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Eye movements reveal memory processes during similarity- and rule-based decision making

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ABSTRACT

Recent research suggests that when people retrieve information from memory they tend to fixate on the location where the information had appeared during encoding. We used this phenomenon to investigate if different information is activated in memory when people use a rule- versus a similarity-based decision strategy. In two studies, participants first memorized multiple pieces of information about various job candidates (exemplars). In subsequent test trials they judged the suitability of new candidates that varied in their similarity to the previously learned exemplars. Results show that when using similarity, but not when using a rule, participants fixated longer on the previous location of exemplars that resembled the new candidates than on the location of dissimilar exemplars. This suggests that people using similarity retrieve previously learned exemplars, whereas people using a rule do not. The study illustrates that eye movements can provide new insights into the memory processes underlying decision making.

1. Introduction

A fundamental distinction in cognitive psychology refers to the contrast between similarity- and rule-based cognitive processes. Although this distinction is intuitively appealing and has stimulated much empirical research, it has proved difficult to pin down on the process level (e.g., Barsalou, 1990; Hahn & Chater, 1998; Milton, Wills, & Hodgson, 2009; Pothos, 2005). One reason could be that a core difference between rule-based and similarity-based processes lies in how information is processed in memory (Hahn & Chater, 1998). This makes the differences between similarity- and rule-based processes difficult to study, because memory processes are hard to observe. For instance, when studying decision processes it is easy to observe what people chose, but not whether people made a choice by focusing on the information provided or by retrieving similar decisions from memory. Recent research has suggested that eye movements can be used to trace information search in memory (Jahn & Braatz, 2014; Renkewitz & Jahn, 2010, 2012; Richardson & Kirkham, 2004; Richardson & Spivey, 2000). We show in the present work that recording eye movements can be used to make differences in memory retrieval between people using similarity- and rule-based strategies visible, providing a possible method for disentangling the two strategies on the process level.

1.1. Using eye movements to make information search in memory visible

Studying cognitive processes that rely on memory, such as categorization, reasoning, problem solving, and decision making, can be challenging because the processes of

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interest are not directly observable. Researchers have tackled this problem by developing indirect methods, using self-reports, computational modeling, and reaction times to gain a window into the mind (Anderson, 1987; Bröder, 2000; Johnson & Krems, 2001; Lewandowsky & Farrell, 2011; Mehlhorn, Taatgen, Lebiere, & Krems, 2011; Payne, Bettman, & Johnson, 1993). Although these methods provide valuable data, they also have important drawbacks. For instance, self-reports about memory processes are often inaccurate and incomplete, and asking about them can affect the process itself (Ericsson & Simon, 1980; Renkewitz & Jahn, 2010; Russo, Johnson, & Stephens, 1989).

Alternatively, eye movements can be used to trace information search (Glaholt & Reingold, 2011; Orquin & Mueller Loose, 2013; Peterson & Beck, 2011). Eye movements are quick, frequent, and highly automatic actions (Irwin, 2004; Rayner, 2009; Spivey & Dale, 2011; van Gompel, Fischer, Murray, & Hill, 2007) that have been shown to reflect attention and information search in a variety of tasks, such as concept learning (Nelson & Cottrell, 2007; Rehder & Hoffman, 2005), text comprehension (Allopenna, Magnuson, & Tanenhaus, 1998; Altmann, 2004; Altmann & Kamide, 2007; Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995), and decision making (Glaholt & Reingold, 2011; Orquin & Mueller Loose, 2013). Lately, evidence has been accumulating that eye movements can also be used to trace memory processes. When people retrieve information from memory they look at spatial locations where the information was originally presented—even if the information is no longer visible (Hoover & Richardson, 2008; Johansson, Holsanova, Dewhurst, & Holmqvist, 2012; Johansson, Holsanova, & Holmqvist, 2006; Laeng, Bloem, D'Ascenzo, & Tommasi, 2014; Laeng & Teodorescu, 2002; Martarelli & Mast, 2013; Richardson & Kirkham, 2004; Richardson & Spivey, 2000; Spivey & Geng, 2001). In the classic paradigm, Richardson and Spivey (2000) presented participants with a spinning cross in one of four equal-sized areas on a computer screen together with spoken factual information. In a later test phase, participants heard a statement regarding the presented facts and had to judge the truth of the statement. Even though during this retrieval phase the computer screen was blank, participants fixated more often on the spatial area where the sought-after information had been presented than on the other three areas on the screen.

