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SHORT REPORT

Where have eye been? Observers can recognise their own fixations

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Abstract. We are often not explicitly aware of the location of our spatial attention, despite its influence on our perception and cognition. During a picture memory task, we asked whether people could later recognise their eye fixations in a two-alternative test. In three separate experiments, participants performed above chance when discriminating their own fixation patterns from random locations or locations fixated in a different image. Recognition was much poorer when the task was to spot your own versus someone else's fixations on the same stimulus, but performance remained better than chance. That we are sensitive to our own scan patterns has implications for perception, memory, and meta-cognition.

Keywords: eye movements, saccades, visual memory

1 Introduction

Eye movements are commonly measured in a wide range of experiments investigating visual cognition. Eye fixations, and spatial attention more generally, can be allocated both volitionally and automatically/exogenously, but it is often the case that we are not explicitly aware of these shifts (eg Theeuwes et al 1998). However, evidence from several experiments suggests that the sequence of eye movements we make during viewing can have implications for both short-term and long-term memory of visual stimuli. For example, we have shown that people are better at recognising a picture when they look in the same places that they did during encoding (Foulsham and Kingstone 2013). This raises the question whether people can actually recognise their own fixations, a question that has never been addressed but which is relevant both for the ways in which fixated items are represented in memory and for meta-cognitive processes in attention.

In three experiments participants viewed a series of natural scenes in preparation for a memory test. The position of each fixation was recorded using an eye-tracker. An old/new memory test for the scenes was then presented, full details of which are described in Foulsham and Kingstone (2013, experiments 2–4). Following the scene memory test, participants were asked to choose which of two fixation patterns was the one they themselves had made while viewing the corresponding image (see figure 1). In experiment 1 participants were presented with a forced-choice between their own fixation pattern ('self') and a set of randomly chosen locations ('random'). In experiment 2 participants had to identify their own pattern from a set of locations that they had fixated while viewing a different image ('other image'). Finally, in experiment 3 the distractors were locations fixated by a different observer looking at the same image ('other person'). In each case the question was whether participants could correctly identify which fixation pattern was their own and how they were able to do so.

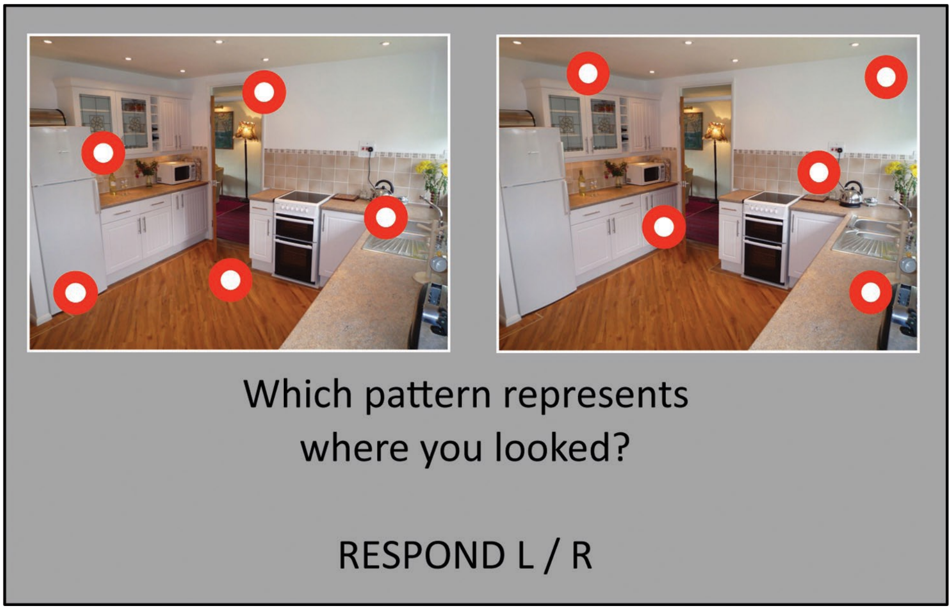

Figure 1. [In colour online, see http://dx.doi.org/10.1068/p7562] A display from the fixation discrimination test.

