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Look here, eye movements play a functional role in memory retrieval

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Abstract

Research on episodic memory has established that spontaneous eye movements occur to spaces associated with the retrieved information even if those spaces are blank at the time of retrieval. While it has been claimed that such looks to “nothing” can function as facilitatory retrieval cues, there is currently no conclusive evidence for such an effect. The present study addressed this fundamental issue via direct eye manipulations in the retrieval phase of an episodic memory task: (1) free viewing on a blank screen, (2) maintaining central fixation, (3) looking inside a square congruent with the location of the to-be-recalled objects, and (4) looking inside a square incongruent with the location of the to-be-recalled objects. Results provide novel evidence of an active and facilitatory role of gaze position during memory retrieval and demonstrate further that memory for the spatial relationship between objects is more readily affected than memory for intrinsic object features.

Keywords

eye movements, memory retrieval, episodic memory, encoding-recall, visual attention

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Look Here, Eye Movements Play a Functional Role in Memory Retrieval

Spontaneous eye movements occur during visuospatial imagery and recent research suggests that they mirror the content and spatial relations of currently retrieved episodic memories (Johansson, Holsanova, Dewhurst, & Holmqvist, 2012). However, the role of such eye movements remains elusive. Do they have an active and functional role facilitating the retrieval of visuospatial information, or are they merely an epiphenomenon contingent upon the operation of mnemonic mechanisms? The present study addressed this fundamental issue via a direct manipulation of eye movement constraints during an episodic memory task, and provides new evidence of a facilitatory role of eye movements.

Episodic memory enables us to travel back in time and re-experience previous events in great detail (Tulving, 1983). Cognitive neuroscience models of memory suggest that such re-experiencing during retrieval is based on the reinstatement of cortical processes that were active at the time of the previous experience (e.g., Marr, 1971; Norman & O'Reilly, 2003). Accumulating evidence supports this notion by demonstrating common neural systems activated during perception and retrieval (e.g. Nyberg, Habib, McIntosh, & Tulving, 2000; Wheeler, Petersen, & Buckner, 2000; see Danker & Anderson, 2010; Kent & Lamberts, 2008; Rugg, Johnson, Park, & Uncapher, 2008, for reviews).

Episodic remembering is considered to depend on the interaction between retrieval cues and stored memory traces (Tulving, 1983). Two principles have been forwarded to explain the effectiveness of the retrieval cues: "encoding specificity" (Tulving & Thompson, 1973) and "transfer-appropriate processing" (Morris, Bransford, & Franks, 1977). Both of these principles maintain that the greater the overlap between the processing engaged during

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encoding and retrieval, the greater the likelihood of successful retrieval. The importance of the compatibility between encoding and retrieval conditions has been underscored by a vast body of memory research (see e.g. Roediger & Guynn, 1996, for review).

Thus, remembering involves the reinstatement of the processes that were active during encoding, and the chance of remembering is best when the processes engaged by a retrieval cue overlap with those engaged at encoding. To what extent do these principles generalize to the interplay between gaze behavior and memory retrieval? Recent research suggests that recognition of scenes and faces may improve when participants look at the same features of the stimuli during study and test (Foulsham & Kingstone, 2013; Holm & Mäntylä, 2007; Mäntylä & Holm, 2006). Remarkably, it has also been shown that the oculomotor system reactivates spontaneously during memory retrieval when there is only a blank screen to look at (e.g., Brandt & Stark, 1997; Johansson, Holsanova, & Holmqvist, 2006; Laeng & Teodorescu, 2002; Richardson & Spivey, 2000; Spivey & Geng, 2001). Although it has been claimed that these so called eye movements to "nothing" can act as facilitatory cues during memory retrieval (cf. Ferreira, Apel, & Henderson, 2008; Richardson, Altman, Spivey, & Hoover, 2009), there is to date no conclusive evidence for such a functional role.

