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The Dispersion of Eye Movements During Visual Imagery is Related to Individual Differences in Spatial Imagery Ability

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Abstract

This study explored individual differences in eye movements during visual imagery. Eye movements were recorded for participants who recalled a picture from memory while looking at a blank screen. All participants were tested for working memory capacity and the OSIVQ (Blazhenkova & Kozhevnikov, 2009) was used as an assessment for individual differences in object imagery, spatial imagery and verbal cognitive style. Results revealed a negative correlation between the overall spatial dispersion of eye movements and the spatial imagery score. Consequently, those with a lower spatial imagery score employed a larger degree of eye movements to blank spaces than those with a higher spatial imagery score. No relationship was found between eye movements and the other aspects. We propose that weaker spatial imagery ability increases the "need" to execute eye movements during recall and discuss this finding in relation to the current literature on eye movements to 'nothing'.

Keywords: Eye movements, object imagery, spatial imagery, spatial cognition, visual attention, working memory.

Introduction

Research of eye movements during visual imagery has a rather long empirical history. Early studies (e.g., Perky, 1910; Jacobsen, 1932) reported a large amount of eye movement activity during visual imagery, and indicated a tight link between eye movements and mental images. Neisser (1967) argued that eye movements are actively associated with the construction of a visual image, and Hebb (1968) suggested that eye movements are necessary to assemble and organize "part images" into a whole visualized image. Theories inspired by Hebb (1968) and Neisser (1967) gained strong support from more recent eye-tracking studies, where it has been shown that spontaneous eye movements occur with visual imagery, and that those eye movements closely reflect content and spatial relations of the visualized scene (e.g., Brandt & Stark, 1997; Gbadamosi & Zangemeister, 2001; Spivey & Geng, 2001; Laeng & Teodorescu, 2002; Johansson, Holsanova & Holmqvist, 2006). The dominant theoretical interpretation of results from these studies is that eye movements reflect a simulation of perception (Hesslow, 2002) in a 'visual buffer' (e.g., Kosslyn, 2006) of working memory. The eye movements would thus reflect the process of activating and arranging part images of a scene into their proper locations, and would as in visual perception, create the illusion of "seeing" this scene as a whole. Kosslyn (1988) has argued that image generation in the visual buffer is processed sequentially and Brandt and Stark (1997) have suggested that eye movements are an important tool in this process, and that they might be necessary for the construction and utilization of visual imagery. Another prominent approach has been favored by Thomas (2009), where perceptual experiences are not considered to consist of internal representations. Instead they are the consequence of an ongoing exploration of the environment where a set of procedures specify how we direct our attention. In this view, visual imagery is a re-enactment of the appropriate exploratory behavior, which includes eye movements.

Several studies have also reported large individual differences in the amount and amplitude of eye movements during visual imagery. An early study by Stoy (1930) found large individual differences in both amplitude and frequency of eye movements when thinking about spatial problems, and Johansson et al. (2006) reported similar findings in a more recent eye-tracking study. In Johansson et al. (2006) participants inspected a complex picture which they subsequently recalled while looking at a blank screen. Some participants "painted" the visualized picture with their eyes over the entire blank screen while others only looked at a smaller part of it. But within this smaller area, positions and directions from the visualization were frequently preserved in the eye movements. Gaze patterns which differ in size, between encoding and recall, have also been reported by Brandt and Stark (1997), and Gbadamosi and Zangemeister (2001). Furthermore, two of the nine participants in Brandt and Stark's (1997) study did not show any eye movements during visual imagery, and neither did two out of twelve participants in Spivey, Tyler, Richardson and Young (2000).

Nevertheless, few studies of eye movements during visual imagery have been dedicated to individual differences. Two exceptions are Brown (1968) and Marks (1973a). Brown (1968) compared eye movement amplitudes during recall of a metronome's motion for poor and vivid visualizers, but found no consistent differences. Unfortunately, details on how visual imagery ability was estimated were not reported. Marks (1973a) investigated two experimental groups of "vivid" and "poor" visualizers in the recall of pictures and reported that poor visualizers had a higher eye movement rate (EMR) during recall than vivid visualizers. Marks (1973a) used the visual imagery questionnaire (VVIQ) (Marks, 1973b) to identify poor and vivid visualizers, which provides a vividness score based on ratings for 16 imagery items. However, the VVIQ only considers vividness and does not make a difference between *object imagery* and *spatial imagery* (e.g., Kozhevnikov, Kosslyn & Shephard, 2005) which makes this result hard to interpret. This distinction is important, since Farah, Hammond, Levine and Calvanio (1988) have demonstrated that there are dissociable systems for object and spatial imagery, which relies either on the object (ventral) or the spatial (dorsal) pathways of the brain (e.g., Gazzaniga, 2004).

