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

Agnes Scholz [a,b,*], Bettina von Helversen [b], Jörg Rieskamp [b]

[a] Technische Universität Chemnitz, Department of Psychology, Wilhelm-Raabe Str. 43, 09120 Chemnitz, Germany
[b] University of Basel, Department of Psychology, Missionsstraße 62a, 4055 Basel, Switzerland

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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

* Corresponding author at: Technische Universtiät Chemnitz, Department of Psychology, Wilhelm-Raabe Str. 43, 09120 Chemnitz, Germany. Tel.: +49 371 53138231.

*E-mail addresses:* agnes.scholz@psychologie.tu-chemnitz.de (A. Scholz), bettina.vonhelversen@unibas.ch (B. von Helversen), joerg.rieskamp@unibas.ch (J. Rieskamp).

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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.

A core theoretical distinction that has been proposed is that the two processes differ in the way mental representations of stored information are accessed (Bailey, 2005; Hahn & Chater, 1998). Similarity-based processes involve comparing the object under consideration to exemplars stored in memory. In contrast, rule-based processes involve processing the information an object under consideration provides according to the processing steps specified by the rule. Accordingly, in a decision task the object's attributes are matched against the conditions for choosing the respective options as specified in the rule. This suggests that similarity-based but not rule-based processes require the retrieval of previously encountered instances from memory. Consistently, similarity-based judgments rely more on episodic memory than rule-based judgments (Hoffmann, von Helversen, & Rieskamp, 2014). However, direct evidence that similarity- and rule-based processes rely on different retrieval processes is scarce (Ashby & O'Brien, 2005). One problem is that differentiating the two processes is far from trivial on a conceptual and empirical level (Barsalou, 1990; Hahn & Chater, 1998; Markman et al., 2005; Pothos, 2005). Research trying to tease apart rule- and similarity-based processes has frequently relied on computational modeling approaches (e.g., Bröder et al., 2010; Juslin et al., 2008; Juslin, Olsson, & Olsson, 2003; Karlsson, Juslin, & Olsson, 2007; Nosofsky & Bergert, 2007; Pachur & Olsson, 2012; Persson & Rieskamp, 2009; Platzer & Bröder, 2013; von Helversen, Karlsson, Mata, & Wilke, 2013; von Helversen et al., 2010). Although computational modeling approaches can provide relevant insights into the cognitive processes underlying behavior, there are important limitations. First, the decision of which model best describes the data is usually based on some measure of *goodness of fit*. However, depending on the selected measure the results may diverge considerably (Scheibehenne, Rieskamp, & Wagenmakers, 2013). Furthermore, just because a model can predict the outcome of a decision process does not necessarily mean it also reflects the underlying cognitive processes. Indeed, looking at process data may reveal that a model misses important aspects of the cognitive processes leading to the decision (e.g., Johnson, Schulte-Mecklenbeck, & Willemsen, 2008). Accordingly, it seems necessary to complement cognitive modeling approaches with process data to reach a full understanding of the cognitive processes underlying a decision (see also Schulte-Mecklenbeck, Kühberger, & Ranyard, 2011).

We used the looking-at-nothing effect to clarify how memory processes involved in similarity- and rule-based decisions differ. Specifically, if rule and similarity processes differ in the information that is retrieved from memory when making a decision, it should be possible to make these search processes visible by associating exemplars with specific spatial locations and then tracking the eye movements during the retrieval process to capture information search in memory. If people retrieve exemplars from memory when relying on a similarity-based process, the looking-at-nothing effect would predict that people gaze back at associated exemplar locations. In contrast, if people do not retrieve similar exemplars from memory when using a rule, fixation on the locations associated with exemplars should be rare. Furthermore, when using an exemplar-based strategy the eye movements to exemplar locations should be a function of the exemplars' similarity, because the probability with which an exemplar is retrieved from memory depends on the exemplar's similarity to the object under evaluation (Dougherty, Gettys, & Ogden, 1999; Hintzman, 1988; Nosofsky & Palmeri, 1997).

To test these hypotheses, we conducted two experiments using a multi-cue decision paradigm. We chose this type of problem because the assumption that people rely on rule- and similarity-based strategies to make decisions is widespread (Bröder et al., 2010; Hahn et al., 2010; Juslin et al., 2003, 2008; Karlsson et al., 2007; Pachur & Olsson, 2012; Persson & Rieskamp, 2009; Platzer & Bröder, 2013; von Helversen et al., 2010, 2013).

## 2. Study 1

Study 1 examined if relying on a rule versus relying on similarity leads to different information retrieval from memory, which, in turn, is reflected in different eye movements. Participants had to decide if job candidates applying for a position were suitable, that is, whether they should be invited for an interview or rejected. In a training phase participants learned information about two suitable and two unsuitable job candidates. In a subsequent test phase they were instructed to decide if new job candidates should be invited, either by using a rule that was provided to them or by using similarity to the previously learned job candidates (exemplars). To study eye movements, the information about the four exemplars was presented in four different locations on the screen during the training phase. During the test phase we used the eye movements to the exemplar locations to measure memory retrieval.

### 2.1. Method

#### 2.1.1. Participants

We included participants in the experiment only if the tracking validity reached a visual angle smaller than 2°. This was the case for 63 participants. From the 63, we excluded 10 participants from the analyses, 5 because they did not decide according to the instructed strategy and 5 because in the majority of trials less than 60% of eye movement data was recorded (see Renkewitz & Jahn, 2012, for a similar procedure). The final 53 participants were all students from Technische Universität Chemnitz (34 female; $M_{age}$ = 22.4 years, range 18–31 years). All had normal or corrected-to-normal vision with glasses or contact lenses. Participants were randomly assigned to the different strategy conditions, 27 to the rule condition and 26 to the similarity condition. For their participation they received course credit and a performance-dependent bonus ($M$ = 4.80 euros). On average, the experiment lasted 60 min.

#### 2.1.2. Apparatus

Participants were seated in front of a 22-in. computer screen (resolution: 1680 × 1050 pixels) at a distance of 630 mm and instructed to position their head in a chin rest. Stimuli were presented using E-Prime 2.0 running on a separate computer. The eye tracker system SMI iView RED120 sampled data of the right eye at 120 Hz and recorded with iView X 2.5 following a 5-point calibration. Auditory material was presented via headphones. All auditory recordings were spoken by a female voice using a shell script in Mac OSx. Participants responded by pressing one of two keys on a standard keyboard or with mouse clicks on cue values. Data were analyzed with BeGaze 2.3. Fixation detection followed a dispersion threshold of 2° of visual angle and a duration threshold of 100 ms.

*2.1.3. Decision task*

In the decision task, participants decided to invite job candidates for an interview or reject them based on information on three attribute dimensions (i.e., cues). The decision task consisted of three phases: a memorization phase, a strategy-learning phase, and a test phase (see Fig. 1).

*2.1.3.1. Memorization phase.* During the memorization phase participants memorized information about four male "learning" candidates (candidates used in the memorization and strategy-learning phases). For each learning candidate participants learned the candidate's name, his values on the three cues, and whether he had been invited to an interview. The three cues were knowledge of a foreign language (with cue values French, Italian, Portuguese, and Spanish), possession of computer skills (with cue values HTML, Photoshop, SPSS, and SQL), and previous work experience (with cue values automobile industry, financial sector, mobile phone industry, and pharmaceutical industry). Names of the learning (and test) candidates were taken from an online resource for popular first names (http://www.beliebte-vornamen.de). Each learning candidate had a unique combination of cue values (see Table A.1 in the Appendix). Two of the learning candidates were suitable (i.e., had been invited) and two were unsuitable (i.e., had been rejected). Each of the four learning candidates was associated with a different spatial area located in the upper two-thirds of the screen and at an equal distance from the center of the screen (see Fig. 1). The candidate's name always appeared on top followed by the cue values and the suitability information (whether the candidate had been invited or rejected). Cue values and suitability information appeared as single words in four rectangles. Positions of learning candidates and the order of the cue values were randomized across participants with the constraint that the two invited learning candidates were always located at the same side of the screen, that is, both were on either the right or the left half of the screen. For a given participant, the order of the cues was the same for all learning candidates (e.g., for the same participant the cue "language" appeared in the second rectangle for all learning candidates).

To learn the names, cue values, and suitability of the four learning candidates, participants first saw all the information about the four learning candidates in the rectangles on the screen and could study it. Once they had studied the information they could click on "continue" and all the information disappeared. Then the name of one of the learning candidates appeared on the screen and participants had to fill in the correct information for this candidate. They could do so by selecting the correct cue value from a table presented at the bottom of the screen. If they selected the correct information it was highlighted in green and appeared in the corresponding rectangle of the learning candidate where it remained visible for the rest of the trial. If they selected incorrect information, it was highlighted in red. In addition, the correct information was highlighted in green and appeared in the rectangle. Participants always filled in cue information for the learning candidates from top to bottom. After reproducing all the information for a learning candidate, the complete information was visible on the screen and was auditorily presented to the participant over the headphones. Then the name of the next learning candidate appeared and the candidate's cue information had to be filled in. After participants filled in the information for all four learning candidates they received feedback about the percentage of correct decisions that had been made and a new cycle began. The sequence in which they had to reproduce the information for the four learning candidates was randomized within a cycle. This procedure was repeated until the participants correctly reproduced the information for all four learning candidates twice. Participant got a bonus of 1 euro if they finished learning within 40 cycles (e.g., each learning applicant would be presented 40 times).