Two previous studies have manipulated eye movements on a blank screen during episodic memory retrieval by restricting gaze behavior to a central fixation cross at the center of the screen, and reported an impaired memory performance as compared with free viewing (Laeng & Teodorescu, 2002; Johansson et al., 2012). However, it is possible to attribute the lowered performance in those cases to a higher cognitive load due to the additional task of maintaining gaze on the fixation cross (cf. Johansson et al., 2012; Mast & Kosslyn, 2002). Moreover, a

recent study failed to observe any consequence of eye position during memory retrieval (Martarelli & Mast, 2012) and previous studies without eye movement manipulations have failed to find an influence of gaze position on retrieval accuracy (Richardson & Spivey, 2000; Spivey & Geng, 2001), thus the overall picture remains unclear.

The present study departs from previous research in several ways. First, our paradigm imposed eye movement restriction during visuospatial memory retrieval (free viewing vs. central fixation) of an arrangement of multiple objects. Previous studies have typically focused on memory for visual properties of single objects (Laeng & Teodorescu, 2002; Martarelli & Mast, 2012; Spivey & Geng, 2001) or on verbal memory for spoken information (Richardson & Spivey, 2000). Second, we considered the role of participants looking at a specific location that did or did not correspond to the sought-after memories (congruent vs. incongruent). It has been argued that eye movements function as “spatial indexes” and that those indexes are a part of the internal memory representation for an object or an event. When some part of this episodic trace is accessed during subsequent memory retrieval an eye movement is considered to be spontaneously triggered towards the indexed location (Altmann, 2004; Richardson & Spivey, 2000). We thus tested the idea that positioning the eyes on a congruent location increases the likelihood of successful retrieval. Third, we investigated the extent to which interactions between eye movements and visuospatial memory retrieval depend on the nature of the queried memory representation. Much evidence suggests that the ventral (“what”) and dorsal (“how/where”) streams of visual processing (Milner & Goodale, 1995; Ungerleider & Mishkin, 1982) establish the bases for object and location memory respectively (e.g., Farah et al., 1988; Pollatsek, Rayner, & Henderson, 1990). It is conceivable that the influence of eye movements on visuospatial remembering

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may be different for intrinsic object features as compared with the spatial relationship between two or more objects. This issue has not been examined in previous work and we therefore included a comparison of memory for intrinsic object features with memory for the spatial arrangement between objects (intra vs. inter item memories). Fourth, in contrast to previous work, our analyses of memory performance included response times (RT), which provide a complementary and potentially more sensitive measure of the availability of the sought-after memory trace as compared with binary measures of accuracy (cf. Sternberg, 1969).

Given that gaze behavior has a functional role in memory retrieval, we expected memory performance to be superior a) in the free viewing as compared with the central fixation condition, and b) when eye fixation location was spatially congruent as compared with incongruent with the sought-after memory.

Method

Participants

Twenty-four native Swedish-speaking students at Lund University (15 female) participated in the experiment (mean age 24.5 years; SD = 7.1). All reported normal or corrected-to-normal vision.

Apparatus and stimuli

Stimuli were presented via Experiment Center 3.1 at a 480×300 mm monitor (running at 1680×1050 pixel resolution), while eye movements were measured using an SMI iView

RED500, tracking binocularly at 500 Hz. Data were recorded using iView X 2.5 following 5-point calibration plus validation (average measured accuracy was 0.49° ; $SD = 0.10^\circ$).

Fixations were detected with a saccadic velocity-based algorithm (with a minimum velocity threshold of $40^\circ/s$). 96 pictures of objects (280×262 pixels) were selected from an online database (www.clipart.com). Auditory stimuli consisted of 576 statements (2500–4500 ms in length). The statements served as test probes (questions with a yes/no answer) and were spoken by a female voice.