An analogous result to the one by Marks (1973a) has also been reported in a related but somewhat different research field. Tikhomirov (1971) investigated photographs of eye movements for chess players who imagined chess moves. He found that expert chess players executed less eye movements than novice chess players. This effect has been confirmed in more recent studies of chess players and over different tasks (e.g., Charness, Reingold, Pomplun and Stampe, 2001). Charness et al. (2001) argued that experts encode larger clusters of information into chunks of relevant information and reported that expert chess players have a larger visual span in these tasks. Weber and Malmstrom (1979) have argued that chunking is used in a similar fashion during visual imagery, and suggested that eye movements are not necessary within a chunk and might only be manifested between chunks. Consequently, higher expertise/ability would decrease eye movements also during visual imagery tasks, which would be consistent with the findings by Marks (1973a).

Apart from imagery abilities and expertise there is also reason to believe that working memory (WM) capacity is an important factor for eye movements during visual imagery. Engle (2002) has concluded that WM capacity is the same as executive attention, and only indirectly linked to memory. Greater WM capacity would therefore not mean a larger memory store, but a better ability to control attention. A tight link between eye movement control and WM capacity has, for instance, been found for performance in the antisaccade task (Kane, Bleckley, Conway and Engle, 2001). In this task, participants are looking at a fixation cross in the centre of the screen and must respond to a target presented randomly on either side of the fixation cross. Just before the target is presented an attention-attracting cue appears on the side opposite to where the target will appear. In the study by Kane et al. (2001), participants with low WM capacity executed more eye movements to the misleading cue. Consequently, if eye movements during visual imagery reflect the construction or scanning of mental scene representations in working memory, then it is most likely that individual differences in working memory capacity would affect the degree to which these eye movements are employed.

The goal of the current study was to explore whether individual differences in object imagery ability, spatial imagery ability and WM capacity are related to the spatial dispersion of eye movements during picture recall. To our knowledge, except for Marks (1973a), no previous eye-tracking study has investigated any of these relationships before. However, Marks (1973a) only considered individual differences in vividness ability and did not investigate the spatial layout of eye movements in detail.

Experiment

The experiment consisted of three parts. In the first part, participants inspected a complex picture and subsequently recalled it while looking at a blank screen. To ensure that spatial scanning was employed during recall, the experimental design and method from Johansson et al. (2006) was used, where the imagery task is to orally describe the picture from memory. Eye movements were recorded both during encoding and during recall.

In the second part, participants answered a computerized version of the Object-Spatial Imagery and Verbal questionnaire (OSIVQ) (Blazhenkova & Kozhevnikov, 2009), which gives an assessment for individual differences in object imagery, spatial imagery and verbal cognitive style. The OSIVQ is based on a theoretical model by Kozhevnikov et al. (2005), in which people are categorized as either visualizers or verbalizers. Visualizers prefer to process and represent information visually whereas verbalizers prefer to process and represent information verbally. Furhtermore, as a second step, the visualizers can be divided into those who rely more on either object imagery or spatial imagery. Many tests of individual differences in visual imagery, like the VVIQ (Marks, 1973b), have only focused on vividness and have not considered the two different dimensions of object imagery and spatial imagery. Object imagery refers to information processing of objects and scenes in regard to their color, shape and texture (e.g., Paivio, 1991), and primarily activates the neural architecture of the ventral stream (e.g, Gazzaniga, 2004). Spatial imagery refers to information processing of objects location, spatial relationships, movement and spatial transformations (e.g., Paivio, 1991), and primarily activates the neural architecture of the dorsal stream (e.g, Gazzaniga, 2004). The self-assessment scores of object imagery and spatial imagery provided by the OSIVQ are highly correlated with several different measures of object and spatial ability (Blazhenkova & Kozhevnikov, 2009). Based on the results from the studies by Marks (1973a), Tikhomirov (1971) and Charness et al. (2001), we expected to find a negative correlation between either the object imagery score or the spatial imagery score (from the OSIVQ) and spatial dispersion of the eye movements during picture recall. No correlation was expected for the score of verbal thinking.

