SHORT REPORT

Eye movements disrupt spatial but not visual mental imagery

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Abstract It has long been known that eye movements are functionally involved in the generation and maintenance of mental images. Indeed, a number of studies demonstrated that voluntary eye movements interfere with mental imagery tasks (e.g., Laeng and Teodorescu in Cogn Sci 26:207–231, 2002). However, mental imagery is conceived as a multifarious cognitive function with at least two components, a spatial component and a visual component. The present study investigated the question of whether eye movements disrupt mental imagery in general or only its spatial component. We present data on healthy young adults, who performed visual and spatial imagery tasks concurrently with a smooth pursuit. In line with previous literature, results revealed that eye movements had a strong disruptive effect on spatial imagery. Moreover, we crucially demonstrated that eye movements had no disruptive effect when participants visualized the depictive aspects of an object. Therefore, we suggest that eye movements serve to a greater extent the spatial than the visual component of mental imagery.

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Introduction

Eye movements are functionally involved in mental imagery, but it remains unclear whether they are involved in all or only some of its components. While it seems reasonably clear that the *spatial* component of mental imagery is disrupted by eye movements, it is not as clear whether eye movements interact with the *visual* component of mental imagery.

Early observations (e.g., Perky 1910; Neisser 1967) supported the claim that eye movements are involved in the construction of a mental image and later research confirmed this claim. For example, Laeng and Teodorescu (2002) demonstrated that eye movements and scanpath during imagery of a visual scene reenacted those which occurred during the initial study of the scene. In parallel, a number of studies suggested that eye movements are necessary for the mental construction and maintenance of a spatial frame of reference. The main evidence for this claim is that performance on tests like the spatial version of the Brooks matrices, or the Corsi blocks, is disrupted by concurrent voluntary eye movements (Baddeley et al. 1975; Baddeley and Lieberman 1980; Pearson and Sahraie 2003; Postle et al. 2006). Pearson and Sahraie (2003) observed that eye movements interfere with spatial working memory to a greater extent than covert shifts of

attention. Godijn and Theeuwes (2012) required their participants to memorize a sequence of digits across a retention interval, during which they were either free to move their eyes or were to fix a single location, or to move their eyes to a selection of locations. Although free eye movements during interval did not improve their performance, in the free eye condition participants regularly decide to execute saccades during the retention interval. Thus, participants chose an eye movement strategy to retain spatial locations, when left free to do so. Furthermore, participants have been observed to make specific eye movements when recalling pictorial information from memory. Recently, Laeng et al. (2014)observed that the patterns of gaze that occurred during perception and imagery of the same visual object were highly correlated. When asked to retrieve the image, participants were likely to fixate the same regions of space as those fixated during the perceptual scrutiny of the shape. Furthermore, the authors showed that memory accuracy (for simplified pictures of animals) was slightly, but significantly lower when gaze was forced to maintain fixation (Experiment 3C) than when it was allowed to freely move (Experiment 3B) during recall. However, the authors remarked that accuracy of recall was generally high (the mean number of errors was of 1.94).

These findings are highly consistent with a study by Martarelli and Mast (2013), which presented colored stimuli appearing in one of four areas of a screen and instructed participants to recall the information immediately and a week after. Eye-position manipulation during both recall (immediate and delayed) did not affect their performance. Nonetheless, in the free eye condition during the recall, participants spontaneously moved their eyes toward the areas where the stimuli were initially presented. They had stored the spatial information along with the visual one, although not required to do so. More specifically, Johansson et al. (2012) observed that eye movements play a functional role during encoding and recall. When fixation during encoding and recall was restricted, the scene recollection was hindered. The authors concluded that eye movements serve a supportive role during demanding tasks involving visuo-spatial imagery. And this is particularly true in people with low spatial imagery abilities, who show an increased degree of eye movements corresponding to locations and directions during recall (Johansson et al. 2011). In a more recent study, Johansson and Johansson (2014) showed that constraining eye movements to a central fixation cross or to an incongruent location (i.e., incongruent with the original location of the to-be-remembered object) more readily affected memory for the spatial arrangement between two objects, than memory concerning the visual orientation of an object. Postle et al. (2006, study 4) asked participants for