Design and procedure

The experiment was divided into four runs with each run comprising an encoding phase and a recall phase (see Fig. 1)

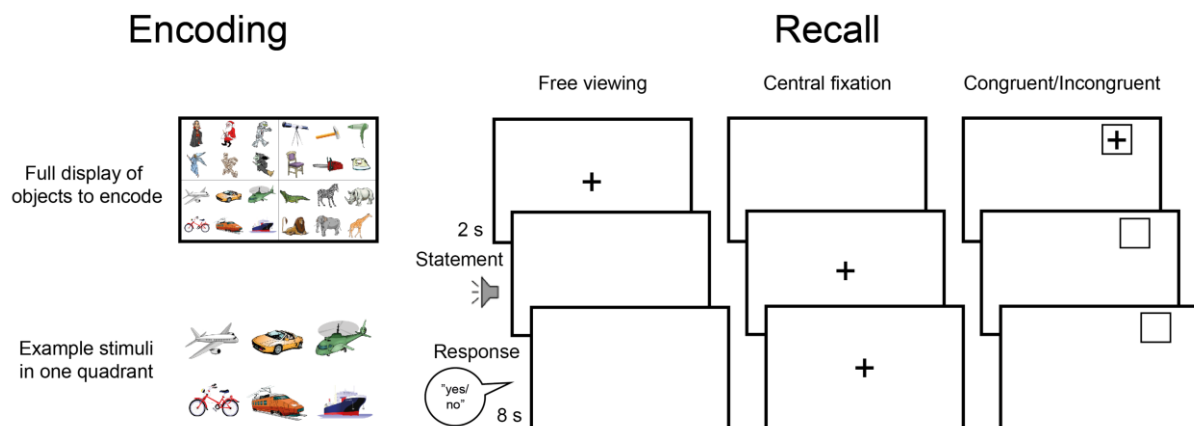


Fig 1. Design exemplifying the encoding stimuli and the eye movement conditions in the recall phase. The entire experiment consisted of four runs of encoding and recall with different objects to-be-encoded in each run.

Encoding phase. Participants studied 24 objects distributed in four quadrants of the computer screen. Each quadrant contained six objects from one of four themes: *humanoids*, *animals*, *things*, and *vehicles*. Half the objects within each quadrant were facing the right and the other

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half facing the left. The encoding procedure was performed in the following sequence. First, a list naming the 6 thematic objects of a quadrant was presented. The objects were then visually presented in the quadrant of the screen (30 s). Participants orally named each object and its orientation. They were then free to inspect the objects and try to remember as much as possible about their orientation and spatial arrangement. Following the same procedure for the remaining quadrants and themes, all 24 objects were inspected simultaneously with the task to rehearse the objects' orientation and spatial arrangement (60 s).

Recall phase. Participants listened to 48 statements of two types: *intra-object* concerning the orientation of an object (e.g., the car was facing the left) and *inter-object* concerning the spatial arrangement between two objects of the same theme (e.g., to the right of the car, the train was located), and responded orally by saying 'yes' or 'no' to the statement. They were encouraged to answer as correct and as fast as possible without guessing. The recall phase comprised four eye movement conditions: (1) *free viewing* on a blank screen, (2) *central fixation*, (3) looking inside a square *congruent* with the location of the to-be-recalled objects, and (4) looking inside a square *incongruent* with the location of the to-be-recalled objects. Each condition comprised 12 statements (6 intra, 6 inter). The free viewing and central fixation conditions were presented in blocked fashion whereas the congruent and incongruent trials were intermingled across two blocks. Participants were not informed that the quadrant would be either congruent or incongruent with the location of the target object. Over the entire experiment each participant responded to 192 statements (96 intra-object and 96 inter-object) with an equal number of true and false statements. Participants were given 8 seconds to respond following statement offset. The order of intra-object and inter-object statements

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and true and false statements was randomized. The order of the four eye movement conditions was counterbalanced in a latin square design within subject over the four runs.