*2.1.3.2. Strategy-learning phase.* In the strategy-learning phase, half of the participants were instructed to use a rule to decide if a candidate should be invited and the other half were instructed to decide according to similarity. In the rule condition participants were instructed to invite a job candidate if at least two of the three cues had a positive value. Positive values for each cue were (1) knowledge of French or Italian, (2) knowledge of HTML or SQL, and (3) experience in the financial sector or the mobile phone industry. For instance, according to this rule a candidate should be invited if he speaks French, has knowledge of HTML, and has experience in the automobile industry. However, a candidate should be rejected if he speaks French, has knowledge of SPSS, and is experienced in the automobile industry. Participants in the similarity condition were instructed to invite a candidate if he had more cue values in common with the learning candidates who had been invited than with the learning candidates who had not been invited. Participants were informed that they would need to use the strategy to evaluate the candidates in the test phase and that they could practice using the strategy by relating the strategy's predictions to the cue information for the learning candidates. During the strategy-learning phase a shortened version of the strategy instructions was presented in a fifth spatial area at the bottom of the screen located at the same distance from the center as the areas of the learning candidates (see Fig. 1). The visual layout of the rectangles in which the strategy instructions were presented was the same as for the information about the learning candidates. With the exception of these different instructions, the strategy-learning phase followed the same procedure in both conditions: the name of one of the learning candidates was presented via headphones and the participants had to decide if he should be invited according to the instructed strategy by retrieving the information about the learning candidate from memory. To make the decision, participants had to press one of two keys on the keyboard. After pressing the key they got visual

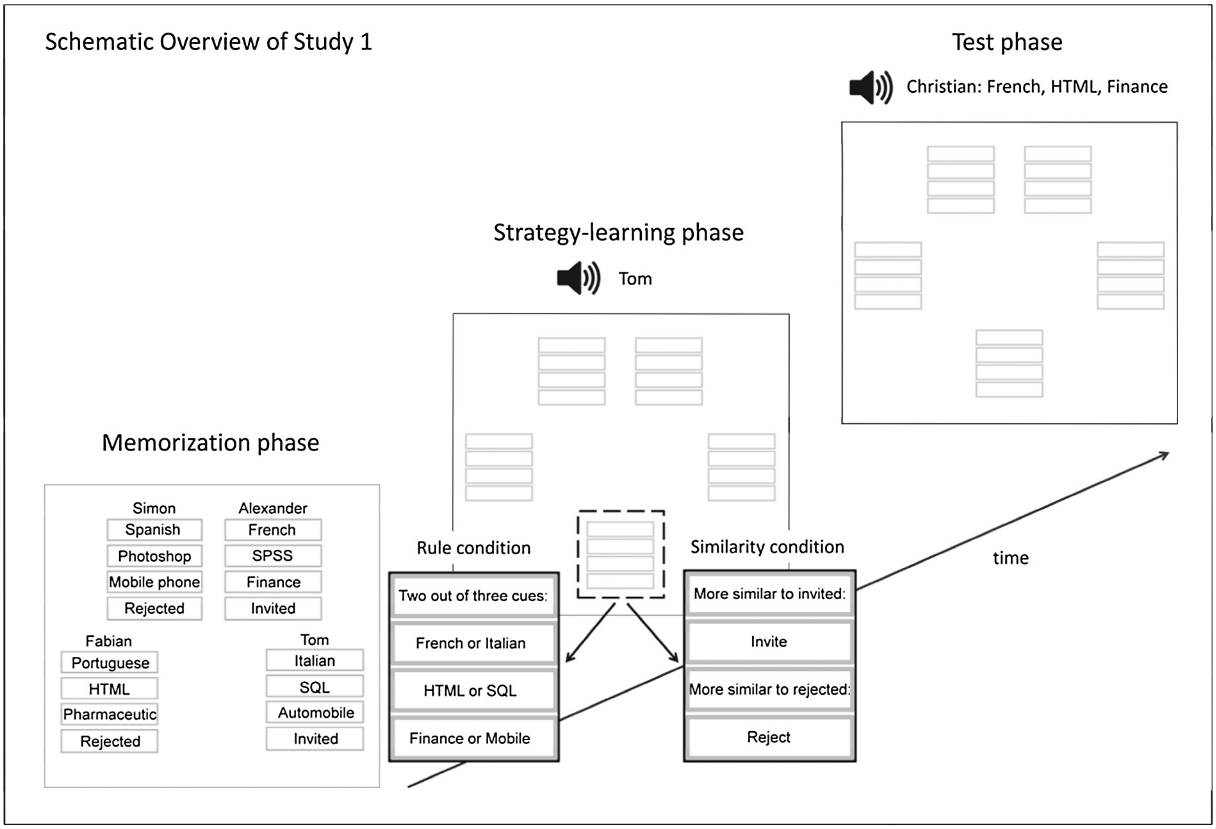


**Fig. 1.** Schematic illustration of the three phases in Study 1. Participants started with the *memorization phase* in which they had to learn the information about the four learning candidates. The candidates appeared in four rectangles in the upper two-thirds of the screen. Note, for the figure we increased the size of the boxes in the illustration of the memorization phase to enhance readability. The actual distribution of the learning candidates' locations on the screen is reflected in the illustrations of the strategy learning and the test phase. In the study all cue information was written in the same font size. During the *strategy-learning phase* participants decided whether to invite the learning candidates for an interview following either a rule-based or a similarity-based strategy. Participants were told which training candidate they were evaluating in each trial via headphones. During the decision, the rectangles within which the information on the four candidates had appeared were visible but empty. In addition, a bottom rectangle appeared that contained information about the strategy participants should use. During the *test phase*, all rectangles remained visible but did not contain any information. The information about the test candidates participants evaluated was provided via headphones. Original materials were in German.

feedback in the center of the screen about whether their decision was correct or wrong. If the decision was correct a green rectangle appeared in the middle of the screen stating: "This decision is correct. The candidate is invited/rejected." In case of a wrong decision a red rectangle appeared stating "This decision is wrong. The candidate is invited/rejected." In addition, the cue information of the judged learning exemplar became visible in the corresponding spatial area and was auditorily repeated to the participants. Then the next trial started. Strategy learning ended when participants had correctly judged the suitability of all four learning candidates within one cycle.

To check if participants had learned the strategies, we asked them at the end of the strategy-learning phase to reproduce the cue values that would allow them to invite a candidate for an interview. For this all possible cue values were presented onscreen in a table, with the cue values of each cue in one row. Participants had to click on the respective cue values. In the rule condition they had to reproduce the cue values that would allow invitation. In the similarity condition they had to reproduce the cue values of the invited learning candidates.

*2.1.3.3. Test phase.* To check if participants had understood how to apply the learned strategy to new candidates, they solved one practice trial at the beginning of the test phase, where they had to judge a new candidate, and received feedback about the correctness of their choice. During subsequent trials no feedback was given.

During the test phase, participants judged the suitability of 20 test candidates. Four of them had cue values identical to those of the learning candidates but had different names. The remaining 16 candidates were new candidates who differed in their similarity to the invited and rejected learning candidates. We constructed the test candidates so that they shared $n = 0$, 1, 2, or 3 cue values with the two invited learning candidates and shared $3 - n$ cue values with the rejected candidates. Thus, a candidate who shared no cue values with the invited learning candidates automatically shared three cue values with the rejected learning candidates, and so on. Details on the task structure can be found in the Appendix, Table A.1.

At the beginning of each trial, participants had to fixate on the center of the screen (2 s). Subsequently, the name and cue values of one candidate were presented auditorily over the headphones (6 s) and participants had to decide whether to invite them for an interview by pressing one of two keys on the keyboard (self-paced). While the information was presented participants saw only the empty rectangles in the spatial areas where cue and strategy information had been presented during the memorization and strategy-learning phases. For each correct judgment, participants were paid a bonus of 20 cents.

### 2.2. Results

#### 2.2.1. Performance

Participants memorized the information about the learning candidates rather quickly. On average they reached the learning criterion in 3.2 cycles ($SD = 1.3$). They also performed well during strategy training: on average, they correctly classified all learning candidates according to the strategy in 1.3 cycles ($SD = 0.6$). Participants in the two strategy conditions (rule, similarity) did not statistically differ in the number of cycles they needed to memorize the information, $M_{\text{rule}} = 3.3$, $SD = 1.5$, $M_{\text{sim}} = 2.9$, $SD = 1$, $t(45.2) = 1.15$, $p = .26$, $d = .34$, and to learn the strategy, $M_{\text{rule}} = 1.2$, $SD = 0.5$, $M_{\text{sim}} = 1.4$, $SD = 0.8$, $t(42.4) = 1.14$, $p = .26$, $d = .36$.

In the test phase, we measured accuracy as the percentage of decisions that were in line with the instructed strategy. Accuracy was high and did not differ between the conditions, $M_{\text{rule}} = 94.3$, $SD = 8.7$ and $M_{\text{sim}} = 96.5$, $SD = 5.8$, $t(51) = 1.12$, $p = .27$, $d = .32$.

Response times were measured from the beginning of the auditory information presentation during a test trial until participants' response. On average participants in the rule condition, $M_{\text{rule}} = 9.6$ s, $SD = 0.6$, took as long as participants in the similarity condition, $M_{\text{sim}} = 9.2$ s, $SD = 1$, $t(51) = 1.54$, $p = .13$, $d = .43$.

#### 2.2.2. Analyses of fixations

To assess differences in gaze behavior between the strategy conditions we excluded all trials in which the dwell criterion (at least 60% of the eye movements were recorded) was not met on the trial level, which led to the exclusion of 70 trials (6.6% of all trials). We then defined rectangular areas of interest (AOIs) around the location of each learning candidate (exemplar locations) and the instruction location. All AOIs were of the same size (8° by 8° of visual angle). These nonoverlapping AOIs exceeded the exemplar locations by 2.7° of visual angle in the horizontal direction and 1.8° of visual angle in the vertical direction. For each trial, we determined the sum of fixation durations at each of the five AOIs. Fixations on other areas were ignored. $F$ values in statistical analyses were Greenhouse–Geisser corrected when necessary. We report the analyses separately for the test candidates who were only similar to the learning candidates and the test candidates who had cue profiles that were identical to the learning candidates' because different memory processes could be involved.

*2.2.2.1. Mean fixation durations for identical test items.* In a first step we analyzed only those test items that had an identical cue profile to that of the learning candidates. Following the looking-at-nothing literature, we assumed that if people retrieve exemplars from memory, they should gaze back at the location associated with the learned exemplar when listening to a test item with an identical cue profile. To test this assumption, we calculated the fixation durations for the five AOIs in the trials in which the four identical test candidates were presented. We then tested how long participants gazed on average at the AOI that contained the identical learning exemplars relative to the other four AOIs. For this we coded the exemplar location that had contained the learning candidate with an identical cue profile to that of the test candidate as "match location." The exemplar location that had contained the second invited or rejected learning candidate was coded as "mismatch 1 location." The remaining exemplar locations were coded as mismatch 2 and mismatch 3 from left to right. The location containing the instruction during strategy learning was coded as "instruction location." A mixed analysis of variance (ANOVA) with the within-subject factor exemplar location (match, mismatch 1, mismatch 2, mismatch 3, instruction) and the between-subjects factor strategy condition (rule or similarity) revealed main effects of exemplar location, $F(2.5, 127.1) = 5.36$, $p = .003$, $\eta^2_p = .10$, and strategy condition, $F(1, 51) = 13.77$, $p = .001$, $\eta^2_p = .21$, and a significant interaction, indicating that the pattern of eye movements differed between the conditions, $F(2.5, 127.1) = 4.02$, $p = .01$, $\eta^2_p = .08$. As illustrated in Fig. 2, participants fixated on the four exemplar locations and the instruction location equally long in the rule condition, $F(2.4, 63.3) = 1.40$, $p = .25$, $\eta^2_p = .05$. In contrast, in the similarity condition the gaze duration depended on the location, $F(2.4, 60.6) = 5.19$, $p = .005$, $\eta^2_p = .17$. Participants fixated longer on the match location than on the other exemplar locations (Bonferroni-corrected post hoc contrasts, all $ps < .03$). Participants also fixated longer on the match location than on the instruction location. However, this post hoc contrast did not reach significance ($p = .22$). Additionally, participants in the similarity condition fixated on the match location longer than participants in the rule condition, $t(32.1) = 4.12$, $p < .001$, $d = 1.45$.

