENT 2

In order to disentangle visual and positional memory stores, we changed the presentation mode of the matrices. Observers saw the squares sequentially (see Figure 1B) to specifically request positional memory (Pickering et al., 2001).

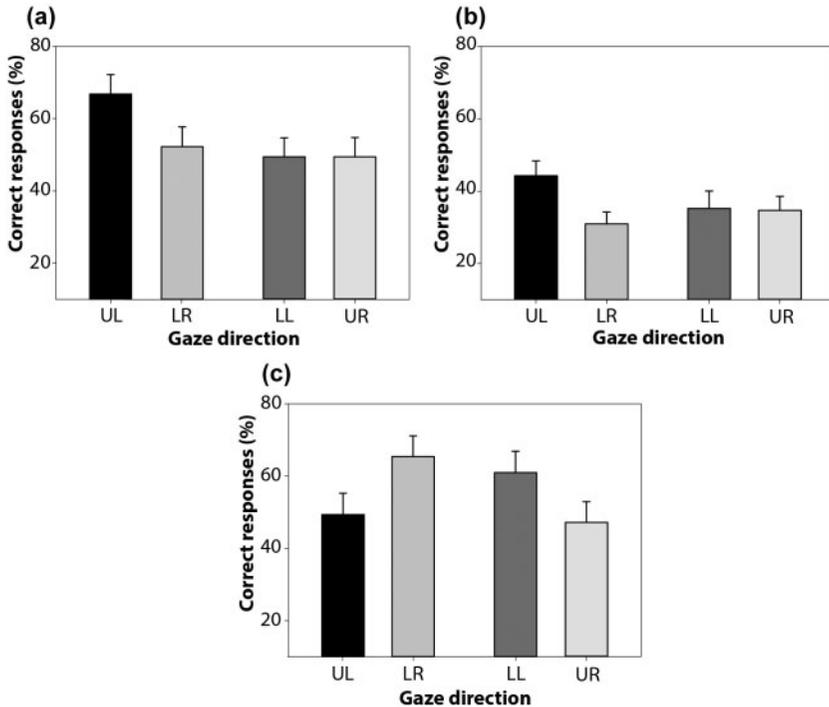


Figure 2. Results from Experiments 1, 2 and 3 are shown in panels A, B and C, respectively. Percentage of correct responses and standard error is shown as a function of gaze direction: Upper Left vs. Lower Right (UL vs. LR) in one group and Lower Left vs. Upper Right (LL vs. UR) in another group of participants.

Methods

Forty-three female students at the University of Geneva (aged from 17 to 24 years) participated in this experiment for course credit. All participants were strongly right-handed (with a score equal or above 80 on a scale of 100 on the Edinburgh Handedness Inventory). None of them had previously participated in the first experiment. Conditions were the same as in Experiment 1; in the first group, 25 participants saw matrices in the upper left and in the lower right corners whereas in the second group, 18 participants saw matrices in the lower left and the upper right corners of the screen.

The experimental procedure was also identical to the first experiment. The only difference was that participants saw the squares sequentially. The presentation time of each square was fixed at one second, resulting in identical total presentation times of the matrices (for the same number of squares) in Experiments 1 and 2.

Results

Figure 2B shows higher percentage of correct responses for the upper left corner than for the lower right corner in the first group (44% vs. 31%), $F(1, 24) = 11.96$, $p = .002$, $\eta_p^2 = .333$. In the second group, there was no difference between the lower left and upper right quadrant (35% vs. 34%), $F(1, 17) = .01$, $p = .907$. As in Experiment 1, a mixed-factors ANOVA revealed a main effect of lateral position, $F(1, 41) = 5.26$, $p = .027$, $\eta_p^2 = .114$, and a significant interaction, $F(1, 41) = 4.44$, $p = .041$, $\eta_p^2 = .098$, confirming that elevation also played a significant role with better performance in the upper left quadrant.

Discussion

We confirmed the advantage of the upper left quadrant for positional memory that we had already observed for visual memory in Experiment 1. We suggest that gaze direction activates brain areas associated with the respective vertical or horizontal hemifield. Therefore, our results are consistent with studies showing that visual and positional short-term memory are two subsystems that both rely on the right hemisphere. Further, both may be facilitated by the activity of the inferior temporal cortex, which is thought to be involved in attention to the upper visual field (Rapcsak et al., 1988; Shelton et al., 1990).

EXPERIMENT 3

The first two experiments have revealed that both visual and positional memory stores show an advantage for gaze directed to the left. Based on known hemispheric asymmetries, we expect that object-location binding will be improved with gaze directed to the right as it is associated with functioning of the left hemisphere (Kessels et al., 2002).

Method

Thirty-six female students at the University of Geneva (aged from 18 to 25 years) participated in this experiment for course credit or pay (15 CHF). All participants were strongly right-handed (with a score equal or above 80 on a scale of 100 on the Edinburgh Handedness Inventory). Nobody knew any Japanese.