The size of the square in the congruent and incongruent condition was the same as the stimulus pictures. The location of the square in the incongruent condition was always dislocated 840 pixels in the horizontal dimension and 262 pixels in the vertical dimension (the maximum distance that could be implemented in a consistent way for all 24 locations).

Data analyses

Repeated measures ANOVAs were conducted using the factors of eye movement condition and memory type (intra- vs. inter-object statements) and response accuracy and RTs as dependent variables. Accuracy was quantified as the discrimination measure Pr (hits minus false alarms; Snodgrass & Corwin, 1988). RTs were quantified as the time between the offset of a spoken statement and the onset of the response. RTs were collapsed over all hits into a median RT for each condition and participant. Trials where participants executed saccades larger than 3° away from the fixation cross or outside the square (3° away from the center of the square) were excluded.

Results

Spontaneous eye movements to “nothing”

Eye movement data from the free viewing condition were analyzed to assess where participants spontaneously looked during memory retrieval (see Fig. 2). Results revealed a main effect of quadrant, $F(3,69) = 27.186$, $p < .001$, $\eta^2 = .54$, 95% CI [.37, .65]. Follow-up tests using Bonferroni correction showed that the proportion of fixation was significantly

higher in the quadrant relevant to the memory task than in all the other three quadrants ($p < .001$). There was no effect involving the factor memory type. These results replicate previous findings (Richardson & Spivey, 2000; Spivey & Geng, 2001) and demonstrate that eye movements are reliably executed towards empty locations where information was previously encoded. Moreover, a paired samples t -test revealed that the overall gaze distance was significantly longer during inter-object than during intra-object trials, $t(23) = 2.348$, $p < .05$, $d = .48$, 95% CI [.05, .90] (see Supplemental Material available online for further details).

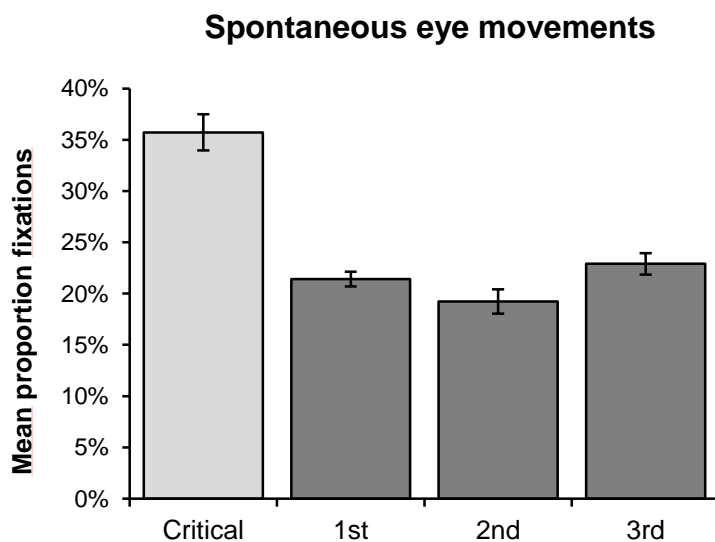


Fig 2. Mean proportion fixations in the four quadrants of the screen during memory retrieval in the free viewing condition. The quadrant that corresponded with the original location of the retrieved objects was coded as the ‘critical’ quadrant and the other three quadrants as 1-3 in a clockwise direction. Error bars represent standard errors.

Constraining eye movements to a central fixation

The hypothesis that memory performance is impaired when one is not allowed to execute spontaneous eye movements to “nothing” was tested by contrasting the free viewing and central fixation conditions (Fig. 3a). Analysis of response accuracy revealed a significant

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main effect of memory type, $F(1,23) = 15.484, p < .01, \eta^2 = .40, 95\% \text{ CI } [.11, .62]$, which was due to better performance to inter-object than intra-object statements, but no reliable effect of eye movement condition. A significant interaction between eye movement condition and memory type was observed for RTs, $F(1,23) = 10.296, p < .01, \eta^2 = .31, 95\% \text{ CI } [.04, .55]$. Interestingly, follow-up analyses revealed a detrimental effect of the eye movement constraint that was observed in prolonged RTs for inter-object statements, $t(23) = 4.08, p < .001, d = .83, 95\% \text{ CI } [.36, 1.29]$. No reliable difference was found for intra-object statements.