Most likely, people show this "looking at nothing" effect because during encoding, information from multiple sources of input, including the locations of perceived objects, is integrated into an episodic memory representation. Once the episodic memory representation is reactivated during retrieval it spreads activation to the motor system, which in turn leads to the execution of eye movements back to the locations linked with the memory representation (Huettig, Mishra, & Olivers, 2012; Huettig, Olivers, & Hartsuiker, 2011; Richardson & Kirkham, 2004). The exact role eye movements play in the retrieval process is still debated (e.g., Ferreira, Apel, & Henderson, 2008; Richardson, Altmann, Spivey, & Hoover, 2009), but early evidence suggests that eye movements can also facilitate memory retrieval (Johansson & Johansson, 2014; Laeng et al., 2014; Scholz, Mehlhorn, & Krems, in press).

Recent research suggests that the looking-at-nothing effect can also be used to trace retrieval processes in higher order cognitive processes such as decision making and diagnostic reasoning. For instance, Renkewitz and Jahn (2010, 2012) found that when participants had to retrieve information about two alternatives to make a decision, they looked at the location where the information about the alternatives had previously appeared. Furthermore, gaze patterns during retrieval were consistent with the information search predicted by the decision strategies participants used. Similarly, Jahn and Braatz (2014) showed that during a diagnostic reasoning task, people tended to look at locations associated with symptoms they had to retrieve from memory to test hypotheses about what caused the symptom. More importantly, the eye movements reflected the diagnostic value of the symptoms and how participants updated their hypotheses about the causes over time. These findings suggest that eye movements are not automatically launched to all associated spatial locations but reflect target-oriented information search in memory during the reasoning process.

In sum, spatial information about the location of information is stored along with the memory of it. Retrieving the respective memory triggers eye movements to the associated locations. These eye movements reflect the currently active memory representation and provide researchers with a new method for monitoring information search in memory. We used this method to differentiate memory processes involved in similarity- and rule-based judgments and decisions.

1.2. Memory retrieval in similarity- and rule-based processes

The distinction between rule- and similarity-based processes is fundamental to understanding human cognition and has stimulated research in a broad range of fields, from categorization and decision making (e.g., Ashby, Alfonso-Reese, Turken, & Waldron, 1998; Erickson et al., 1998; Persson & Rieskamp, 2009; Pothos & Hahn, 2000) to reasoning (Smith, Langston, & Nisbett, 1992) and language acquisition (Pinker & Prince, 1988). In general, it is assumed that rule-based processes involve the application of previously abstracted knowledge to specific instances (Hahn & Chater, 1998). That is, people form a rule defining the relationship between a specific piece of information and the decision outcome and apply it when confronted with a new decision problem (Bröder, Newell, & Platzer, 2010; Juslin, Karlsson, & Olsson, 2008; Mata, von Helversen, Karlsson, & Küpper, 2012; Persson & Rieskamp, 2009; von Helversen, Mata, & Olsson, 2010; von Helversen & Rieskamp, 2008, 2009). For instance, when deciding to take one's bike or car in the morning, one could have learned the rule that it is better to take the car when it is raining. In contrast, similarity processes are generally characterized by the retrieval of similar instances or exemplars from memory (Bröder et al., 2010; Hahn & Chater, 1998; Hahn, Prat-Sala, Pothos, & Brumby, 2010; Juslin & Persson, 2002). That is, when deciding to take the car or the bike in the morning, one might think back to similar occasions and compare how well one fared when taking the bike.