*2.2.2.2. Mean fixation durations as a function of item similarity.* In a second step we analyzed if the duration of fixation on the exemplar locations differed as a function of the similarity to the learning candidates when evaluating new test candidates who did not have identical cue profiles to those of the learning candidates (see Appendix, Table A.1). We first calculated for each participant the mean duration of fixation on the locations of the invited learning candidates, the rejected learning candidates, and the instructions in each trial. Then we calculated for each participant the mean fixation durations for the test candidates who had 0, 1, 2, or 3 cue values in common with the invited learning candidates (and 3, 2, 1, and 0 values in common with the rejected learning candidates, respectively). We then tested if the mean duration of fixation on the locations of the invited and rejected learning candidates varied as a function of similarity (i.e., the number of shared cue values) in the two strategy conditions. For this we ran a mixed ANOVA on the fixation durations with the two within-subject factors similarity (0, 1, 2, 3) and exemplar type (invited versus rejected) and the between-subjects factor strategy condition (rule versus similarity). Overall, participants in

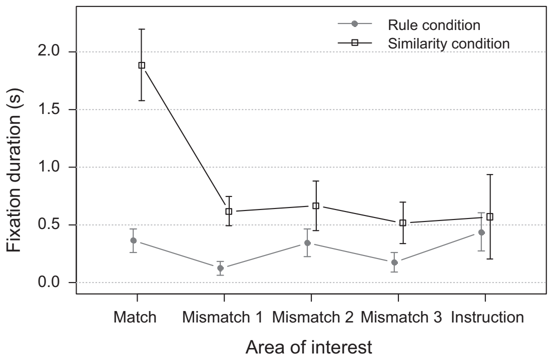


**Fig. 2.** Mean duration of fixation on the five areas of interest (AOIs) in the rule as compared to the similarity condition. The first location marks the exemplar location that contained the learning candidate whose cue profile was identical to the respective test candidate's (match). The second, third, and fourth locations refer to the other three exemplar locations (mismatch 1, mismatch 2, mismatch 3). The fifth location refers to the location of the instructions (instruction). Error bars represent one standard error.

the similarity condition fixated on the exemplar locations longer than participants in the rule condition, as shown by a main effect of strategy condition, $F(1,51) = 16.32$, $p < .001$, $\eta^2_p = .24$. Furthermore, significant interactions between similarity and exemplar type, $F(4.3,216.7) = 8.36$, $p < .001$, $\eta^2_p = .14$, and similarity, strategy condition, and exemplar type, $F(4.3,216.7) = 8.09$, $p < .001$, $\eta^2_p = .14$, suggested that the effect of similarity differed by strategy condition and exemplar type. As illustrated in Fig. 3, when we analyzed the two strategy conditions separately we found that in the rule condition, fixation durations did not differ by similarity. Neither the main effect of similarity, $F(3,78) = 0.92$, $p = .44$, $\eta^2_p = .03$, nor the interaction between similarity and exemplar type, $F(3.4,87.4) = 1.14$, $p = .34$, $\eta^2_p = .04$, was significant. In contrast, in the similarity condition, participants' gaze varied according to similarity, as shown by a significant interaction of similarity and exemplar type, $F(3.3,82.3) = 10.1$, $p < .001$, $\eta^2_p = .29$. Indeed, the more cue values a test candidate shared with the invited learning candidates the more participants gazed at invited candidates and the less they gazed at rejected candidates [linear contrast for the invited candidates: $F(1,25) = 17.84$, $p < .001$, $\eta^2_p = .42$]. In turn, the more similar the test candidates were to rejected learning candidates, the more participants gazed at rejected candidates and the less they gazed at invited candidates [linear contrast rejected candidates: $F(1,25) = 19.90$, $p < .001$, $\eta^2_p = .44$].

### 2.3. Discussion of Study 1

In Study 1 we investigated whether the gaze patterns of participants differ when using a rule-based or a similarity-based decision strategy. Taking into account the finding that when retrieving information from memory people look back at the location where the information previously appeared (e.g., Richardson & Kirkham, 2004; Richardson & Spivey, 2000), we hypothesized that participants' gaze patterns should reflect whether they retrieved the learned exemplars from memory. In line with this hypothesis, we found that when instructed to use a rule, participants did not look back at the locations associated with learning candidates. In contrast, when participants were instructed to make decisions based on the similarity to the learned candidates they looked back at the locations of similar exemplars. These results provide empirical evidence that people retrieve different information from memory when instructed to use a rule- or similarity-based strategy and resonate with the idea that similarity- and rule-based processes differ in how memory representations are accessed (e.g., Bailey, 2005; Hahn & Chater, 1998).

The results are in line with research suggesting that eye movements to locations where information had previously appeared reflect memory retrieval processes (Jahn & Braatz, 2014; Renkewitz & Jahn, 2012) and show that the looking-at-nothing effect not only appears when previously seen exemplars are evaluated but also reflects memory retrieval in response to new information. However, although we found that people looked back at the locations of the previously learned exemplars, we did not find a looking-at-nothing effect for the instruction location in either the rule or the similarity condition. Possibly, the strategy-learning phase was too short to build up a reliable association between the instruction location and episodic memory traces of the strategy. Alternatively, it is possible that the strategy instruction was kept activated during the complete test phase, making retrieval unnecessary.

The goal of the first study was to show that differences in information search in memory can be observed by tracking eye movements during the decision process. We instructed participants to use a rule- or similarity-based strategy—thus ensuring that participants indeed relied on the cognitive process of interest. Based on the first study, however, we cannot tell if the same memory retrieval processes would occur when people spontaneously use a similarity- or rule-based strategy. An explicit instruction to use a strategy induces a deliberate and controlled strategy execution, which could result in different cognitive processes from those that would occur for spontaneous strategy application. In particular, the cognitive processes involved when spontaneously using a similarity-based strategy could differ from a controlled application of similarity, because similarity-based strategies are often thought to be of an implicit and automatic nature (Ashby et al., 1998; Hoffmann, von Helversen, & Rieskamp, 2013; but see Karlsson, Juslin, & Olsson, 2008). In addition, the explicit rule instruction could have impeded retrieval processes that can appear when participants spontaneously rely on a decision rule but not if they deliberately use the rule. Thus, to go one step further and to investigate if the same gaze patterns can be observed when participants spontaneously rely on a rule- or a similarity-based strategy, we conducted a second study in which we did not instruct participants to rely on a specific strategy but aimed to manipulate strategy use implicitly through the task structure.

## 3. Study 2

The purpose of Study 2 was to test if information retrieval from memory also differs between rule-based and similarity-based decision strategies when the strategy is employed spontaneously. To be able to compare explicit

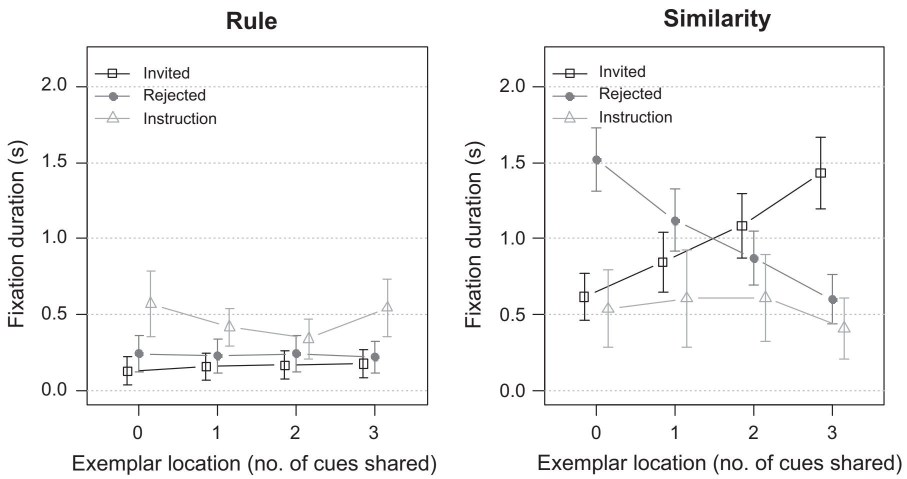


**Fig. 3.** Mean duration of fixation for exemplar locations of invited and rejected candidates and the instruction location in the rule condition (left) and the similarity condition (right). Exemplar location refers to the number of shared cue values with invited learning candidates ranging from 0 to 3. The similarity to the rejected candidates is the opposite of the similarity to the invited ones. Thus a similarity to the invited candidates of 0 corresponds to a similarity of 3 to the rejected ones, and so on. Error bars represent one standard error.

and spontaneous strategy use we investigated the eye movements related to memory processes when strategies are spontaneously employed and when explicit instructions are given to use a specific strategy.

Research in categorization, judgment, and decision making based on cognitive modeling suggests that the accuracy of strategies and the ease with which a strategy can be employed exert a strong influence on strategy selection (Bröder et al., 2010; Hoffmann et al., 2013, 2014; Pachur & Olsson, 2012; Platzer & Bröder, 2013; Rieskamp & Otto, 2006; von Helversen et al., 2013). Specifically, people have been found to rely on rules as long as rules allow the task to be solved and can be easily applied—which is usually the case with one-dimensional rules. However, when the task cannot be solved by (simple) rules, people frequently switch to a similarity-based strategy (Ashby et al., 1998; Ashby & Maddox, 2005; Erickson et al., 1998; Hoffmann et al., 2014; Juslin et al., 2008; Nosofsky & Palmeri, 1998; Nosofsky, Palmeri, & McKinley, 1994; von Helversen et al., 2013). Accordingly, we created two conditions, one in which the decision task could be solved by a simple, one-dimensional rule and the other in which the decision task could only be solved by memorizing the exemplars. In the first condition participants should recognize the rule and rely on a rule-based decision process, whereas in the second condition people should realize that the task cannot be solved by a rule and switch to a similarity-based strategy. We included two test phases. In the first participants could spontaneously choose how to solve the task; in the second phase we instructed them to follow a rule- or similarity-based strategy.