In the third part, the participants were tested for working memory capacity in an automated version of the operation span test (OSPAN) (Unsworth, Heitz, Schrock & Engle, 2005). Based on the results by Kane et al. (2001) we expected a negative correlation between the WM capacity score and spatial dispersion of the eye movements during picture recall.

Participants

Forty-seven students at the University of Lund – twenty-six females and twenty-one males – participated in the experiment. All subjects reported either normal vision or vision corrected to normal (i.e., with contact lenses or glasses). All participants were native Swedish speakers. The mean age of the participants was 22.4 years (SD = 3.6).

Apparatus and stimuli

The participants were seated in front of a computer screen at a distance of 600-700 mm. (The distance varied slightly because of the subjects' freedom to move their head and body.) Eye movements were measured using an SMI iView RED250, tracking binocularly at 120 Hz. The data was recorded with the iView X 2.4 software and participants were calibrated using a 5-point calibration routine with validation. The average calibration error was .41° (SD = .25°). Fixations were identified using a dispersion threshold of 100 pixels and a duration threshold of 80 ms. Eye-tracking data was analyzed with BeGaze 2.4 and in-house MatLab scripts.

The visual stimulus in the experiment was presented using Experiment Center 2.4 on a 480 mm × 300 mm computer screen with a resolution of 1680 × 1050 pixels.

The OSPAN-test (Unsworth et al., 2005) was presented in E-prime 2.0 and the OSIVQ-test (Blazhenkova & Kozhevnikov, 2009) was a Swedish translation of the computerized OSIVQ v 2.0 from MM Virtual Design.

Procedure

Participants were initially informed that the experiment consisted of three different parts.

In the first part of the experiment they were initially told that this part concerned pupil dilation in relation to mental workload. This instruction was used to conceal the true objective of the experiment. It was explained that we would be filming their eyes, but nothing was said about us recording their eye movements. They were throughout the experiment asked to keep their eyes open so that we could film their pupils, and to look directly ahead so that our equipment could accurately measure their pupil dilation. The eye tracker was calibrated using a five point calibration routine. Then the participants were instructed that they would soon see a picture, that it would be shown for thirty seconds and that they were to inspect it as thoroughly as possible. When they had understood the task instructions, the picture appeared on the computer screen for thirty seconds. They were then instructed to orally describe the picture from memory as they liked, with their own words and to try their best. They were told explicitly to keep their eyes open and to look directly ahead so that the equipment could record their pupil dilation. When they had understood the task instructions, the screen went blank and they orally described the picture. The experiment leader always disappeared behind a large screen, which was located behind the stimulus computer, and was never present when the participants looked at the picture or described it from memory. Figure 1 shows schematics of how the picture was encoded and recalled.

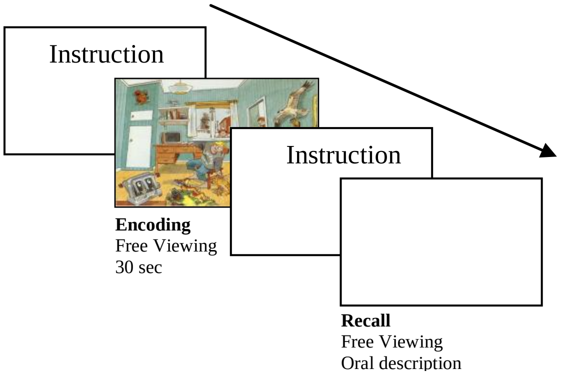

Figure 1: Schematics of encoding and recall

When the participants had finished their descriptions they rated how well they were able to visualize the picture during recall on a scale ranging from 1 (*no visualization at all*) to 5 (*almost as if the picture was still in front of me*). Then they did the self-paced OSIVQ and OSPAN-test on the same computer, but without us recording their eyes. The OSIVQ consists of 45 statements (15 object imagery, 15 spatial imagery and 15 verbal), which are to be rated on a 5-point scale according to agreement. For further details, see Blazhenkova and Kozhevnikov (2009). In the OSPAN-test they were required to judge as quickly as possible if mathematics operations were false or correct while trying to remember a set of letters. For further details, see Unsworth et al. (2005). Finally, to assess whether any of the participants had seen through the nature of the experiment, we asked what they thought the true objective of the experiment was.