At the beginning of the experiment, the object-location binding span was determined for each of our subjects by increasing the number of symbols until participants were unable to provide a correct answer. After the presentation of the stimulus matrix, participants were asked to recall the position of each Japanese symbol (see Figure 3). Blue dots were displayed to indicate the stimulus positions in the test phase and participants had to assign a symbol to each

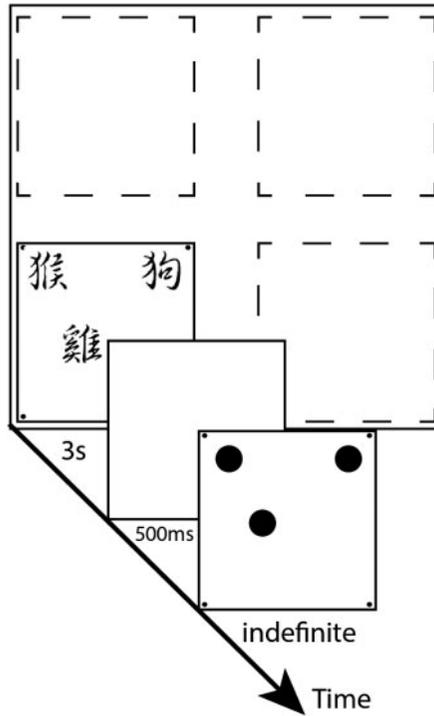


Figure 3. Illustration of the object-location binding paradigm in Experiment 3. The stimulus matrix appeared at once in one of the quadrants for as many seconds as there were Japanese symbols (3 seconds in the example). At the end of the presentation, a response matrix appeared. Dots indicated the positions of previously displayed stimuli. Participants clicked on the dots to browse through all the symbols displayed initially.

location. To assign a symbol to a location, participants left-clicked on the dot to browse through the different objects (i.e., the image shown at the dot location changed with each click). Right-clicking allowed the participants to browse backwards. For each location, the participant could browse all symbols displayed initially. Once satisfied with the response, the participant proceeded to the next trial by clicking on a separate button.

In the experiment proper, the same procedure as in the span test was employed, but the position of the stimulus matrix (and therefore gaze position) was manipulated. As in our previous experiments, participants experienced two counterbalanced conditions (upper left/lower right or lower left/upper right) with 10 trials for each quadrant. There were 18 participants in both groups. In the two conditions, matrices were displayed in random order in two of the four corners of the screen.

Results

Figure 2C shows that percentage of correct responses in the first group was higher in the lower right corner than in the upper left corner (66% vs. 49%), $F(1, 17) = 13.18$, $p = .002$, $\eta_p^2 = .437$. In the second group, the percentage of correct responses was higher in the lower left corner than in the upper right corner (61% vs. 47%), $F(1, 17) = 10.49$, $p = .005$, $\eta_p^2 = .382$. A mixed-factors ANOVA showed no main effect of lateralization but an interaction, $F(1, 34) = 23.63$, $p < .001$, $\eta_p^2 = .410$, confirming better performance with gaze directed downwards.

Discussion

Consistent with the hypothesis that vertical eye movements would activate cortical regions responsible for improved visual discrimination in the lower visual field, we observed better performance when gaze was directed downwards and participants had to visually discriminate unknown Japanese symbols.

However, we did not find any difference in laterality. We had predicted better performance when observers looked to the right, consistent with the deficit in object-location binding observed after right-hemisphere lesions (Kessels et al., 2002). In our view, this discrepancy is accounted for by our stimuli that discouraged verbal strategies because they could not be named. In contrast, the stimuli in Kessels et al. (2002) were everyday objects that could be easily named. Therefore, Kessel et al.'s conclusion that object-location binding relies on the left hemisphere may arise from the contribution of verbal memory to task performance. Our results suggest that without the involvement of verbal processing, the lateralization to the left hemisphere disappears. However, more work is needed to confirm this conclusion.

GENERAL DISCUSSION

In Experiments 1 and 2, better performance was observed when gaze was directed to the upper left quadrant. In Experiment 3, subjects performed better when the task was performed in the lower visual field without any difference between left and right.

The finding of Experiments 1–2 was predicted and is in line with studies mentioned above showing that visual and positional memory tend to be located in the right hemisphere (Kessels et al., 2002) and may be facilitated by the activation of the inferior temporal cortex (Rapcsak et al., 1988; Shelton et al., 1990) when the stimuli are presented in the upper visual field. In the first two tasks, the participant had to remember different positions of the same “object” (i.e., a black square). These tasks do not need any fine discrimination of the displayed matrices but only memorization of simultaneous (visual memory) or consecutive (positional memory) positions. In other words, these tasks involve

memory representations in which relations between objects are more important than the visual details of individual objects. There is evidence that processing global aspects of visual stimuli is facilitated in the left visual field compared to the right visual field (Sergent, 1982). We claim that the matrix task in Experiments 1–2 also involved global visual processing to store spatial relations, which explains why performance was better when gaze was directed to the left and consequently, the right hemisphere was activated.