the delayed recognition of the shape of previously provided targets and for the delayed recognition of the location of previous targets. After the presentation of the target, participants underwent a "distraction period" in which they were asked either to continuously move their eyes or to read some words appearing on the screen. The results indicated that saccadic distraction affects spatial working memory performance, but not performance on a non-spatial task that is equally difficult. On the contrary, word reading disrupts working memory for shape, but not for locations. Participants were found to systematically move their eyes also when instructed to solve reasoning tasks using mental models (Sima et al. 2013). In this case, spontaneous eye movements occurred when the instructions asked to use visual mental representations and not when spatial mental representation was required. Such results led to the conclusion that voluntary control of eye movement interfered with mental imagery (Andrade et al. 1997; Postle et al. 2006).

This conclusion might be too general, though. Mental imagery is conceived as a multifarious cognitive function with at least two components, a *spatial* component and a *depictive* (Kosslyn and Thompson 2000), also labeled *visual*, component (Reisberg and Heuer 2002). For example, Kosslyn and Thompson (2000) suggested that image maintenance may rely on both a *spatial-properties-processing* subsystem (representing the location of objects) and on an *object-properties-processing* subsystem (representing the visual characteristics of objects). In similar vein, Logie (2011) described visuo-spatial working memory as relying on both a *spatial store* (an "inner scribe" tracking dynamic properties) and a *visual store* (a "visual cache" tracking visual appearance). Finally, patient data confirm that visuo-spatial working memory and imagery involve distinct visual and spatial components (Farah et al. 1988; Della Sala et al. 1999).

So far, it is still unclear whether voluntary eye movements disrupt all components of mental imagery (i.e., spatial and visual), or only one of them.

The present study addresses the question of whether the disruptive effect of eye movements affects to the same extent the two components of mental imagery. To this end, two visual imagery tasks (animal tails and curvy letters) and one spatial imagery task (Brooks matrix task) were used. The three tasks were presented in both an iconic and a verbal version, to make sure that disruptions were specific to the iconic version. Furthermore, we used a further concurrent task, namely the hand tapping. The tapping task was spatial in nature, voluntary and exogenously driven to match the fundamental characteristics of the eye movement task and was added to replicate previous studies (see Quinn and Ralston 1986).

Methods

Participants

Twenty-six young adults (11 men) entered this experiment. Participants were right-handed students recruited at the University of Edinburgh. Their average age was 20.3 years (SD = 1.4). None was under psychoactive pharmacological treatment or had a history of neurological or psychiatric disorder. Participants did not receive any compensation. Before starting the testing session, participants signed an informed consent form. The study procedures were approved by the local ethical committee and were carried out in accordance with the Declaration of Helsinki.

Materials

Two visual imagery tasks (animal tails task and curvy letter task) and one spatial imagery task (Brooks matrix task) were adopted, in their iconic and verbal versions.

Animal tails

Three lists, each involving 20 animal names, were used. In line with Farah et al. (1988), we selected animal names that were not verbally associated with tails (e.g., we did not use rats, beavers, or peacocks) (see "Appendix"). The animal names were verbally presented to the participants, and the order of presentation of the lists was counterbalanced across the subjects. In the iconic version of the task, participants were asked to judge whether or not the animals had long tails, proportional to their body size. In the verbal version of the task, they were asked to respond whether the animals were native to the UK (Kosslyn 1975).

Curvy letters

Each participant was orally presented with all the letters from the English alphabet. According to the procedures described by Farah et al. (1985) and Kosslyn et al. (1985), each letter was presented auditorily one at a time in random order. For the iconic version of the task, participants were instructed to decide whether the letters in their standard uppercase form contain a curve line segment (e.g., "P") or not (e.g., "A"). In the verbal version, they were required to respond whether they contain the sound "ee" (Coltheart et al. 1975).