Analysis

To analyze the overall spatial dispersion of the gaze pattern, a coverage measure proposed by Holmqvist, Nyström, Andersson, Dewhurst, Jarodzka & van de Weijer (in press, subsection 11.2.8) was calculated for the gaze pattern during recall. Using this measure an "attention map" was created by centering a Gaussian function at each fixation point (σ was set to span 10 % of the screen width; $\sigma = 0.1 \times 1680$

pixels). Next, all the Gaussian functions were superimposed and the volume under the attention map, after being normalized to unit height, was used to estimate the spatial dispersion of the gaze pattern. Finally, the computed volume was normalized against its theoretical peak value (1680 × 1050 × 1), which gives a proportion value between 0 and 1. A Pearson's correlation analysis was then performed for the overall spatial dispersion of the gaze patterns, the scores from the OSPAN-test, the scores from the OSIVQ and the participants' subjective visualization ratings.

Results and discussion

Average values for spatial dispersion of the gaze pattern, the OSIVQ object, spatial and verbal scores, the OSPAN scores and the subjective visualization ratings are shown in table 1, and the correlations among the measures are presented in table 2.

Table 1: Average values for all measures (with standard deviations within brackets).

Measure	Mean (SD)
1. Gaze pattern: spatial dispersion	.14 (.058)
2. OSPAN	62.22 (7.84)
3. OSIVQ object	3.11 (.66)
4. OSIVQ spatial	2.67 (.75)
5. OSIVQ verbal	3.25 (.54)
6. Visualization rating	3.43 (.77)

Table 2: The Pearson product-moment correlations among the measures from table 1.

	1	2	3	4	5	6
1	———	-.13	.08	**-.32***	-.27	.06
2		———	-.10	.00	-.24	-.03
3			———	**-.35***	.16	**.43****
4				———	.09	-.05
5					———	-.06
6						———

$^{**}p < .01$ (2-tailed)
$^{*}p < .05$ (2-tailed)

A negative correlation (r = -0.32, p < 0.05) was found between the OSIVQ spatial-imagery score and the overall spatial dispersion of the eye-tracking data during recall. No correlations were found between the other aspects and the overall spatial dispersion of the eye-tracking data during recall. However, a positive correlation (r = 0.43, p < 0.01) was found between the participants subjective visualization rating and object imagery. This correlation indicates that when participants are to rate their own visualization this judgment is primarily associated with vividness and object imagery aspects (e.g., color, shape and texture). Furthermore, a negative correlation (r = -0.35, p < 0.05) was found between the OSIVQ object-imagery score and the OSIVQ spatial-imagery score, suggesting that a higher spatial imagery score results in a lower object imagery score, and vice versa. Kozhevnikov, Blazhenkova and Becker (2010) have found similar results and have concluded that there is a trade-off, rather than independence, between object and spatial imagery abilities.

Figure 2 illustrates gaze patterns during encoding and recall for one typical participant with a relatively low score in spatial imagery (1.9), and figure 3 illustrates gaze patterns for another typical participant with a relatively high score in spatial imagery (3.8).

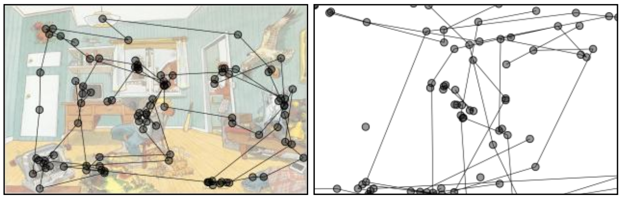
Encoding
Inspecting a picture (30 s)
Recall
Orally describing the picture (52 s)

Figure 2: Gaze patterns after encoding and recall for one participant with a low spatial imagery score of **1.9**.

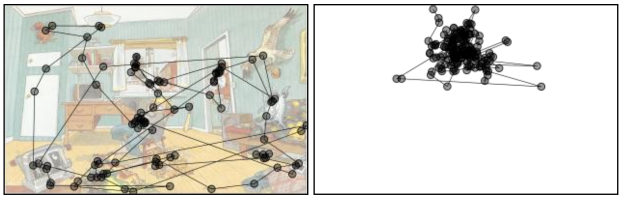
Encoding
Inspecting a picture (30 s)
Recall
Orally describing the picture (126 s)

Figure 3: Gaze patterns after encoding and recall for one participant with a high spatial imagery score of **3.8**.

The results partly confirmed our expectation and indicate that the overall spatial dispersion of eye movements during recall is related to individual differences in spatial imagery ability. We propose that those with weaker spatial imagery ability "need" to do more eye movements during recall to compensate for weaker spatial imagery ability and to reduce cognitive load. Possibly these eye movements support a re-construction of the picture and enhance memory retrieval. However, contrary to our expectation, no correlation was found between eye movements and WM capacity (OSPAN).

