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Scrutinizing visual images: The role of gaze in mental imagery and memory

Bruno Laeng [a,*], Ilona M. Bloem [b], Stefania D'Ascenzo [c], Luca Tommasi [d]

[a] Department of Psychology, University of Oslo, Oslo, Norway
[b] Faculty of Psychology and Neuroscience, Maastricht University, The Netherlands
[c] Department of Communication and Economics, University of Modena and Reggio Emilia, Italy
[d] Department of Psychological Sciences, Humanities and Territory, G. d'Annunzio University, Chieti, Italy

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ABSTRACT

Gaze was monitored by use of an infrared remote eye-tracker during perception and imagery of geometric forms and figures of animals. Based on the idea that gaze prioritizes locations where features with high information content are visible, we hypothesized that eye fixations should focus on regions that contain one or more local features that are relevant for object recognition. Most importantly, we predicted that when observers looked at an empty screen and at the same time generated a detailed visual image of what they had previously seen, their gaze would probabilistically dwell within regions corresponding to the original positions of salient features or parts. Correlation analyses showed positive relations between gaze's dwell time within locations visited during perception and those in which gaze dwelled during the imagery generation task. Moreover, the more faithful an observer's gaze enactment, the more accurate was the observer's memory, in a separate test, of the dimension or size in which the forms had been perceived. In another experiment, observers saw a series of pictures of animals and were requested to memorize them. They were then asked later, in a recall phase, to answer a question about a property of one of the encoded forms; it was found that, when retrieving from long-term memory a previously seen picture, gaze returned to the location of the part probed by the question. In another experimental condition, the observers were asked to maintain fixation away from the original location of the shape while thinking about the answer, so as to interfere with the gaze enactment process; such a manipulation resulted in measurable costs in the quality of memory. We conclude that the generation of mental images relies upon a process of enactment of gaze that can be beneficial to visual memory.

1. Introduction

In his book *Inquiries into Human Faculty and its Development* (1883), Sir Francis Galton discussed mental imagery as a special ability of human visual memory. Specifically, he wondered whether mental images could be "so clear and sharp as [...] to be scrutinized with nearly as much ease and prolonged attention as if they were real objects." Galton prompted his informants to "think of some definite object—suppose it is your breakfast-table as you sat down to it this morning—and consider carefully the picture that rises before your mind's eye [...] Is the image dim or fairly clear? [...] Are all the objects pretty well defined at the same time, or is the place of sharpest definition at any one moment more contracted than it is in a real scene?" Reports about the "definition" of the imagined breakfast items varied very much across individuals; however, a

* Corresponding author. Address: Department of Psychology, University of Oslo, 1094 Blindern, 0317 Oslo, Norway. Tel.: +47 22 84 51 16.
E-mail address: bruno.laeng@psykologi.uio.no (B. Laeng).

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common report was that one or two objects would appear much more distinct than the others but these could come out clearly if attention be paid to them. Thus, different objects were not clear all at once but only successively, by focusing attention on them at different time points.

About a century later, although accounts of imagery did not rely any longer exclusively on introspective reports, the modern cognitive psychologists also concluded that whenever we generate a visual image of an object, the different parts of the object are not clear all at once but only successively (e.g., Hebb, 1968; Neisser, 1976). Kosslyn (1980), Kosslyn (1994) has also put forward an influential computational model for visual imagery, according to which each part of an image is added in successive steps (Kosslyn, Cave, Provost, & Von Gierke, 1988; Kosslyn, Reiser, Farah, & Fliegel, 1983). Visual images take time both to generate and to inspect and, in many respects, they strongly resemble the normal perception of objects at close range, where a high-resolution perceptual representation of the object cannot be achieved in a single glance but a series of eye movements must bring into 'foveal' focus the different parts of the object.

One remarkable finding of several studies of imagery is that while imagining something there appears to be a lot of motor activity, which resembles the exploratory movements typically made during perceptual scrutiny of an object or scene. Jacobson (1932; see also Totten, 1935) had originally observed with a galvanometer that engaging in imagery (e.g., recollection) resulted in the measurement of action potentials in muscle groups that were specific to the body part which was imaginatively moved (e.g., during visual imagination, movements of the eye-balls was registered, while when thinking, one could register brief contractions in muscles of tongue). Moreover, several researchers have noticed a remarkable similarity in the duration of imagined actions compared to the time it takes to perform them (e.g., Decety, 1996; Decety, Jeannerod, & Prablanc, 1989; Jeannerod, 1994; Parsons, 1987). These findings clearly implicate the presence of motor processing during imagery, although the motor processes would often seem to constitute only a subset of those activated during overt movement (Ellis, 1995).