Constraining eye movements to a congruent versus incongruent location

The final and crucial set of analyses concerned the impact of constraining eye movements to a location that differed in the extent to which it corresponded with the encoding location of the to-be-remembered information (Fig. 3b). Analysis of accuracy revealed better memory performance to inter-object as compared with intra-object statements, $F(1,23) = 17.523, p < .001, \eta^2 = .43, 95\% \text{ CI } [.13, .64]$. More importantly, however, participants demonstrated a reliable benefit of looking at a congruent location, both in terms of accuracy, $F(1,23) = 13.443, p < .01, \eta^2 = .37, 95\% \text{ CI } [.08, .60]$, and RTs, $F(1,23) = 14.809, p < .001, \eta^2 = .39, 95\% \text{ CI } [.10, .62]$ This pattern of results lends new support to the notion of gaze position playing a functional role in memory retrieval. Furthermore, given that the task was identical in the congruent and the incongruent conditions (constraining eye movements to a smaller space), these results cannot be explained as a mere artifact due to increased cognitive load induced by a secondary task.

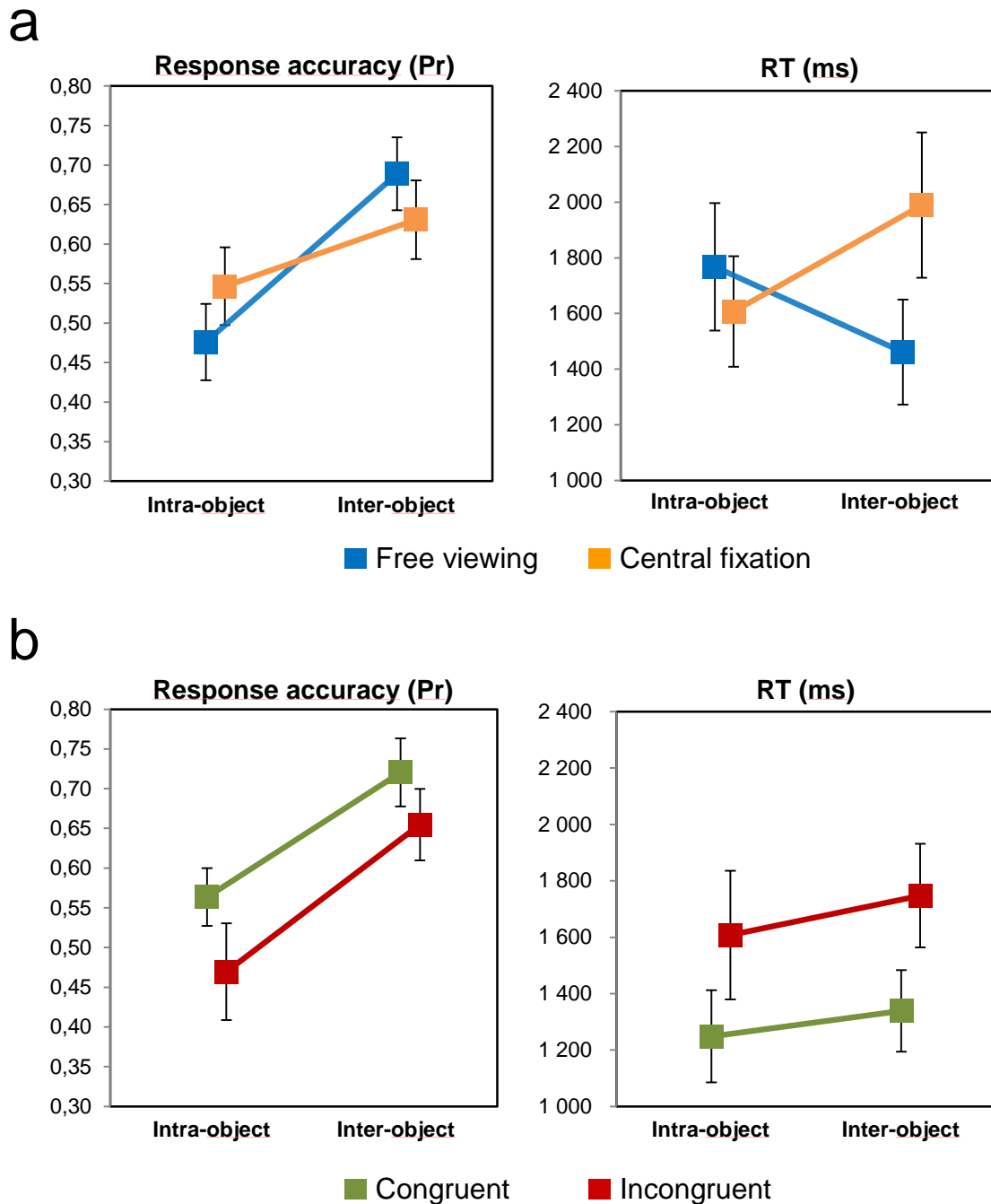


Fig 3. Mean memory performance as measured by the discrimination measure Pr (Hits – False alarms) and mean response time (RT) for correct responses (displayed separately for intra-object and inter-object statements). The top panel (a) shows results for the eye movement conditions of free viewing on a blank screen and maintaining central fixation. The bottom panel (b) shows results for the eye movement conditions of looking inside a square

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congruent with the location of the to-be-recalled objects, and looking inside a square incongruent with the location of the to-be-recalled objects. Error bars represent standard errors.

Discussion

The present study employed multiple eye movement conditions to examine the role of gaze behavior in episodic memory retrieval. Taken together, our results provide new evidence of a facilitatory influence of gaze position during remembering.