Brooks matrix

In the iconic version of the task, the participants were told to imagine a 4 × 4 matrix and were told that the second square in the second row would be always the starting square, with successive digits appearing in adjacent squares. The orders were presented in the sequence from 1 to 8 and described the position of each digit (e.g., in the starting square put a 1; in the next square to the *left* put a 2; in the next square *up* put a 3). The verbal version was made up by nonsense messages, which were formally equivalent, except that the spatial prepositions were replaced with qualitative adjectives (e.g., in the starting square put a 1; in the next square to the *slow* put a 2; in the next square *good* put a 3). Once the presented series was complete participants had to verbatim verbally recall the sequence of sentences (Brooks 1967; Baddeley and Lieberman 1980). The order of presentation of the tests was counterbalanced across participants. The verbal and the iconic versions of the imagery tasks were alternated with half of the participants receiving the iconic version first, and the rest receiving the verbal version first.

Procedure

All participants were tested individually in a quiet testing environment, in a single session. They performed the six tasks in three experimental conditions. The order of the conditions was counterbalanced across participants. The control condition was a free viewing condition not involving a concurrent task. In the hand-tapping condition, participants performed each task concurrently with a square (right) hand tapping on a board. The hand tapping was paced by a metronome. Furthermore, participants' hands were covered so that movements were performed without visual processing. This condition was added to replicate previous studies (see Quinn and Ralston 1986) and so to ensure that our procedure was apt to show secondary task interference effects. Finally, in the critical "eye movement" condition, the tasks were performed concurrently with a continuous, voluntary smooth pursuit. Red fixation and green target stimuli on a white background were presented on a 17-inch CTR monitor (1,024 × 768 pixels) at 100 Hz. Participants were seated with their head in a chin rest, and their eyes horizontally and vertically aligned with the center of the screen at a distance of 80 cm. Eye movements were recorded with the EyeLink 1000 system (detection algorithm: pupil and corneal reflex, 1,000 Hz sampling). A five-point horizontal–vertical calibration was run at the start of the experiment. Each trial began with a drift correction and a tone accompanying the onset of a .5° red dot presented on the left side of the screen at an eccentricity of 8.5° of visual angle. The experimenter started each trial by pressing the spacebar. As soon as the experimenter started the trail, the dot became green and moved continuously from left to right at a frequency of .6 Hz, spanning a total distance of 17° of visual angle. Participants were required to fixate the dot until it was red

and then to follow it with their gaze as soon as it became green and started moving. The experimenter stopped the trial when the imagery task was concluded. Participants were also asked to perform a baseline condition in which they were instructed solely to follow the dot for 60 s.

Results

The performance in each task, in each condition, is shown in Fig. 1. For the ease of comparison, Fig. 1 displays performance as the percentage of correct responses in each task. For purposes of statistical analyses, separate 3 (concurrent task: eye movements vs. tapping vs. control) × 2 (imagery task version: verbal vs. visual) analyses of variance (ANOVAs), with both variables as within-subject factors, were carried out on the mean scores obtained at each task.
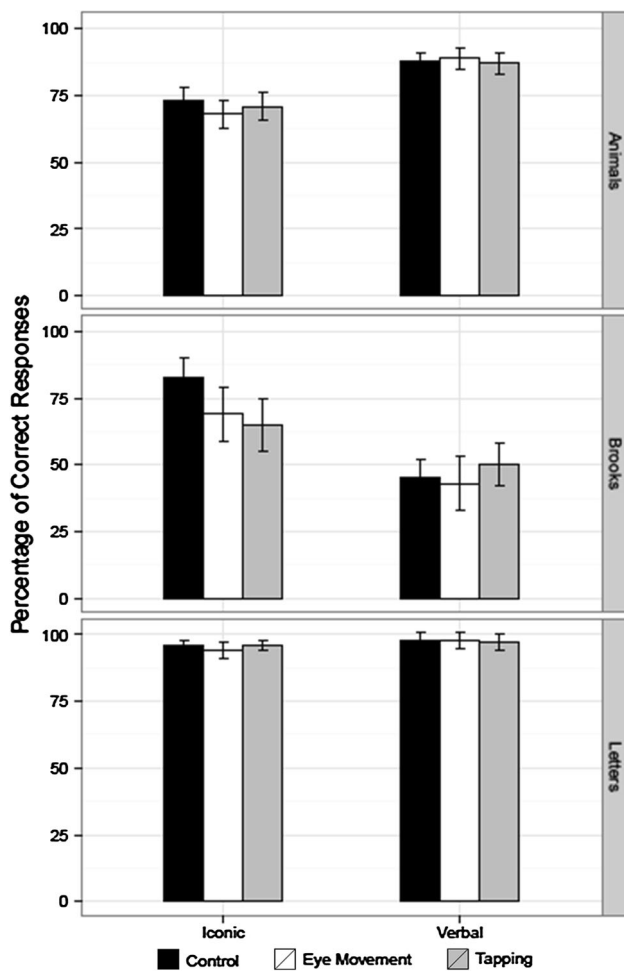
Fig. 1 Performance (expressed as a percentage of correct responses) in all combinations of tasks and conditions. *Error bars* show the 95 % confidence interval for the mean, corrected for a within-subject design