It is more difficult to situate the effect of vertical gaze position (i.e., advantage in the upper left quadrant) in the literature. Perhaps the advantage with upwards gaze is consistent with Previc's (1990) idea that visual search or attention is better in the upper visual field. More attention is definitely beneficial in our paradigm, but it is difficult to reconcile better performance in the upper visual field with previous research on vertical hemifield asymmetries that have used vastly different tasks and obtained mixed results (Carrasco et al., 2001; Genzano, Di Nocera, & Ferlazzo, 2001; He et al., 1996; Rezec & Dobkins, 2004). When comparing our results with those of Niebauer and Christman (1998), one may conclude that the activation of cortical areas involved in categorical judgements of spatial relations improves performance in our task. Possibly, distance information was not as important as categorical relations (left of, right of, etc.) because the grid had only five rows and columns. If we had required our participants to judge distances more accurately, the advantage of upward gaze may have turned into an advantage of downward gaze.

Neural substrates

Our results showed that manipulating orientation of gaze is a way to differentiate subcomponents of visuo-spatial short-term memory. Moreover, our findings support the hypothesis that horizontal gaze increases contralateral hemispheric activation (cf. Propper et al., 2012) and facilitates cognitive functions associated with the activated hemisphere (cf. introduction). We believe that our unilateral gaze method has similar effects as the unilateral visual stimulation method used by Schiffer et al. (2004). When vision was limited to only one hemifield by wearing special glasses, Schiffer et al. observed stronger activation in the contralateral cerebral hemisphere.

In addition to the distinction between the left and right hemisphere, there is also neurophysiological evidence for the dichotomy between the lower and upper visual field. For instance, Portin, Vanni, Virsu, and Hari (1999) have confirmed the visual discrimination advantage for the lower field by showing differences in magneto-encephalographic activation of occipital regions. Also, Qu, Song, and Ding (2006) found that the early N1 component was larger in the lower visual field compared to the upper field over the occipito-parietal areas while the P1 component, which is modulated by spatial selective attention, was more pronounced for the upper visual field.

Based on studies investigating cerebral differences between attention directed to the upper and lower visual field (Rapcsak et al., 1988; Shelton et al., 1990), we claim that vertical ocular movements will activate different parts of the brain. According to this hypothesis, looking up will activate ventral parts of the brain such as temporal lobes whereas looking down will activate dorsal parts of the brain such as parietal lobes. While these hypotheses are in line with the reported effects of gaze direction, they clearly need further testing in neurophysiological experiments.

Non-visual eye movements

It is interesting to note that research on eye movements has mostly focused on visually triggered saccades (Land & Tatler, 2009). The main purpose of saccadic eye movements is to place the projection of a visual stimulus on the part of the retina with the highest spatial resolution (Young & Sheena, 1975). Far less research has been conducted on non-visual saccades that occur when a person is not looking at a specific visual stimulus, but is engaged in some internal cognitive processing such as thought or imagination. Unlike visual saccades, they are devoid of a visual purpose, occur independently of visual stimulation and are not consciously controlled.

Non-visual saccades have been described as “random”, “spontaneous” or as “waking ocular rapid movements” (Lynch, 1980; Weitzenhoffer & Brockmeier, 1970). They are often not even noticed by the person performing them, suggesting that non-visual eye movements are rather automatic and do not require conscious attention.

While most studies agree that non-visual eye movements are an epiphenomenon of mental processes, there is some recent evidence that the execution of eye movements changes cognitive functioning. Christman, Garvey, Propper, and Phaneuf (2003) asked participants to make large ocular movements from left to right during 30 seconds before recalling a list of words or autobiographical events. The authors found that horizontal saccades improved recall, while vertical saccades did not have any effect. The authors hypothesized that lateral saccades resulted in sequential activation of the left and right hemispheres, which improved hemispheric interaction (Christman & Garvey, 2001) and subsequently improved episodic memory. Consistent with our assumptions, changes of gaze direction are thought to result in changes of cortical activation. From our perspective, it would be interesting to investigate whether lateral eye movements also affect visual short-term memory, which we found to be improved when observers looked at the upper left.

Neurolinguistic programming

Further claims of a causal link between gaze direction and behaviour come from Neuro-Linguistic Programming (NLP). NLP is a set of models and techniques

aimed at improving communication skills (Bandler & Grinder, 1979). This discipline is currently considered as a pseudo-science by most researchers (Witkowski, 2010). Nevertheless, it is interesting to note that NLP holds that non-visual eye movements (“ocular access”) reflects our way of thinking and that gaze direction may unconsciously help us to retrieve existing mental representations or to create new ones (Buckner, Meara, Reese, & Reese, 1987). The NLP model on eye movements claims that looking to the upper left is a way to increase the retrieval of images from memory. The findings of Experiments 1 and 2 with better performances when gaze was directed to the upper left quadrant for visual and positional memory support the model. It is more difficult to interpret the results from Experiment 3 in light of NLP theory because there are no specific assumptions for object-location binding.

Conclusion

We investigated the effects of gaze direction on the different components of visual short-term memory. Our findings demonstrate the functional role of gaze direction in cognitive processing and contribute to a better understand of hemispheric asymmetries and the cortical specialization. Further, our insights may be useful in everyday life. For instance, looking to the left may increase performance in tasks involving visual short-term memory.

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