### 3.1. Method

Overall, we used a very similar decision task to that in Study 1. Again, participants had to decide whether to invite job candidates for an interview based on three cues. However, to be better able to induce strategy selection through task structure, we increased the number of learning exemplars to eight and adapted the strategy-learning phase to encourage a spontaneous use of the strategies. We recorded participants' eye movements during the two test phases (spontaneous, instructed).

#### 3.1.1. Participants

Fifty-seven people met the validity criterion. We excluded three of them from the analysis, one for not finishing the memorization phase within 1.5 h and two because in the majority of trials less than 60% of eye movement data was recorded, resulting in a final sample of 54 participants. The majority of the participants were students from the University of Basel (32 female; $M_{age}$ = 27.7 years, range 18–51 years). Participants took part for course credit or financial compensation [16 Swiss francs (CHF) per hour]. In addition, they could earn a bonus depending on their performance in the learning and test phases ($M$ = 5.1 CHF). All had normal or corrected-to-normal vision with glasses or contact lenses. Participants were randomly assigned, 26 to the rule condition and 28 to the similarity condition. On average, the experiment lasted 90 min.

#### 3.1.2. Apparatus

The same setup as in Study 1 was implemented at the University of Basel. Participants were seated in front of a 22-in. computer screen and the eye tracker system SMI iView RED120 sampled data of the right eye at 120 Hz. Auditory materials were presented via loudspeakers. Fixation detection followed a dispersion threshold of 2° of visual angle and a duration threshold of 100 ms.

#### 3.1.3. Decision task

We used the same procedure and materials as in Study 1 with some adaptations to induce participants to use either a rule or similarity without instructing them to do so. This time the study consisted of four phases: a memorization phase, a strategy-learning phase, and two test phases. In addition, we probed participants' memory of learning candidates' cue values at the end.

*3.1.3.1. Memorization phase.* During the memorization phase, participants had to learn the cue values and names of eight learning candidates by heart. We increased the number of learning candidates to be better able to induce using a rule or similarity via the task structure and outcome feedback. In contrast to Study 1, where each cue value was unique to a learning candidate, in Study 2 each cue value was associated with two learning candidates. The complete task structure can be found in the Appendix, Table A.2. As in Study 1, each of the eight learning candidates was presented at a different spatial location on the screen that was equidistant from the center and from the neighboring learning candidates (see Fig. 4). In contrast to Study 1, we kept the order of the cues constant for all participants, starting with work experience and following with possession of computer skills and knowledge of a foreign language. In addition, participants did not learn about the suitability of the learning candidate (i.e., whether the candidate was invited to an interview) during the memorization phase. Presentation and test of cue values followed the same procedure as in Study 1.

*3.1.3.2. Strategy-learning phase.* During the strategy-learning phase, participants were informed that they had to learn how to decide which candidates should be invited to an interview and that the knowledge they gained during the strategy-learning phase would be necessary to perform the task accurately in the subsequent test phases. Participants could learn to make the decisions based on trial-by-trial outcome feedback. In each trial, participants first fixated on a fixation cross at the center of the screen for 2 s. They then saw a screen containing only the empty rectangles where the learning exemplars had appeared during the memorization phase and heard the name of one of the learning candidates. Then, they had to decide whether they would invite him by pressing one of two keys. After their response, participants got visual feedback on whether they had given the correct response, and the cue information for the judged learning candidate was presented visually and auditorily. The eight learning candidates were presented repeatedly in randomized order with all candidates shown before a new cycle started. Within one cycle the order of the learning candidates was randomized. Strategy learning continued until the participants had correctly judged all learning exemplars in one cycle once or had completed 160 trials (i.e., 20 cycles).

In each condition, four of the learning candidates were invited for an interview and four were rejected. In the rule condition, the task could be solved with a simple rule based on the foreign language cue: a candidate was invited if he spoke French or Italian but not if he spoke Spanish or Portuguese.[1] In the similarity condition, the task could not be solved by a rule but only by memorizing the unique cue profile of each learning candidate. Specifically, we selected which of the eight candidates were invited and which were rejected so that every cue value appeared once with an invited and once with a rejected learning candidate (see Appendix, Table A.2).

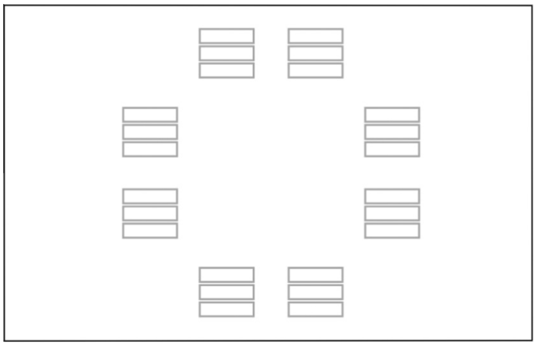

**Fig. 4.** Visual layout during both test phases of Study 2. During the tests only the empty rectangles were visible.

Positions of learning candidates were balanced in two spatial layouts. In both layouts no more than two learning candidates who belonged to the same category (invited or rejected) appeared in adjacent spatial locations. In each strategy condition, half the participants were presented with one spatial layout and the other half with the second layout.

*3.1.3.3. Test Phases 1 and 2.* In the test phases, participants had to judge 28 test candidates twice, once in Test Phase 1 and once in Test Phase 2. Eight of them were the learning candidates. Additionally, 20 new candidates were presented who shared 0–2 cue values with the learning candidates. As in Study 1, participants first saw the fixation cross in the center of the screen (2 s). Then they saw the blank screen (except for the empty rectangles) and listened to the name and cue information of a test candidate. After that, they decided if the candidate should be invited by pressing one of two keys. No feedback was given to the participants.

In Test Phase 1, participants were told to judge the test candidates according to their experience gained in the strategy-learning phase. After Test Phase 1, we asked participants to write down how they solved the judgment task, so we could check if they had indeed used different strategies in the two strategy conditions. In Test Phase 2, participants in the rule condition were instructed to invite participants who knew French or Italian (the same rule that was used to determine feedback in the strategy-learning phase) and participants in the similarity condition were instructed to invite test candidates if they shared more cue values with the invited than with the rejected learning candidates.

*3.1.3.4. Memory test.* After completing both test phases, participants were asked to retrieve the cue values of the learning candidates. Participants saw a blank screen containing empty rectangles and filled in cue values of the learning candidates one by one by choosing the appropriate value from a selection that was presented in the center of the screen. For each correct judgment, participants were paid a bonus of 10 cents.

[1] This rule was rather simple for two reasons: first, it was based on dichotomous cue values of a single cue. Second, the cue values matched with Swiss participants' prior knowledge about languages that are particularly applicable in Switzerland.

## 3.2. Results

### 3.2.1. Performance and strategy classification

Participants were able to memorize the information on the eight learning candidates rather quickly and did not differ between conditions in the learning cycles they required, $M_{rule} = 4.9$, $SD = 2.4$, $M_{sim} = 4.8$, $SD = 1.9$, $t(52) = 0.10$, $p = .92$, $d = .03$. There were only small differences in the amount of practice it took to complete the strategy-learning phase with participants in the rule condition needing somewhat fewer cycles than participants in the similarity condition, $M_{rule} = 3.7$, $SD = 1.3$, $M_{sim} = 5$, $SD = 3.8$, $t(52) = 1.82$, $p = .08$, $d = .50$.

In the test phases, we measured accuracy as the percentage of responses that were in line with the strategy that they learned during the strategy-learning phase. Overall, the accuracy was rather high in both conditions, $M_{rule} = 91.5$, $SD = 11.5$, $M_{sim} = 80.4$, $SD = 11$.

We then checked if participants had used the intended strategy by classifying them as selecting a similarity- or a rule-based strategy based on their verbal reports after Test Phase 1.[2] Participants were classified into three categories by three independent raters: (1) Simple rule users: Participants mentioned one cue that they used to make a decision, for example, "I concentrated on the cue foreign language. I invited candidates speaking French or Italian. I did not invite candidates speaking Spanish or Portuguese." (2) Complex rule users: Participants mentioned two or more cues, for example, "First I looked up language knowledge. If the candidate spoke French or Italian, I looked up other cues." (3) Similarity users: Participants referred explicitly to using similarity to the learning candidates, for example, "I tried to find the most similar learning candidate and decided [to invite or reject a test candidate] according to this learning candidate." Overall, rater agreement was high. In the cases where the raters disagreed, the case was discussed until agreement was reached. In the rule feedback condition, 10 participants were classified as using a simple rule, 4 as using a complex rule, and 8 as using similarity. In the similarity feedback condition, no participant used a simple rule, 3 participants used a complex rule, and 18 participants used similarity. In four cases in the rule feedback condition and in three cases in the similarity feedback condition participants did not report a strategy or reported problems verbalizing the strategy they used. Similarity is often considered an implicit strategy, which can impair the ability to verbalize it (Ashby et al., 1998). For this reason we included these participants in the similarity user category. To ensure that this did not influence the pattern of results, we additionally ran the analyses without these participants, which yielded the same pattern of results. We excluded four participants in the similarity condition because they reported using different strategies, such as responding by chance. Because participants differed in the strategies they selected in the two conditions, we used strategy classification as an additional factor in the following analyses. We excluded the three participants who were classified as rule users in the similarity condition from the analysis because the low number of rule users in this condition did not allow a statistical comparison. Descriptive statistics for the three rule users in the similarity condition and the four participants who reported using different strategies are included in the Appendix, Table A.3.

**Table 1**
Means, standard deviations, and sample size for response accuracy (%) in the two test phases.

| Test phase | Strategy condition | | | | | |
|---|---|---|---|---|---|---|
| | Rule | | | Similarity | | |
| | *M* | *SD* | *n* | *M* | *SD* | *n* |
| *1* | | | | | | |
| Rule users | 93 | 12.4 | 14 | 87.7 | 9 | 3 |
| Similarity users | 77.5 | 14.9 | 12 | 77.7 | 12 | 21 |
| *2* | | | | | | |
| Rule users | 99 | 2.2 | 14 | 89.9 | 5.1 | 3 |
| Similarity users | 95.1 | 10.6 | 12 | 82.5 | 11 | 21 |

We then compared accuracy in the two test phases depending on the strategy condition (rule or similarity) and strategy classification (see Table 1). In the rule condition in Test Phase 1, participants using similarity performed worse than participants using a rule, $t(24) = 2.90$, $p = .008$, $d = 1.16$. Participants using similarity in the rule condition improved from Test Phase 1–2, $t(11) = 4.85$, $p = .001$, $d = 1.46$, and in Test Phase 2 rule and similarity users were equally accurate, $t(11.83) = 1.22$, $p = .25$, $d = .07$.