For the animal tails task, the analysis detected a significant effect of task version, $F(1, 25) = 95.88$, MSE $= 484.77$, $p < .001$, but no effect of concurrent task, $F(1, 25) = .43$, MSE $= 1.27$, and no interaction, $F(1, 25) = 1.07$, MSE $= 3.97$. The effect of the task version was due to the verbal version ($M = 17.63$, SD $= 1.84$) scoring higher than the iconic version ($M = 14.11$, SD $= 2.13$).

Results for the curvy letter task also showed an effect of task version, $F(1, 25) = 8.84$, MSE $= 17.33$, $p < .01$, but no effect of concurrent task, $F(1, 25) = .54$, MSE $= 1.04$, and no interaction, $F(1, 25) = 1.68$, MSE $= 2.00$. The effect of the task version was due to higher scores obtained with the verbal version ($M = 25.45$, SD $= 1.06$) than the iconic version ($M = 24.79$, SD $= 1.58$). Results must be interpreted carefully though, given the extremely high performance on this task.

For the Brooks matrix task, results showed an effect of concurrent task, $F(1, 25) = 3.46$, MSE $= 5.44$, $p < .05$, an effect of task version, $F(1, 25) = 36.38$, MSE $= 176.64$, $p < .001$, and a significant interaction, $F(1, 25) = 4.16$, MSE $= 10.62$, $p < .05$. The main effect of concurrent tasks was due to higher scores being obtained in the control condition ($M = 5.09$, SD $= 1.96$) than in the two dual task conditions (tapping: $M = 4.61$, SD $= 2.15$; eye movements: $M = 4.47$, SD $= 2.45$). The main effect of task version was due to scores on the iconic version of the Brooks task ($M = 5.79$, SD $= 2.29$) being higher than those on the verbal version ($M = 3.66$, SD $= 2.08$). The interaction was driven by the scores on the iconic version of the Brooks task in the control condition ($M = 6.61$, SD $= 2.02$) being higher than those on the iconic version in eye movement condition ($M = 5.53$, SD $= 2.51$), $t(25) = 3.54$, MSE $= .30$, $p < .005$, and higher than those in the tapping condition ($M = 5.23$, SD $= 2.35$), $t(25) = 3.71$, MSE $= .37$, $p < .005$. No significant difference related to any of the concurrent tasks was observed in the verbal version of the Brooks task.

Eye-tracking data can also shed light on the specific link between eye movements and spatial imagery. In the eye movement condition, we recorded the mean "error" distance (in mm) between the position of a participant's gaze and the position of the dot on the screen. The higher the conflict between eye movements and a primary task, the greater this error distance should be. In all versions of tasks, the error distance was greater than the 11.51 mm (SD $= 8.44$) observed in the baseline condition, all $t_s > 1.96$, all $p_s < .05$. Whether this error distance was the same or not in the iconic and verbal versions, though, varied from one task to another.

For the animal tails task, the error distance in the iconic version ($M = 17.32$, SD $= 14.31$) was not detectably different from the error distance in the verbal version

($M = 16.63$, SD $= 13.81$), $t(25) = .85$, MSE $= .82$, $p > .40$. Likewise, for the curvy letters task, the error distance in the iconic version ($M = 17.45$, SD $= 14.23$) was not detectably different from the error distance in the verbal version ($M = 16.83$, SD $= 14.21$), $t(25) = .43$, MSE $= 1.41$, $p > .66$. However, for the Brooks matrix task, the error distance in the iconic version ($M = 24.75$, SD $= 14.83$) was significantly greater than the error distance in the verbal version ($M = 18.92$, SD $= 13.19$), $t(25) = 3.70$, MSE $= 1.57$, $p = .001$. Furthermore, the error distance in the iconic version of the Brooks matrix task was significantly greater than the error distance in any version of all the other tasks (all $p_s < .001$).