First, it was demonstrated that hindering eye movements can influence visuospatial remembering. A central fixation constraint perturbed retrieval performance (as indicated by longer RT) for inter-object representations. This finding adds weight to previous results (Laeng & Teodorescu, 2002; Johansson et al., 2012), and further suggests that the impact of eye movements on visuospatial memory may differ depending on the nature of the memory representation one is searching for. The results indicate that memory for the spatial relationship between objects is more readily affected than memory for intrinsic object features.

Second, our results confirm that memory retrieval is indeed facilitated when eye movements are manipulated towards a blank area that corresponds with the original location of the to-be-recalled object. Results were robust both in respect to memory accuracy and RTs and evident irrespective of memory type. Looking at a congruent location thus facilitated retrieval of both intra-object and inter-object memory representations. Importantly, this facilitatory effect cannot be attributed to a difference in cognitive resources taxed by the compared conditions

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(in previous research: free viewing vs. central fixation), since both the congruent and incongruent conditions were characterized by identical eye movement constraints (to look inside a square).

Experience in everyday life constantly reminds us that our memories often are a subject of distortion. We may misremember properties of past events and completely fail to retrieve a desired fact or previous episode. Distorted memories and inaccurate retrieval of this kind often depend on insufficient retrieval cues. The present study demonstrates that how and where you launch your eye movements provide important retrieval cues for visuospatial remembering. Thus, remembering is not only accompanied by eye movements that mirror the retrieved content, we here demonstrate that gaze positions showing a compatibility between encoding and retrieval conditions increases the likelihood of successful episodic remembering (cf. Tulving, 1983). This is a novel finding that extends previous literature and informs current theoretical models of episodic memory.

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Authorship

Data collection and analysis were performed by R.J. R.J. and M.J. designed the research and wrote the paper. Both authors approved the final version of the paper for submission.

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