Similarity users in the similarity condition were as accurate as similarity users in the rule condition in Test Phase 1, $t(31) = 0.042$, $p = .97$, $d = 0$, but less accurate in Test Phase 2, $t(31) = 3.23$, $p = .003$, $d = .16$. Similarity users in the similarity condition did not differ in terms of accuracy between Test Phase 1 and Test Phase 2, $t(20) = 1.69$, $p = .11$, $d = .38$.

As in Study 1, response times were measured from the beginning of the auditory information presentation until participants' response in a test trial. In Test Phase 1 there were no differences in response times between the rule condition and the similarity condition, $M_{rule} = 10.6$ s, $SD = 4.3$, $M_{sim} = 11.2$ s, $SD = 3.6$, $t(28) = 0.53$, $p = .60$, $d = .10$, nor between rule and similarity users, $M_{rule} = 10.5$ s, $SD = 4.1$, $M_{sim} = 11.2$ s, $SD = 3.9$, $t(48) = 0.60$, $p = .55$, $d = .17$. In Test Phase 2 participants in the rule condition were faster than participants in the similarity condition, $M_{rule} = 8.8$ s, $SD = 0.4$, $M_{sim} = 10.8$ s, $SD = 2.3$, $t(28.8) = 4.52$, $p < .001$, $d = 1.68$. Performance in the memory test at the end of the experiment was very high, with participants remembering almost all information about the learning candidates in both conditions, $M_{rule} = 99.2$, $SD = 2.1$, $M_{sim} = 99.1$, $SD = 1.7$, $t(48) = 0.12$, $p = .90$, $d = .03$, independent of the strategy they used.

### 3.2.2. Analyses of fixations

To analyze if similarity influenced eye movements we first defined rectangular AOIs around the eight exemplar locations in the same way as in Study 1. All AOIs were of

[2] The adaptive learning criterion in the strategy-learning phase ensured that participants judged all eight learning candidates in line with the strategy feedback. However, in our task it was not possible to unambiguously determine the strategy a participant used purely based on the participants' decisions. In particular, in the rule condition we cannot rule out based on the decisions that a participant solved the task by using the similarity of the test candidates to the learning candidates on the foreign language cue to make the decision. Thus, we used the verbal reports to determine strategy choices.

the same size (5.5° by 6° of visual angle). These nonoverlapping AOIs exceeded the exemplar locations by approximately 1.5° of visual angle in each direction. As in Study 1, we excluded all trials where the dwell criterion was not met (6.5% of all trials). Then we aggregated durations of fixation on the exemplar locations depending on their similarity to the test candidate in a given trial for each participant. Unlike in Study 1, in Study 2 more than one exemplar location contained cue values identical to cue values of learning or test candidates. More precisely, for the eight test candidates who were identical to the learning candidates (old test items), one exemplar location contained an identical cue profile, three exemplar locations contained one identical cue, and four exemplar locations contained no identical cues. For the 20 new test candidates (new test items), one or two exemplar locations contained two identical cue values, two to four exemplar locations contained one identical cue, and three or four locations contained no identical cue values. Thus for the old test items, the exemplar locations shared 0, 1, or 3 cue values with the test candidates and for the new items the exemplar locations shared 0, 1, or 2 cue values with the new test items. As in Study 1, we analyzed mean duration of fixation on the exemplar locations separately for the old and new items and for Test Phases 1 and 2 (see Figs. 5 and 6). *F* values in statistical analyses were Greenhouse–Geisser corrected when necessary.

*3.2.2.1. Mean fixation durations for old items. Test Phase 1:* In a first step, we analyzed effects of strategy condition and strategy classification on duration of fixation on exemplar locations when judging the old items for Test Phase 1. We assumed that if exemplar retrieval takes place, participants should have fixated on AOIs that contained identical cue values during learning. First, we tested whether mean duration of fixation on exemplar locations differed between participants classified as rule or similarity users in the rule condition of Test Phase 1 (Fig. 5a). A mixed ANOVA with the within-subject factor exemplar similarity (0, 1, 3 shared cue values) and the between-subjects factor strategy classification (rule or similarity user) revealed that overall, similarity users looked longer at the exemplar locations than rule users, as shown by a main effect of strategy classification, $F(1,24) = 4.87$, $p = .04$, $\eta_p^2 = .17$. Furthermore, a main effect of exemplar similarity suggests that participants looked longer at the exemplar location associated with the identical learning candidate than at the other exemplar locations, $F(1,24.8) = 21.74$, $p < .001$, $\eta_p^2 = .48$. Finally, similarity and rule users differed in the degree to which they looked back at the locations of similar learning candidates, as shown by a significant interaction between exemplar similarity and strategy classification, $F(1,24.8) = 5.05$, $p = .03$, $\eta_p^2 = .17$. In particular, similarity users clearly gazed more often at exemplar locations that were associated with the identical learning candidate than rule users did, $t(24) = 2.29$, $p = .02$, $d = .93$.

Second, we tested whether similarity users in the similarity condition also looked longer at the identical learning candidates (Fig. 5b). Indeed, an ANOVA for repeated measures testing the factor exemplar similarity revealed a significant effect for exemplar similarity, $F(1,20.9) = 23.13$, $p < .001$, $\eta_p^2 = .54$, suggesting that participants in the similarity condition looked much more frequently at the location of the identical learning candidate than at the other exemplar locations. Last, a test to determine if similarity users in the rule condition differed from similarity users in the similarity condition showed no difference, as indicated by no main effect for condition, $F(1,31) = 1.14$, $p = .30$, $\eta_p^2 = .04$, and no interaction between condition and exemplar similarity, $F(1,32.2) = 0.85$, $p = .43$, $\eta_p^2 = .03$.

*Test Phase 2:* We repeated the same set of analyses for Test Phase 2. As illustrated in Fig. 5c, we still found a main effect for exemplar similarity, indicating that participants in the rule condition looked longer at the location of the identical learning candidate than at the other exemplar locations, $F(1,24.7) = 10.77$, $p < .001$, $\eta_p^2 = .31$. However, in Test Phase 2, participants classified as rule users no longer differed from participants classified as similarity users, as indicated by the lack of a main effect for strategy classification, $F(1,24) = 0.01$, $p = .91$, $\eta_p^2 = 0$, and no interaction between exemplar similarity and strategy classification, $F(1,24.7) = 0.76$, $p = .93$, $\eta_p^2 = 0$. This suggests that after being instructed to use a rule, participants changed their strategy according to the instructions. In the similarity condition, the effect of exemplar similarity on fixation durations persisted in Test Phase 2, $F(1,20.2) = 40.01$, $p < .001$, $\eta_p^2 = .67$ (Fig. 5d). Last, in Test Phase 2 we found that participants originally classified as similarity users in the rule condition showed a smaller exemplar similarity effect than similarity users in the similarity condition, as shown by a significant main effect for the strategy condition, $F(1,31) = 11.04$, $p = .002$, $\eta_p^2 = .26$, and an interaction between strategy condition and exemplar similarity, $F(1,31.5) = 10.73$, $p < .001$, $\eta_p^2 = .26$.

*3.2.2.2. Mean fixation durations for new items. Test Phase 1:* Next, we tested if the effect of exemplar similarity also existed for the new test items that shared 0, 1, or 2 cue values with the learning candidates. As with the old items, we first tested whether similarity users differed from rule users in the rule condition (Fig. 6a). Similar to what we found for the old items, similarity users looked more at the exemplar locations than did rule users, $F(1,24) = 5.33$, $p = .03$, $\eta_p^2 = .18$, and overall fixation durations increased with exemplar similarity, $F(1.1,26.7) = 11.69$, $p < .001$, $\eta_p^2 = .33$. Furthermore, a significant interaction between exemplar similarity and strategy classification indicated that similarity users differed from rule users in the degree to which they looked back at the locations of similar learning candidates, $F(1.1,26.7) = 6.16$, $p = .02$, $\eta_p^2 = .20$. Whereas exemplar similarity did not play a role for the rule users, $F(1,13) = 2.34$, $p = .15$, $\eta_p^2 = .15$, similarity users gazed more at the locations of the learning candidates the more cue values these shared with the test candidates, $F(1,11) = 9.19$, $p = .01$, $\eta_p^2 = .45$.

In the same vein, we found that similarity users in the similarity condition also looked more at the exemplar locations of similar learning candidates than at the locations of learning candidates that had different cue values, $F(1.3,26.6) = 13.01$, $p < .001$, $\eta_p^2 = .39$ (Fig. 6b). Similarity users in the similarity condition and similarity users in the rule condition did not differ significantly from each other, as indicated by the lack of a main effect for