No significant correlation was observed between the participants' error in following the dot during the baseline condition and the scores that they obtained in the three iconic versions of the tests. Furthermore, we also split-halved our participants in two groups on the basis of the errors (in mm) made during the baseline condition: good and poor performers in following the dot (respectively, $M = 6.77$, SD $= 1.12$ and $M = 16.26$, SD $= 9.91$). A series of t tests comparing the good and poor dot following performers on their scores in the three iconic versions of the tests failed to show significant differences.

Discussion

Eye movements are said to play a functional role in the generation and maintenance of mental images: a number of studies demonstrated that voluntary eye movements interfered with mental imagery tasks (e.g., Andrade et al. 1997; Barrowcliff et al. 2004; Gunter and Bodner 2008; Postle et al. 2006). Some studies have failed to show a facilitatory effect during recall of eye movements on memory (e.g., Richardson and Spivey 2000). However, it has been noticed that Richardson and Spivey (2000) presented their participants with tasks that did not necessarily need detailed mental images to be accomplished (for a discussion see Laeng et al. 2014). On the contrary, many other studies observed that participants regularly and spontaneously choose to execute eye movements as a strategy to retain spatial locations both during immediate (Godijn and Theeuwes 2012) and in delayed recall (Martarelli and Mast 2013). When fixation during the encoding and recall of a scene was restricted, the scene recollection has been shown to be hindered (Johansson et al. 2012), especially in people with low spatial imagery abilities (Johansson et al. 2011). Laeng et al. (2014) showed that eye movements occurred to spaces corresponding to the original positions of salient features or parts of retrieved information and that hindering eye movements during recall resulted in measurable costs in terms of memory accuracy. Moreover, a study by

Johansson and Johansson (2014) indicated that hindering eye movements interferes more markedly with memory for the spatial relationship between objects (inter-object statements) than with memory for intrinsic object features (intra-object statements).

Therefore, it may be interesting to evaluate the different role of eye movements during tasks tapping into different (i.e., *spatial* and *visual*) components of mental imagery.

Indeed, mental imagery is not an encapsulated cognitive function, but rather draws on several constituent abilities (Slotnick et al. 2012). To say that eye movements serve a functional role in mental imagery is not enough: the necessary next step is to specify the components of mental imagery that they serve.

So far, data suggested that eye movements during imagery helped to position correctly each part of a scene or of an object. It is well established that arm movements disrupt visual imagery. Brooks (1968) noticed that a strong conflict with the recall of spatial information is "evident when the movements are either visually or tactually monitored" (p. 365–366). Byrne (1974) showed that visually guided arm movements disrupted recall of spatially arranged pictures. Furthermore, Quinn and Ralston (1986) observed that "arm movements, like eye movements, can disrupt recall of spatial material if the arms are moved simultaneously with and are incompatible with the presentation of, the spatial material" (p. 699).

The hand-tapping condition was added with a view to replicate previous studies and so to ensure that our procedure was apt to show secondary task interference effects.

Our novel contribution was to investigate the effect of voluntary eye movements on the *visual* component of mental imagery, whose role is to represent the depictive characteristics of a scene or of an object.

Critically, we demonstrated that eye movements had no disruptive effect when participants visualized the depictive characteristics of an object, like animal tails or curve segments in the letters of the alphabet. These two tasks were used because a relevant body of research with both healthy people and patients has identified animals' parts and letters' shapes as properties that are unlikely to be encoded through any modality other than vision and has consequently adopted these properties to address visual imagery. In many experiments, Kosslyn (e.g., 1975) required his participants to retrieve size and shape of animals' body parts, considering this visual form information presumably represented visually. Accordingly, Kerr (1983) attributed the impossibility to administer animal body-part imagery test to his congenitally blind patients to the fact that this material was unlikely to have been encoded any way different from visually. In line with these interpretations, Farah et al. (1988) observed a dissociation in L.H., who showed profound visual imagery deficit despite a

spared spatial imagery. The severe L.H.'s impairment in visual imagery was tested using also the animal tails task. Similarly, Rosebaum et al. (2004) demonstrated a dissociation between K.C.'s intensive retrograde amnesia and a preserved visual imagery, by testing the visual imagery of their patient on the animal tails and the letter shape tests.