2 Results

2.1 *Discrimination performance*

Performance was significantly above chance in all three experiments, but there was a significant effect of the type of foil used (between-subjects ANOVA: $F_{2,47} = 11.0$, $p < 0.001$; figure 2). Performance was highest when participants discriminated their fixations from random locations (different from chance as indicated by a one-sample *t*-test, $t_{15} = 6.9$, $p < 0.001$). Participants were marginally less accurate when 'self' was contrasted to 'other image' (a posteriori LSD test, $p = 0.09$), but remained well above chance ($t_{16} = 7.4$, $p < 0.001$). The poorest discrimination performance was shown between 'self' and 'other person' (reliably different from experiments 1 and 2, both $p < 0.005$). However, even under these conditions, correct responses were made statistically more frequently than predicted by chance ($t_{14} = 2.2$, $p = 0.04$). Thus, participants could correctly recognise their own eye movements, although performance was modulated by the foils that were used.

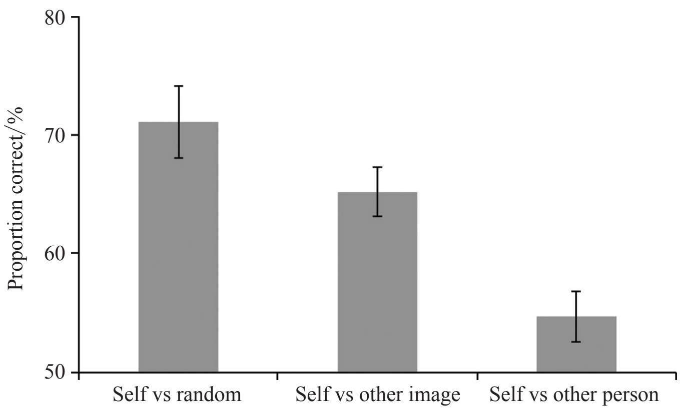

Figure 2. Discrimination accuracy in each condition (mean, with standard error bars).

2.2 *Between-scanpath similarity*

These results could potentially be attributed to variations in the similarity between the to-be-discriminated fixations. Because human fixations are not uniformly distributed, we would expect them to be less similar in position, on average, to the 'random' condition. In contrast, self and other person locations are likely to be confined to a much more restricted area of the display. It may be, therefore, that performance dropped in experiment 3 because the places where two different people look while viewing the same image are more similar than self and random or self and other images.

We therefore evaluated the spatial similarity between all the self and nonself pairs, in order to see whether this similarity influenced fixation recognition. Measuring scanpath similarity remains a challenge for eye-movement researchers, and one that is met by several recent algorithms (Cristino et al 2010; Dewhurst et al 2012; Foulsham et al 2012). In the present experiment, where only the spatial pattern of fixations was displayed for participants (and not their temporal order), a linear distance metric was sufficient (see Henderson et al 2007; Mannan et al 1995). Average between-fixation distances were normalised by the screen diagonal, resulting in a distance score from 0 (spatially identical) to 1 (maximally different).

Consistent with our expectations, the average distance between scan patterns was highest in experiment 1 (self versus random; mean distance = 0.21, SEM = 0.003), significantly reduced in experiment 2 (self versus other image; $M = 0.16$, SEM = 0.006), and lowest in experiment 3 (self versus other person; $M = 0.14$, SEM = 0.004). This trend was statistically reliable ($F_{2,47} = 46.7$, $p < 0.001$). However, within the self and other person pairs there was no relationship between recognition and similarity both when averaged across participants and on a trial-by-trial basis (*t*-tests between correct and incorrect responses; both *t*s < 1). It is likely that correct discrimination under these conditions arose when participants recognised the items that they themselves had fixated, rather than through general spatial cues.

3 Discussion

We set out to determine whether participants could recognise their own scan patterns. This might seem unlikely given that people are often not aware of where they are looking, and that some researchers take between-participant variation in fixation location to be essentially random (eg Boccignone and Ferraro 2004). Moreover, the experiments provide a conservative test of fixation recognition, because memory was probed after a block of viewing many similar images (a delay of around 10 minutes), which also ensured that the surprise fixation memory test could not affect their viewing behaviour, and because no feedback was given. The results showed that participants could indeed recognise their own scan patterns with accuracy better than chance. While performance was reduced when one had to determine which self-generated eye movement belonged to a particular image (self versus other image), and reduced further still when two sets of human-generated eye movements from the same image were discriminated (self versus other person), sensitivity remained persistently greater than chance.