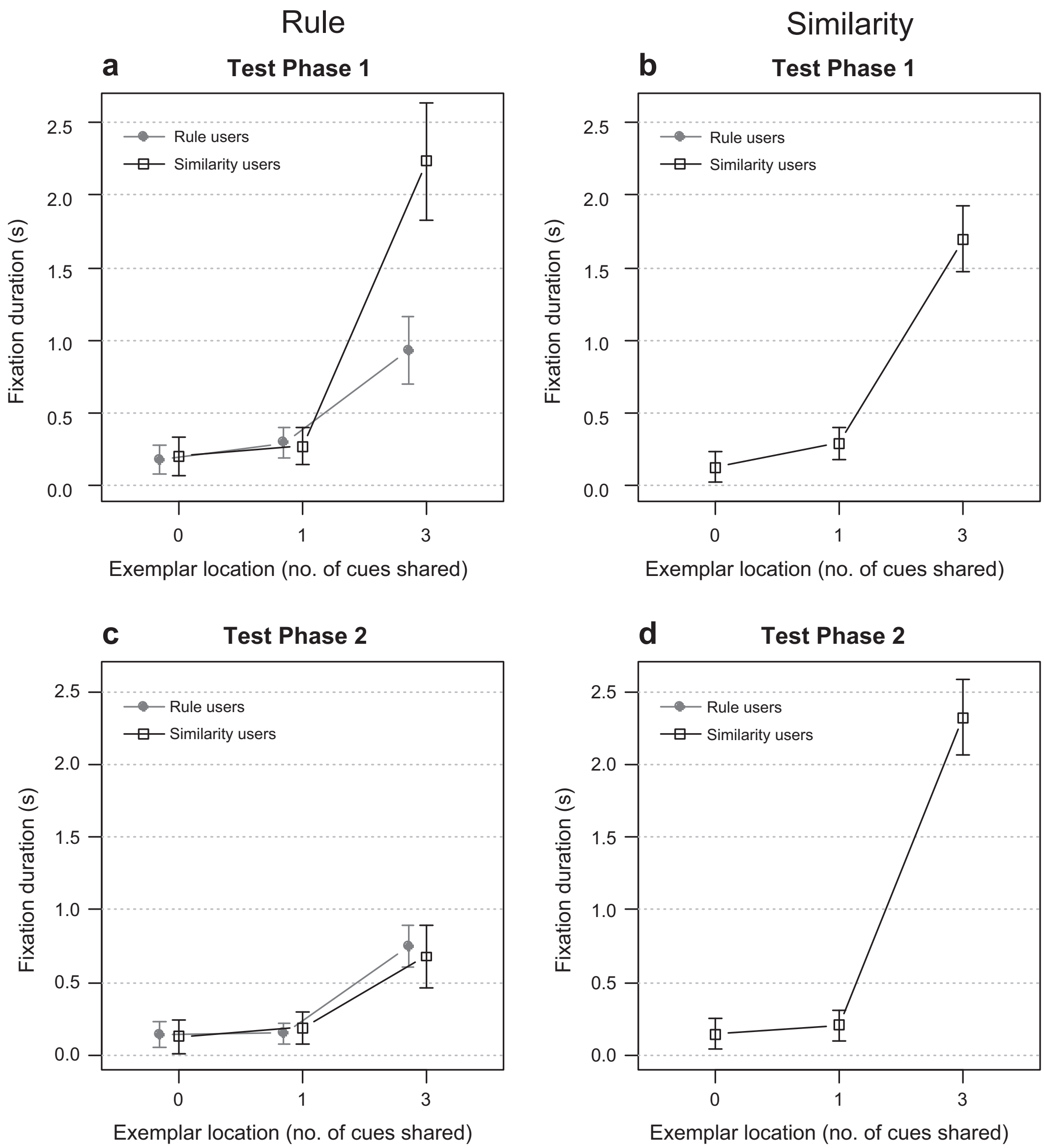


**Fig. 5.** Mean duration of fixation on exemplar locations sharing 0–3 cue values with old test items for the rule condition (a and c) and the similarity condition (b and d) by strategy classification (rule user, similarity user) and test phase (Test Phase 1 spontaneous use: a and b; Test Phase 2 strategy instruction: c and d). Error bars show standard errors.

condition, $F(1,31) = 2.10$, $p = .16$, $\eta_p^2 = .06$, and a nonsignificant interaction between condition and exemplar similarity, $F(1.2,37.4) = 1.63$, $p = .21$, $\eta_p^2 = .05$.

*Test Phase 2:* We repeated the same analyses for Test Phase 2. As shown in Fig. 6c, we did not find an effect for exemplar similarity, $F(2,48) = 0.81$, $p = .45$, $\eta_p^2 = .03$, or strategy classification, $F(1,24) = 0.24$, $p = .88$, $\eta_p^2 = .00$, nor an interaction between these two factors in the rule condition, $F(2,48) = 0.51$, $p = .60$, $\eta_p^2 = .02$. Participants almost did not look at exemplar locations, regardless of their classification as rule or similarity user. In contrast, we still found an effect of exemplar similarity in the similarity condition, $F(1.2,23.0) = 26.10$, $p < .001$, $\eta_p^2 = .57$ (Fig. 6d).

Last, we compared participants classified as similarity users in the rule and similarity conditions. Whereas similarity users in the similarity condition looked more at the exemplar locations of similar learning candidates than the locations of learning exemplars with different cue values, similarity users in the rule condition did not look back at the exemplar locations of similar learning candidates. This gaze pattern is confirmed by the results of a mixed ANOVA that showed a main effect for the factor strategy condition, $F(1,31) = 12.48$, $p = .001$, $\eta_p^2 = .29$, and a significant interaction between the factors exemplar similarity and strategy condition, $F(1.3,38.0) = 13.99$, $p < .001$, $\eta_p^2 = .31$.

### 3.3. Discussion of Study 2

Overall, we found a similar pattern of results to that in Study 1. Participants using a similarity-based strategy

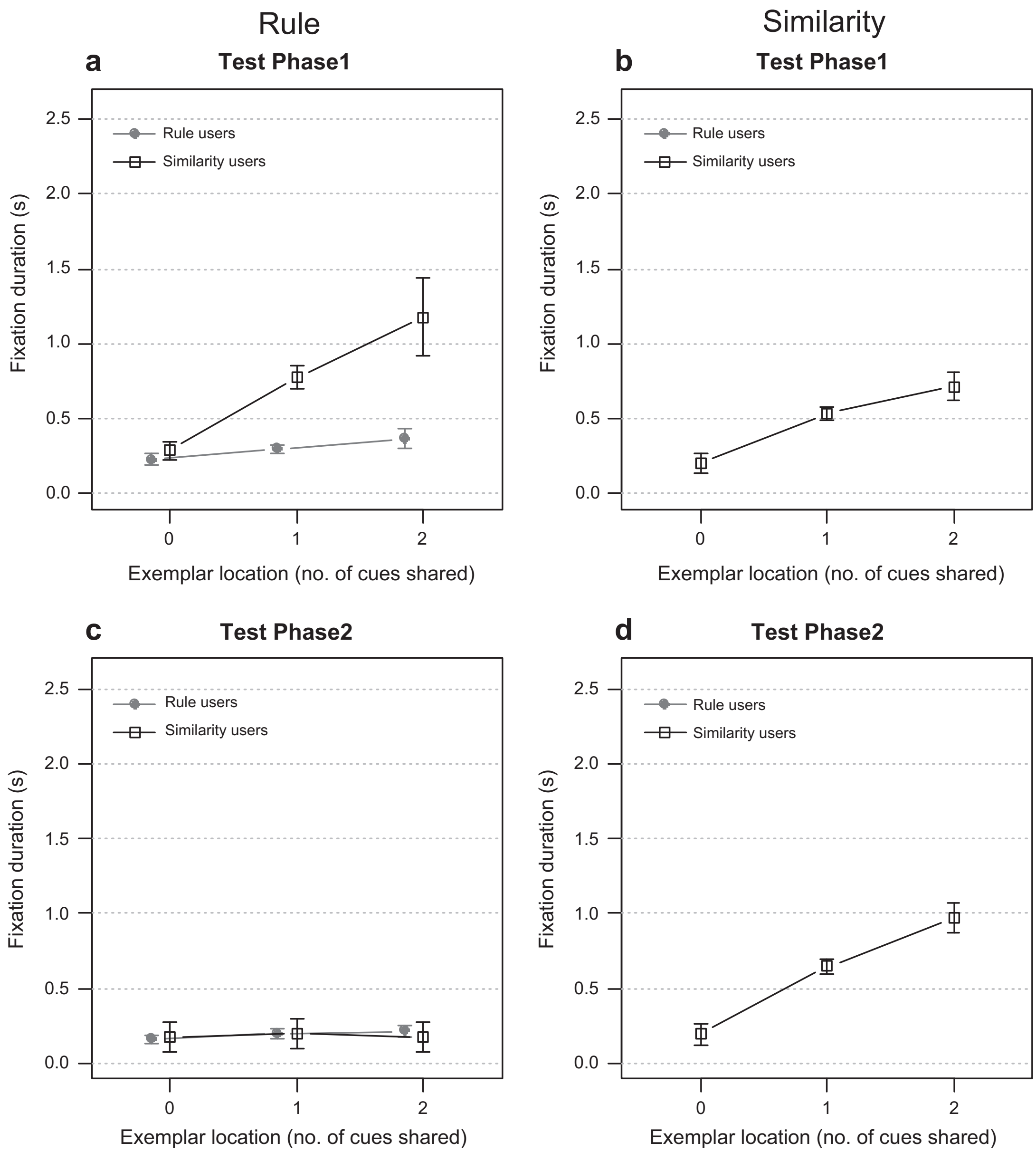


**Fig. 6.** Mean duration of fixation on exemplar locations sharing 0–2 cue values with new test items for the rule condition (a and c) and the similarity condition (b and d) by strategy classification (rule user, similarity user) and test phase (Test Phase 1 spontaneous use: a and b; Test Phase 2 strategy instruction: c and d). Error bars show standard errors.

showed a strong effect of similarity on eye movements. They looked more frequently at locations where identical but also where similar exemplars to the candidate under consideration had been presented. This was the case when participants were not instructed to use a specific strategy as well as when instructed to rely on similarity. Furthermore, the same effect appeared for all participants classified as using similarity, independent of whether they had received feedback inducing a similarity-based strategy or not.

As in Study 1 participants classified as using a rule or instructed to use a rule did not look back at the locations of similar exemplars. However, in contrast to Study 1, we found a memory effect when the same candidates appeared during test that had been studied previously. Here we found that even participants instructed to use a rule looked more frequently at the location where the specific candidate had appeared before. This indicates that when it was not necessary to use a rule because a specific candidate was recognized, participants relied on memory retrieval, but not when new candidates were evaluated. Possibly this effect did not appear in Study 1 because there the "identical" candidates appeared with new names during test, whereas they had the same names in Study 2, which could have induced recognition regardless of the strategy they used.

We were only partly able to induce participants to use a rule- or similarity-based strategy. Participants' self-reports showed that also in the rule feedback condition a considerable number of participants used similarity. These results are in contrast to studies showing that usually people prefer simple rules to similarity (Ashby & Maddox, 2005; Erickson et al., 1998; Hoffmann et al., 2014; Nosofsky et al., 1994). However, our studies differed from these experiments, because in our task participants had to learn the rule while retrieving the cue values from memory. Indeed, Platzer and Bröder (2013) showed that in memory-based decisions people more frequently rely on similarity—in particular if the cue polarity (i.e., which cue value is associated with a positive outcome) is not known. In our task, learning about the direction of a cue was even more complex because every cue could take on four values compared to two cue values in the experiment by Platzer and Bröder (2013).

In the analysis, we classified participants based on verbal descriptions of the strategies they used. The ability to verbalize is frequently considered a feature of rule application, whereas similarity-based strategies are often considered implicit and thus less accessible to deliberate reporting. Thus, similarity users might be less able to accurately report the strategy they used (Ashby et al., 1998; Ashby & Maddox, 2005). Indeed, participants who reported using a rule were easily classified and rater agreement was very high, reaching 100% for participants classified as using a simple rule. The majority of similarity users could be clearly classified as using similarity based on their description, but because similarity might be difficult to verbalize we included participants who were unable to verbalize the strategy they used in the similarity user category. However, we cannot rule out that these participants actually followed a different strategy, combined a rule-based and a similarity-based strategy, or switched strategies between trials. Overall, our results suggest that the gaze patterns of these participants reflect retrieval processes caused by similarity. Future research, however, should investigate if there are differences between people who rely on a single strategy and those who use multiple strategies as well as possible differences between participants who have insight into the strategies they used and participants who do not. Furthermore, researchers disagree on the degree to which self-reports reflect people's actual cognitive processes versus only general beliefs about how they made a decision (e.g., Harries, Evans, & Dennis, 2000; Lagnado, Newell, Kahan, & Shanks, 2006). This suggests that future research should use additional methods such as cognitive modeling to corroborate our findings.