It may be suggested, as an alternative hypothesis, that the horizontal pursuit of the dot may be less interfering for the animal than the Brooks task, since the slow horizontal sweep of the dot may be used as a dynamic framework on which one could place the body parts (first the head, then the trunk, and then the tail). Although we also used animals with a vertical spatial configuration of their body parts (e.g., parrot, flamingo, sea horse), it is true, as also remarked in Laeng et al. (2014), that one of the crucial properties of mental imagery is of being dynamic. Imagined elements might be translated or rotated in space. Assuming that this was the strategy that participants adopted in the animal task, it may be easier to rotate a parrot and place its body parts along the horizontal line of the eye movements, rather than solving the Brooks matrices task. However, it may be easier for the different nature of the two tasks. It is easier to adopt a dynamic framework for a static task. The parrot may be visualized as a static image, and, hence, it may be rotated and scrutinized. In this case, eye movements during the recall may serve as an alternative strategy. The image may be somehow adapted in the case of a manipulation of the eye movements. On the contrary, when one needs to track dynamic, spatial properties, a manipulation of the gaze during recall may have a more crucial, disruptive effect. Therefore, we are likely to need eye movements when mentally tracking the spatial (dynamic) properties of an object more than when mentally inspecting its depictive (static) properties.

Therefore, we suggest that eye movements are not required to the same extent for the different components of mental imagery. This claim is also supported by the extra difficulty of visually tracking a dot, while performing the iconic version of the Brooks matrix task, as compared with its verbal version. Hence, excluding any possible trade-off effect. Although an argument of possible different cognitive demands across the tasks could be raised for the curvy letters, this does not apply to the animal tails task, as the performance on the iconic version of this task is no better than that on the Brooks matrix. Furthermore, the verbal version of Brooks matrix, which has long been known to be more difficult than the iconic one, as participants' performances in our study further confirmed, was not affected by eye movements.

In sum, the present study has provided evidence that voluntary eye movements selectively disrupt spatial mental imagery. Spatial mental imagery is conceived of as one among an assortment of differentiated abilities within the mental imagery. It entails short-term spatial representations, which are generated on the basis of information stored in memory (Kosslyn and Thompson 2000). It is crucially important to gather such evidence, because spatial imagery might play a key role in many forms of cognition. For example, visual memory might involve imagery of previously learned stimuli (Slotnick et al. 2012). Furthermore, it has also been suggested that spatial mental imagery might be important in future thinking (de Vito 2012; de Vito and Della Sala 2011) and intelligence (Deary 2000). Previous studies have suggested that mental imagery and visuo-spatial working memory might derive from the same cognitive resources that control voluntary eye movements (Postle et al. 2006). The present study further refines this statement and cast new light on the role of eye movements in imagery and working memory. Our results suggest that the spatial component of mental imagery and working memory may be interfered by concurrent eye movements to a greater extent than its visual component.

Appendix

The three lists, each involving 20 animal names, which were used in the *animal tails* task are reported below.

List 1: DEER, DALMATIAN, FLAMINGO, GIRAFFE, CHIMPANZEE, KANGAROO, CROW, SQUIRREL, OWL, HAMSTER, SWAN, SAINT BERNARD, RAT, JAGUAR, KOALA, HUSKY, LAMB, COW, GREAT DANE, and RHINOCEROS.

List 2: SEAL, COCKEREL, HYENA, GREYHOUND, PELICAN, HEDGEHOG, ZEBRA, CAMEL, SEA HORSE, DONKEY, TURTLE, HORSE, GAZELLE, TIGER, CHAMELEON, BULL, BUFFALO, PANDA, PIG, and PERSIAN CAT.

List 3: LION, WOLF, GIBBON, CROCODILE, SHEEP, OTTER, LEOPARD, PARROT, HIPPOPOTAMUS, DUCK, ANTELOPE, BAT, LIZARD, BADGER, PENGUIN, ANT EATER, MOUSE, SEAGULL, SIAMESE CAT, and GOAT.

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