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To cite this article: Claudia Damiano & Dirk B. Walther (2015) Content, not context, facilitates memory for real-world scenes, *Visual Cognition*, 23:7, 852-855, DOI: [10.1080/13506285.2015.1093241](https://doi.org/10.1080/13506285.2015.1093241)

To link to this article: <http://dx.doi.org/10.1080/13506285.2015.1093241>



Published online: 20 Oct 2015.



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## Content, not context, facilitates memory for real-world scenes

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### ABSTRACT

Can eye movements tell us whether people will remember a scene? In order to investigate the link between eye movements and memory encoding and retrieval, we asked participants to study photographs of real-world scenes while their eye movements were being tracked. We found eye gaze patterns during study to be predictive of subsequent memory for scenes. Moreover, gaze patterns during study were more similar to gaze patterns during test for remembered than for forgotten scenes. Thus, eye movements are indeed indicative of scene memory. In an explicit test for context effects of eye movements on memory, we found recognition rate to be unaffected by the disruption of spatial and/or temporal context of repeated eye movements. Therefore, we conclude that eye movements cue memory by selecting and accessing the most relevant scene content, regardless of its spatial location within the scene or the order in which it was selected.

**ARTICLE HISTORY** Received 18 July 2014; Accepted 25 August 2015

**KEYWORDS** Eye movements; Scene recognition; Memory

Selective attention and eye movements serve to facilitate processing in visual perception, as well as in memory encoding and retrieval (Noton & Stark, 1971). The interaction of eye movements and memory in complex real-world scenes has been investigated previously (Henderson & Hollingworth, 2003; Irwin & Zelinsky, 2002), but it is unclear whether specific patterns of eye movements are beneficial for successful memory encoding and retrieval. There is evidence that memory has an effect on eye movements (Ryan, Hannula, & Cohen, 2007). However, eye movements may also have an effect on memory, as repeated patterns of eye movements reinstate spatial and temporal context, both of which have been shown to be beneficial for memory retrieval (Chun & Jiang, 1998; Howard & Kahana, 2002).

Here we use a predictive decoding approach in the analysis of gaze patterns to predict whether scenes are correctly remembered on a trial-by-trial basis (Experiment 1). Furthermore, we determine to what extent the relationship between memory and gaze patterns is due to spatial and/or temporal context provided by eye movements compared to the repeated exposure to previously seen scene content at the fixated

locations (Experiment 2). Specifically, we address the following three research questions:

- (1) Do eye movements during the study phase determine whether an image is subsequently remembered?
- (2) Is successful recognition of a scene facilitated by similar patterns of eye movements during the study and recognition phases?
- (3) If so, is the spatial and/or temporal context provided by repeating eye movements beneficial to recognition? Or are eye movements mainly used to select specific scene content?

## Methods

We performed two eye tracking experiments. In Experiment 1, 77 participants were asked to study and memorize a series of photographs of real-world scenes (3 s viewing time). In separate recognition test blocks, a subset of the studied images along with novel lures were shown, and participants were asked to indicate whether they had previously seen the image. Using predictive decoding analysis with leave-one-subject-out cross validation, we tested whether patterns of eye movements during study could predict subsequent success in remembering the scene. We also compared similarity of eye movement patterns for the same images during the study and test phases, independently for hits and misses.

Experiment 2, with 20 new participants, followed a similar design, but images during the test phase were covered by an opaque grey mask, which only revealed the image through a small circular aperture. The aperture moved over the image, mimicking the eye movements of the participant during the free-viewing study phase. In four separate conditions, we either reproduced the eye movements faithfully (Context-Intact), scrambled the temporal order of the content of the fixations while leaving the spatial arrangement intact (Spatial-Only), scrambled the spatial locations of the content of the fixations while leaving the temporal order intact (Temporal-Only), or scrambled both temporal order and spatial locations (No-Context). In all four conditions, participants saw the same image content, but in potentially different temporal order and/or at potentially different spatial locations.

## Results and Discussion

In Experiment 1, we were able to predict whether an image would subsequently be remembered, solely based on the eye movement patterns during study, with an accuracy of 60% (significantly above chance level of 50%,  $p < 10^{-13}$ ). This was replicated in Experiment 2 (accuracy = 55%,

$p < .001$ ). Subsequent memory prediction was also possible across experiments, i.e., by training on Experiment 1 and testing on Experiment 2 (accuracy = 62%,  $p < 10^{-11}$ ). This indicates that specific gaze patterns during the first presentation of an image are an important step to successful recognition, as they promote proper encoding of the scene. Moreover, gaze patterns between study and test viewings were more similar when the image was successfully remembered ( $r = 0.39$ ) than when it was forgotten ( $r = 0.32$ ,  $p < .001$ ).

These results confirm that gaze patterns and memory are interlinked. However, they leave open the directionality of the interaction. One possibility is that the sequence of eye movements made during study might be retrieved from memory upon successful recognition of the scene itself. Alternatively, eye movements might provide spatial and/or temporal context, thereby enabling successful retrieval of the scene from memory. We explicitly tested context effects in Experiment 2. Surprisingly, we found no effect of the context manipulation on recognition of scenes. There was no difference in hit rates among the four conditions (Intact:  $H = 0.82$ ; Spatial-Only:  $H = 0.80$ ; Temporal-Only:  $H = 0.81$ ; No-Context:  $H = 0.81$ ; ANOVA:  $F(3,76) = 0.09$ ,  $p > .05$ ). Thus, we failed to find modulation of recognition performance by destroying either spatial or temporal context. This lack of contextual modulation suggests that scene recognition is triggered by the critical image content selected during study, rather than the context provided by eye movements.

## Conclusions

- (1) The pattern of eye movements while studying a scene image is predictive of subsequent memory of the scene. We could correctly predict subsequent memory in 60% of trials.
- (2) Gaze patterns during the test phase (second presentation) resemble gaze patterns during the study phase (first presentation) more when the image was successfully recognized (hit) than when it was forgotten (miss).
- (3) Disruption of spatial or temporal context (or both) as provided by eye movements did not affect recognition performance, as long as the same scene content was presented. We conclude that gaze patterns do not facilitate scene recognition by way of context effects, but that they serve as selection processes to access the most relevant information in the scene.

## Disclosure statement

No potential conflict of interest was reported by the authors.

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## Similarity judgments of same-category object representations: Effects of physical size, manipulability, and word frequency

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### ABSTRACT

Studies of object similarity have focused on the relationship between different physical objects and their mental representations or between instances of the same physical object and its mental representation. The present study is the first to investigate the structure of within-category psychological space. We provided evidence that large objects and frequently mentioned objects are perceived as less similar to each other compared to small objects or less frequently mentioned objects. Further, similarity judgments were higher for manipulable objects compared to non-manipulable objects. The relevance of these data to the isomorphism between physical and psychological spaces is also discussed.

**ARTICLE HISTORY** Received 18 July 2015; Accepted 17 August 2015

**KEYWORDS** Similarity; category representation; manipulability; isomorphy of psychological and physical space