General discussion

The current study confirmed previous research that eye movements are spontaneously executed to blank spaces when engaged in recall of a scene (e.g., Brandt & Stark, 1997; Johansson et al., 2006). Furthermore, although not analyzed in this study, those eye movements did – as in Johansson et al. (2006) – closely correspond with content and spatial relations from the original picture. The documented finding (e.g., Johansson et al. 2006) that the spatial dispersion of the eye movements are different in size during the recall phase than during the encoding phase, and that this size varies among individuals, was also apparent in the data.

A correlation analysis with scores from the Object Spatial Imagery and Verbal Questionnaire (OSIVQ) revealed a negative correlation between spatial dispersion in eye movements and the spatial imagery score. Consequently, it appears that weaker spatial imagery ability constitutes a greater effect on eye movements to blank spaces. We propose that eye movements during visual imagery tasks are employed to reduce cognitive resources associated with the processing of spatial information and that weaker spatial imagery ability thus increases the need for those eye movements.

For example, Blazhenkova and Kozhevnikov (2009) have argued that when engaged in complex imagery tasks, where pictorial details have to be maintained and combined with spatial manipulations, there is an overload in visuospatial working memory. Possibly, those with stronger spatial imagery ability were able to divide their visualizations into larger chunks of relevant information than those with weaker spatial imagery ability, which would be consistent with Weber and Malmstrom's (1979) suggestion that eye movements are only manifested between these chunks, not within them. This is also in line with a situated view of cognition where motor processes and/or the external world are used to minimize visuospatial working memory demands. For instance, Ballard, Hayhoe, Pook and Rao (1997) have argued that eye movements are used as spatial indexes to coordinate elements of an internal model with the external world, and Keehner, Hegarty, Cohen, Khooshabeh and Montello (2008) have shown a strong relationship between success in spatial reasoning tasks and the ability to offload cognition in the external world. However, to what degree visuospatial information in spatial indexing relies on internal representations versus the external world is debatable (cf., Richardson, Altmann, Spivey & Hoover, 2009).

Our interpretation gains further support from findings that eye movements to nothing are highly task and stimuli dependent. We have, for example, in pilot studies observed that eye movements during visual imagery are less likely to appear for scenes of low complexity and for recall tasks that are relatively easy (e.g., questions about color, shape and location for single objects in a scene). Similar observations have been made by Brandt and Stark (1997), who in the discussion described pilot studies where they used simple geometrical figures (circles, squares and rectangles) as stimuli and where they failed to find corresponding eye movements during recall.

Several studies have interpreted eye movements to blank spaces during recall as a reinstatement of the encoding phase (e.g., Laeng & Teodorescu, 2002), and it has been proposed that those eye movements enhance memory retrieval (Ferreira, Apel & Henderson, 2008). However, Johansson, Holsanova and Holmqvist (2010) have shown that participants who maintained central fixation during encoding of a complex picture still employed eye movements that corresponded to directions and positions during recall, and concluded that eye movements during visual imagery are not a pure reinstatement of those from encoding. On the other hand, Laeng and Teodorescu (2002) found the opposite results, i.e., maintaining central fixation during encoding spontaneously induced participants to look in the center also during recall. However, the study by Laeng and Teodorescu (2002) used much simpler stimuli during encoding (grid patterns or single objects) than the complex scenes in Johansson et al. (2010). These contrasting results give further support to an interpretation that task complexity, stimuli complexity, expertise and ability represent crucial aspects of the "need" to employ eye movements to blank spaces.

There is, however, no proof for a strong relationship between eye movements to nothing and memory retrieval (cf., Richardson et al., 2009). But studies of memory retrieval and eye movements to nothing (e.g., Spivey & Geng, 2001; Laeng & Teodorescu, 2002) have used rather simple stimuli and the memory task has mostly been related to object imagery processing (e.g., color and shape). Results from the present study indicate that eye movements during visual imagery are primarily related to spatial imagery processing and not to aspects of object imagery.

Finally, the current study only reported a correlative relationship between eye movements and spatial imagery. Further studies, where eye movements are manipulated as an independent variable, have to be conducted before any causal claims can be made between eye movements, spatial imagery and/or memory retrieval.

Summary

This study showed that the spatial dispersion of eye movements during recall of pictures is related to individual differences in spatial imagery. We suggest that weaker spatial imagery ability increases the "need" to employ eye movements to blank spaces which correspond to positions in the original scene.

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