## 4. General discussion

When making everyday decisions from memory people can apply abstract rules that process the available information for a decision or they can make a decision according to similar decision situations encountered in the past (Ashby et al., 1998; Erickson et al., 1998; Juslin & Persson, 2002; Nosofsky et al., 1994; Platzer & Bröder, 2013). Although this distinction is intuitively appealing it proves hard to separate on a process level. One reason is that the two processes are conceptually difficult to distinguish (Hahn & Chater, 1998; Markman et al., 2005; Pothos, 2005). Another problem is that hardly any tools exist that can trace memory processes during higher-level mental processes that are not intrusive and can measure the ongoing memory processes online (e.g., Bröder, 2000; Peterson & Beck, 2011).

In two studies we explored memory processes during similarity- versus rule-based retrieval processes using a recently developed method based on the measurement of eye movements (Jahn & Braatz, 2014; Renkewitz & Jahn, 2012). We found that participants using a similarity-based strategy differed in their eye movements from participants using a rule-based strategy: whereas participants using similarity fixated on spatial locations that were associated with exemplars during learning, participants using a rule did not look back at the locations of the previously learned exemplars. This was the case when applying a complex rule based on multiple cues (Study 1) as well as a simple one-dimensional rule (Study 2), when applying similarity based on matches to four exemplars with unique cue values (Study 1) as well as when applying similarity to eight exemplars with each cue value associated with two exemplars (Study 2), and when instructed to use a strategy (Study 1) as well as when selecting a strategy spontaneously (Study 2).[3] In sum, these results provide robust evidence that participants using a similarity-based strategy retrieved exemplar information from memory, whereas participants who used a rule to arrive at a decision did not retrieve exemplar information from memory.

### 4.1. Using eye movements to study memory retrieval in decision making

In both studies we found that people showed differences in eye movements depending on the retrieval demands of the decision strategy they employed. These results are in line with the idea that eye movements to associated spatial locations can be seen as direct evidence for memory retrieval, and the results dovetail with an ever-growing number of papers showing that when retrieving information from memory, people gaze back at spatial locations that have been associated with the to-be-retrieved information during encoding (e.g., Hoover & Richardson, 2008; Jahn & Braatz, 2014; Renkewitz & Jahn, 2012; Richardson & Kirkham, 2004; Richardson & Spivey, 2000).

In addition, our findings support the idea that eye movements do not reflect an automatic response that is executed upon listening to a statement probing associated spatial information, but rather a strategy-based retrieval process (Jahn & Braatz, 2014; Renkewitz & Jahn, 2012). If eye movements are the result of an automatic link between perception and retrieval, rule users should have shown the same pattern of eye movements as similarity users, because listening to cue information should have automatically activated the episodic memory trace and

[3] To test memory processes during similarity- and rule-based decision making we analyzed mean fixation durations. The results are also robust when analyzing the proportion of the total decision time in one trial spent fixating on each location.

triggered eye movements back to the associated spatial locations. Instead, rule user did not look back at these locations. This view is in line with findings in diagnostic reasoning where gaze behavior has been shown to reflect the activation status of a hypothesis in memory (Jahn & Braatz, 2014). Here, we demonstrated that this research can be extended to study how eye movements reflect the memory processes involved in similarity- and rule-based decision and judgment processes.

In our study people's eye movements were free and unrestricted. Recent research, however, suggests that triggering the eyes to move to a specific location during retrieval can enhance the retrieval of the information associated with that location (Johansson et al., 2012; Johansson & Johansson, 2014; Laeng et al., 2014; Scholz et al., in press). Similarly, manipulating the salience of cues (Platzer & Bröder, 2012) and guiding the eyes toward valid and invalid cue information (Platzer, Bröder, & Heck, 2014) have been shown to influence the probability with which the cues are retrieved from memory and the resulting decision strategy. This suggests that guiding eye movements to locations could be a subtle way to alter the decision-making process, even if these locations no longer contain any information. However, with unrestricted eye movements, enhanced retrieval accuracy due to eye movements to associated but emptied spatial locations is unlikely (cf. Richardson et al., 2009; Richardson & Kirkham, 2004).

### 4.2. Memory retrieval in rule-based and similarity-based decisions

We found in both studies that people using a rule did not look back at the locations of previously learned exemplars, but people using a similarity-based strategy did, independent of the complexity of the task structure and if the strategy was instructed or spontaneously used. This suggests that similarity-based and rule-based decisions rely on different memory processes. These results are in line with the assumptions of Hahn and Chater (1998; see also Bailey, 2005), who proposed that the core difference between rule and similarity lies not in the nature of the mental representations that are built, but in the way memory representations of stored information are matched with a novel object. Whereas similarity users make a decision by matching the object under consideration against the stored exemplars, rule users compare the object against the conditions for choosing a specific option specified by the rule. Correspondingly, we found that only participants using similarity returned their gaze to the locations associated with exemplars, even though we made sure that rule and similarity users had the same information available in memory: similarity and rule users received the same cue information about job candidates and we ensured that they were equally able to retrieve this information throughout the decision-making phase. Furthermore, a memory check at the end of Study 2 showed that participants remembered almost all the cue information and that there was no difference in recall accuracy between users of similarity- and rule-based strategies.

Eye movements suggest that for participants using a similarity-based strategy, memory retrieval was a direct function of similarity with similar exemplars being fixated on more than nonsimilar exemplars. This idea is in line with multiple-trace models of memory such as the MINERVA model, which assumes that recall is a function of similarity to the object under consideration and the frequency and recency with which it was encountered during learning (Hintzman, 1988; Nosofsky & Palmeri, 1997). In our study, frequency and recency were the same for all exemplars, leaving the effect of similarity. However, our results suggest that using eye movements to trace memory retrieval could be a promising avenue to investigate how frequency and recency interact with similarity when retrieving information.

Overall, the differences between rule and similarity users were somewhat more pronounced when they followed instruction than when we compared participants who were classified based on their verbal reports. This suggests that the memory processes involved in an explicit and deliberate application of a strategy are comparable to the processes triggered by spontaneous use. However, a considerable number of participants were unable to verbalize the strategy they used, and it is possible that this is the result of using a combination of similarity and rule-based processes (e.g., Brooks & Hannah, 2006; Hahn et al., 2010; von Helversen, Herzog, & Rieskamp, 2014). Here, making retrieval processes visible by tracing eye movements during the decision phase could be a valuable tool to analyze the memory processes involved in spontaneous decisions.

## 5. Conclusion

By observing eye movements while people performed memory-based decisions using a similarity-based or a rule-based strategy, we showed that the two strategies involve different memory processes. Although similarity and rule users had built the same memory representations, they differed in how these representations were accessed when making a decision. Whereas similarity users retrieved information about similar exemplars, rule users did not—providing empirical evidence that the two processes can be disentangled on the process level. Our results show that observing peoples' eye movements to "nothing" can make cognitive processes visible that otherwise would be hidden from sight.

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## Appendix A

See Tables A.1–A.3.

**Table A.1**
Item structure in Study 1.

| Test candidate no. | Cue 1: Language skills | Cue 2: Computer skills | Cue 3: Work experience | Exemplar location (no. cues shared) | Strategy prediction | |
|---|---|---|---|---|---|---|
| | | | | | Rule | Similarity |
| *1* | *Italian* | *SQL* | *Automobile* | *3* | *Invited* | *Invited* |
| *2* | *French* | *SPSS* | *Finance* | *3* | *Invited* | *Invited* |
| 3 | French | SQL | Finance | 3 | Invited | Invited |
| 4 | Italian | SPSS | Finance | 3 | Invited | Invited |
| 5 | French | SPSS | Mobile phone | 2 | Invited | Invited |
| 6 | Italian | HTML | Automobile | 2 | Invited | Invited |
| 7 | Portuguese | HTML | Finance | 1 | Invited | Rejected |
| 8 | French | Photoshop | Mobile phone | 1 | Invited | Rejected |
| 9 | Spanish | HTML | Mobile phone | 0 | Invited | Rejected |
| 10 | Portuguese | HTML | Mobile phone | 0 | Invited | Rejected |
| *11* | *Portuguese* | *HTML* | *Pharmaceutical* | *0* | *Rejected* | *Rejected* |
| *12* | *Spanish* | *Photoshop* | *Mobile phone* | *0* | *Rejected* | *Rejected* |
| 13 | Spanish | Photoshop | Pharmaceutical | 0 | Rejected | Rejected |
| 14 | Portuguese | Photoshop | Mobile phone | 0 | Rejected | Rejected |
| 15 | Portuguese | HTML | Automobile | 1 | Rejected | Rejected |
| 16 | Spanish | SPSS | Mobile phone | 1 | Rejected | Rejected |
| 17 | Spanish | SQL | Automobile | 2 | Rejected | Invited |
| 18 | Italian | Photoshop | Automobile | 2 | Rejected | Invited |
| 19 | French | SPSS | Automobile | 3 | Rejected | Invited |
| 20 | Italian | SPSS | Automobile | 3 | Rejected | Invited |

*Note:* Exemplar location indicates number of corresponding cue values with the invited learning candidates. Strategy prediction indicates if a test candidate was invited or rejected according to the rule or similarity instruction. Italic type denotes test candidates who had cue patterns identical to those of the learning candidates (identical test items). Test Candidates 1 and 2 correspond with invited learning candidates and Candidates 11 and 12 with rejected learning candidates. All remaining test candidates varied in their similarity to the invited learning candidates (new test items).