The difference in discrimination performance between conditions reveals a number of cues that participants could use to accomplish their task. First, they could make a judgment from the general distribution of fixations in the image (eg by using the intuition that they would have been unlikely to fixate the edges or corners of the display). Unlike randomly generated locations, fixations tend to cluster at the centre of images (Tatler 2007). Thus, in experiment 1 the random foil locations would have shown a different distribution from the participant's own fixations. Experiment 2 removed this cue by presenting foils which were drawn from actual fixation locations from another image. Discrimination from this other image condition was less accurate, consistent with the fact that participants could no longer use image-general eye-movement biases.

A second potential strategy available to participants would be to consider how meaningful the fixated items are. Locations from a random (uniform) distribution or from another image are less likely to be on meaningful objects than actual fixations (Mackworth and Morandi 1967). By this account, participants might infer that the fixation pattern which covers more meaningful regions (such as objects) is likely to be their own. This strategy may have been successful in experiments 1 and 2. However, in experiment 3, the foils were locations fixated by another observer. Self and other person locations are both equally likely to be on plausible regions (even if those objects are different from the ones you yourself looked at). Indeed, across all participants the two sets of locations would have been exactly the same in terms of spatial, visual, and semantic features present at that point. Our interpretation of the drop in performance in experiment 3 is therefore that participants could no longer use the spatial and semantic cues available in the previous experiments, and hence experiment 3 provides the most stringent test of recognition for one's own scanpath.

Recognition in experiment 3 remained above chance. This demonstrates that, at least some of the time, participants can discriminate their own fixations from those made by somebody else. How did they accomplish this? Participants in this condition reported that they found the test difficult, to the extent that many thought that they were guessing. Given the poor performance, it is quite possible that discrimination was driven by only one or two of the five presented fixations. This could be determined in future experiments by varying the number of re-presented fixations, or their order. A task where participants must explicitly regenerate their own fixations (eg by clicking the mouse) would also test the level of memory for these locations. We only presented a *spatial* representation, and it remains to be seen whether participants can remember the order or rate with which different items were fixated. It is also not possible, from the current experiments, to determine whether participants remember *where* they looked ("I remember positioning my eyes at that point") or *what* they looked *at* ("I remember a refrigerator, and so I must have looked at it …"). In either case, this requires detailed meta-awareness of attention and memory.

The demonstration that participants can recognise some of their fixations has important implications. For example, in the human factors approaches known as eye-movement-cued retrospection, or PEEP (the postexperience eye-tracking protocol), participants are asked to verbalise their cognitive or decision processes from a previously completed task while watching a replay of their gaze (Hyrskykari et al 2008; Russo 1979). The validity of this approach rests partly on the assumption that participants are sensitive to their own, individual eye movements and can retrieve information based on their scanning pattern. The present results provide some support for this assumption.

Eye fixation patterns are idiosyncratic (eg Foulsham et al 2012). The scanpath made by an individual has significance in some theories of visual memory (Noton and Stark 1971; Rybak et al 1998), but the current results do not necessitate that fixation locations or motor commands are stored explicitly. Instead, the effect of the particular scene and the source of the other pattern (random versus other person) suggest that participants use their memory for (or familiarity with) particular scene details to infer that they must have looked in that location. These results provide further evidence that, although both vision and visual memory appears seamless, fixations have a continued impact on our recognition and awareness.

4 Experimental methods

4.1 *Participants*

Three separate groups of student volunteers took part in exchange for course credit. There were sixteen, seventeen, and fifteen participants in experiments 1–3, respectively.

4.2 *Stimuli and apparatus*

Participants viewed a series of 48 colour photographs depicting indoor and outdoor environments. Images were displayed on a 19″ computer monitor at a viewing distance of 60 cm (resulting in approximately 30 deg × 25 deg). Eye-tracking was accomplished with an EyeLink 1000 system which used an online parser to record the location of each fixation, which was written to a data file and subsequently reloaded during the fixation recognition test. During the test, two versions of each image were re-presented with circular fixation markers (see figure 1). The same images were used in all three experiments.

4.3 *Procedure*

In the first phase all images were presented in a random order, for 2.5 s each, with the instruction to try to remember the images. Viewing commenced following the fixation of a central drift correction marker.

During the fixation memory test, the two-alternative forced-choice task preceded in a self-paced fashion, and again stimulus order was randomised. Self fixations were equally likely to appear on the left or right of the display, and no feedback was given. Participants responded using a gamepad to indicate whether the left or right fixation pattern was their own.

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