According to recent studies, gaze patterns (i.e., fixations and/or direction of saccades) that are measured in real time during recollection of a previous event look remarkably similar to the scanpaths during a perceptual recognition test of the same scene, despite the fact that when thinking about the episode there is nothing at all to look at on a blank computer screen. This phenomenon has been repeatedly observed in a variety of studies (e.g., Moore, 1903: Altmann, 2004; Brandt & Stark, 1997; Brandt, Stark, Hacisalihzade, Allen, & Tharp, 1989; de'Sperati, 2003; Gbadamosi & Zangemeister, 2001; Hollingworth, 2005; Humphrey & Underwood, 2008; Jeannerod & Mouret, 1962; Johansson, Holsanova, & Holmqvist, 2006; Laeng & Teodorescu, 2002; Laeng et al., 2007; Martarelli & Mast, 2013; Renkewitz & Jahn, 2012; Spivey & Geng, 2001). It would seem that, when retrieving a visual image or episode, not only there occur spontaneous eye movements but these tend to reflect the content of the original scene. Deckert (1964) had observed that participants instructed to imagine a beating pendulum developed pursuit ocular movements of a frequency comparable to the frequency of a previously seen real pendulum. Intriguingly, studies of rapid eye movements or REM during sleep also would seem to show some relationship between the types of eye movements and the content of dreams (e.g., Aserinsky & Kleitman, 1953; Dement & Kleitman, 1957; Doricchi, Iaria, Silvetti, Figliozzi, & Siegler, 2007; Hong et al., 1997; Hong et al., 2009; Roffwarg, Dement, Muzio, & Fisher, 1962) as well as time-locked activity within primary visual cortex (Miyauchi, Misaki, Kan, Fukunaga, & Koike, 2009).

At a first glance, the above phenomena are puzzling because it seems a meaningless expenditure of bodily energy and cognitive effort to move about the eyes when there is nothing to be seen. Purposeful saccades that cannot garner any visual input appear completely paradoxical in relation to normal visual processing, since the pattern of saccadic movements during perception seems to be purposefully guided towards visual information or 'objects' that are relevant for the cognitive system at that particular time (e.g., Einhäuser, Spain, & Perona, 2008; Findlay & Gilchrist, 2003; Hayhoe & Ballard, 2005; Noton & Stark, 1971a; Noton & Stark, 1971b; Rothkopf, Ballard, & Hayhoe, 2007; Rucci, Iovin, Poletti, & Santini, 2007; Schütz, Trommershäuser, & Gegenfurtner, 2012; Stark & Ellis, 1981; Trommershäuser, Maloney, & Landy, 2009; Yarbus, 1967). Importantly, eye movements indicate the occurrence of shifts in spatial attention (Craighero, Nascimben, & Fadiga, 2004; Deubel & Schneider, 1996; Henderson, 1992; Moore & Fallah, 2001; Rolfs, Jonikaitis, Deubel, & Cavanagh, 2011; Shepherd, Findlay, & Hockey, 1986) and covert visual attention may consist in the motor preparation of an eye movement (Rizzolatti, Matelli, & Pavesi, 1983; Rizzolatti, Riggio, Dascola, & Umiltá, 1987). Hence, oculomotor activity could overload the cognitive system and/or interfere with other processes (cf. Loftus, 1972). Since the early days of research on mental imagery, both Francis Galton and Alfred Binet (Hadamard, 1945, pp. 72–73) had suggested that there may be an antagonism between the vividness or detail of a visual image and the presence of other activities.

A solution to the above puzzle is to assume that, contrary to the idea that such "empty" looks during recollection and imagination are either deleterious or irrelevant to cognition, they may actually serve some useful function. There is growing evidence for shared mechanisms of perception and imagery (e.g., Kan, Barsalou, Solomon, Minor, & Thompson-Schill, 2003; Kosslyn & Thompson, 2000). In addition, the idea that perception is "active" or "embodied" has been gaining strength over the years within the cognitive sciences and neurosciences (Barsalou, 1999; Ellis, 1995; Findlay & Gilchrist, 2003; Gibbs, 2006; Gibson, 1979; Pezzulo et al., 2001; Pulvermüller & Fadiga, 2010). This perspective stresses the idea that the visual system does not merely register its environment but explores it and poses questions by "grasping" objects with the eyes and/or hands (Ballard, Hayhoe, Pook, & Rao, 1997; Castelhano, Mack, & Henderson, 2009; Karn & Hayhoe, 2000; Land et al., 1999). If perception and imagery share processing mechanisms, then also imagery may be "active" in the sense that adjustments of the body organs, even in a vacuum, could play a significant role in the retrieval of