**Table A.2**
Item structure in Study 2.

| Test candidate no. | Cue 1: Language skills | Cue 2: Computer skills | Cue 3: Work experience | Strategy prediction | |
|---|---|---|---|---|---|
| | | | | Rule | Similarity |
| 1 | French | SPSS | Automobile | Invited | Rejected |
| 2 | French | SQL | Mobile phone | Invited | Rejected |
| *3* | *French* | *SPSS* | *Mobile phone* | *Invited* | *Rejected* |
| 4 | French | Photoshop | Mobile phone | Invited | Invited |
| 5 | French | SPSS | Financial | Invited | Invited |
| 6 | French | HTML | Financial | Invited | Ambiguous |
| *7* | *French* | *Photoshop* | *Financial* | *Invited* | *Invited* |
| *8* | *Italian* | *SQL* | *Automobile* | *Invited* | *Invited* |
| 9 | Italian | SPSS | Automobile | Invited | Ambiguous |
| 10 | Italian | HTML | Automobile | Invited | Invited |
| 11 | Italian | SQL | Pharmaceutical | Invited | Invited |
| *12* | *Italian* | *HTML* | *Pharmaceutical* | *Invited* | *Rejected* |
| 13 | Italian | Photoshop | Pharmaceutical | Invited | Rejected |
| 14 | Italian | HTML | Financial | Invited | Rejected |
| 15 | Spanish | SPSS | Automobile | Rejected | Ambiguous |
| 16 | Spanish | SQL | Pharmaceutical | Rejected | Invited |
| *17* | *Spanish* | *SPSS* | *Pharmaceutical* | *Rejected* | *Invited* |
| 18 | Spanish | Photoshop | Pharmaceutical | Rejected | Ambiguous |
| 19 | Spanish | SQL | Mobile phone | Rejected | Rejected |
| *20* | *Spanish* | *SQL* | *Financial* | *Rejected* | *Rejected* |
| 21 | Spanish | SPSS | Financial | Rejected | Invited |
| 22 | Portuguese | HTML | Automobile | Rejected | Invited |
| *23* | *Portuguese* | *Photoshop* | *Automobile* | *Rejected* | *Rejected* |
| 24 | Portuguese | Photoshop | Pharmaceutical | Rejected | Rejected |
| 25 | Portuguese | SQL | Mobile phone | Rejected | Ambiguous |
| *26* | *Portuguese* | *HTML* | *Mobile phone* | *Rejected* | *Invited* |
| 27 | Portuguese | Photoshop | Mobile phone | Rejected | Invited |
| 28 | Portuguese | HTML | Financial | Rejected | Ambiguous |

*Note:* Strategy prediction indicates if a test candidate was invited according to the received strategy feedback (rule or similarity). According to the similarity feedback, six test candidates were equally similar to an invited and a rejected learning candidate and were classified as ambiguous. Italics denote test candidates who corresponded in their cue patterns with the eight learning candidates (old items). According to the rule feedback, candidates with the numbers 3, 7, 8, and 12 were invited and candidates number 17, 20, 23, and 26 were rejected. According to the similarity feedback, candidates number 7, 8, 17, and 26 were invited and candidates number 3, 12, 20, and 23 were rejected. All other test candidates varied in their similarity with the learning candidates (new items).

**Table A.3**
Means and standard deviations for response accuracy (%), response times (s) and fixation durations (s) on exemplar locations for old and new test items and test phases 1 and 2 for the seven participants in the similarity condition in Study 2 who either used a rule (Participants 1–3) or reported using a different strategy (Participants 4–7).

| Participant no. | Response accuracy | | Response time | | Exemplar location (no. cues shared) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 0 | | 1 | | 2/3 | |
| | *M* | *SD* | *M* | *SD* | *M* | *SD* | *M* | *SD* | *M* | *SD* |
| *Old items* | | | | | | | | | | |
| Test Phase 1 | | | | | | | | | | |
| 1 | 100 | 0 | 9.2 | 1.2 | 0.2 | 0.2 | 0.2 | 0.2 | 1.3 | 2.4 |
| 2 | 86 | 38 | 22.4 | 14.9 | 0.2 | 0.2 | 1.1 | 1 | 3.4 | 3.8 |
| 3 | 100 | 0 | 9 | 0.6 | 0 | 0.1 | 0 | 0.1 | 0.1 | 0.2 |
| 4 | 75 | 46 | 9.3 | 1.7 | 0 | 0 | 0 | 0.1 | 3.3 | 1.8 |
| 5 | 100 | 0 | 9.2 | 1.3 | 0 | 0 | 0 | 0.1 | 0 | 0 |
| 6 | 88 | 35 | 10.2 | 3.7 | 0.1 | 0.2 | 0.8 | 1.1 | 2.3 | 1.8 |
| 7 | 100 | 0 | 9 | 0.4 | 0.2 | 0.3 | 0.1 | 0.2 | 0.3 | 0.7 |
| Test Phase 2 | | | | | | | | | | |
| 1 | 100 | 0 | 9.1 | 1 | 0.2 | 0.2 | 0.3 | 0.2 | 1.9 | 1.6 |
| 2 | 67 | 52 | 12.5 | 8.8 | 0.3 | 0.4 | 0.6 | 0.6 | 2.6 | 4.7 |
| 3 | 100 | 0 | 8.4 | 0.3 | 0.1 | 0.2 | 0.2 | 0.5 | 0 | 0 |
| 4 | 63 | 52 | 8.5 | 0.5 | 0.1 | 0.1 | 0 | 0.1 | 3.9 | 0.7 |
| 5 | 100 | 0 | 9.1 | 1 | 0.2 | 0.6 | 0.2 | 0.4 | 1.6 | 3.7 |
| 6 | 100 | 0 | 10.1 | 2.1 | 0.1 | 0.2 | 0.3 | 0.3 | 5 | 1.8 |
| 7 | 88 | 35 | 8.8 | 0.7 | 0.5 | 0.5 | 0.5 | 0.5 | 0.9 | 1.7 |
| *New items* | | | | | | | | | | |
| Test Phase 1 | | | | | | | | | | |
| 1 | 90 | 31 | 10.6 | 2.3 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 1.1 |
| 2 | 73 | 46 | 27.8 | 16.4 | 0.7 | 1.3 | 1.2 | 1.4 | 1.1 | 1.6 |
| 3 | 90 | 31 | 11.9 | 2.9 | 0.4 | 0.4 | 0.4 | 0.5 | 0.4 | 0.6 |
| 4 | 75 | 44 | 8.8 | 0.5 | 0.1 | 0.1 | 0.3 | 0.4 | 0.3 | 0.8 |
| 5 | 80 | 41 | 15.9 | 6 | 0 | 0.2 | 0 | 0.1 | 0.2 | 0.8 |
| 6 | 75 | 44 | 11.6 | 3 | 0.4 | 0.6 | 0.8 | 1 | 0.7 | 1.1 |
| 7 | 70 | 47 | 9.1 | 0.7 | 0.1 | 0.3 | 0.2 | 0.4 | 0.2 | 0.6 |
| Test Phase 2 | | | | | | | | | | |
| 1 | 90 | 31 | 12.7 | 6.0 | 0.3 | 0.4 | 0.7 | 0.7 | 1.2 | 0.9 |
| 2 | 89 | 32 | 13 | 8.4 | 0.2 | 0.2 | 0.8 | 1.2 | 1.2 | 1.4 |
| 3 | 90 | 31 | 10.6 | 2.5 | 0 | 0 | 0 | 0.1 | 0.1 | 0.3 |
| 4 | 75 | 44 | 10.5 | 1.7 | 0.2 | 0.2 | 0.9 | 0.6 | 0.9 | 1 |
| 5 | 90 | 31 | 22.7 | 17.5 | 0.1 | 0.1 | 1.2 | 2.9 | 1.4 | 4.8 |
| 6 | 65 | 49 | 13 | 5 | 0.4 | 0.6 | 1.5 | 0.9 | 1.8 | 1.6 |
| 7 | 70 | 47 | 11.1 | 1.9 | 0.4 | 0.4 | 0.4 | 0.5 | 0.4 | 0.6 |

*Note:* Old items shared 0, 1, and 3 cue vales with exemplars and new items shared 0, 1, and 2 cue values with exemplars.

## References


Allopenna, P. D., Magnuson, J. S., & Tanenhaus, M. K. (1998). Tracking the time course of spoken word recognition using eye movements: Evidence for continuous mapping models. *Journal of Memory and Language, 38*, 419–439. http://dx.doi.org/10.1006/jmla.1997.2558.

Altmann, G. T. M. (2004). Language-mediated eye movements in the absence of a visual world: The "blank screen paradigm". *Cognition, 93*, 79–87. http://dx.doi.org/10.1016/j.cognition.2004.02.005.

Altmann, G. T. M., & Kamide, Y. (2007). The real-time mediation of visual attention by language and world knowledge: Linking anticipatory (and other) eye movements to linguistic processing. *Journal of Memory and Language, 57*, 502–518. http://dx.doi.org/10.1016/j.jml.2006.12.004.

Anderson, J. R. (1987). Methodologies for studying human knowledge. *Behavioral and Brain Sciences, 10*, 467–505.

Ashby, F. G., Alfonso-Reese, L. A., Turken, U., & Waldron, E. M. (1998). A neuropsychological theory of multiple systems in category learning. *Psychological Review, 105*, 442–481.

Ashby, F. G., & Maddox, W. T. (2005). Human category learning. *Annual Review of Psychology, 56*, 149–178. http://dx.doi.org/10.1146/annurev.psych.56.091103.070217.

Ashby, F. G., & O'Brien, J. B. (2005). Category learning and multiple memory systems. *Trends in Cognitive Sciences, 9*, 83–89. http://dx.doi.org/10.1016/j.tics.2004.12.003.

Bailey, T. M. (2005). Rules work on one representation; similarity compares two representations. *Behavioral and Brain Sciences, 28*, 16.

Barsalou, L. W. (1990). On the indistinguishability of exemplar memory and abstraction in category representation. In T. K. Srull & R. S. Wyer (Eds.), *Advances in social cognition. Content and process specificity in the effects of prior experiences* (Vol. III, pp. 61–88). Hillsdale, NJ: Erlbaum.

Bröder, A. (2000). A methodological comment on behavioral decision making. *Psychologische Beiträge, 42*, 645–662.

Bröder, A., Newell, B. R., & Platzer, C. (2010). Cue integration vs. exemplar-based reasoning in multi-attribute decisions from memory: A matter of cue representation. *Judgment and Decision Making, 5*, 326–338.

Brooks, L. R., & Hannah, S. D. (2006). Instantiated features and the use of "rules". *Journal of Experimental Psychology: General, 135*, 133–151. http://dx.doi.org/10.1037/0096-3445.135.2.133.

Dougherty, M. R. P., Gettys, C. F., & Ogden, E. E. (1999). MINERVA-DM: A memory process model for judgments of likelihood. *Psychological Review, 106*, 180–209.

Erickson, M. A., Kruschke, J. K., Blair, N., Fragassi, M., Johansen, M., & Nosofsky, R. (1998). Rules and exemplars in category learning. *Journal of Experimental Psychology: General, 127*, 107–139.

Ericsson, K. A., & Simon, H. A. (1980). Verbal reports as data. *Psychological Review, 87*, 215–261.

Ferreira, F., Apel, J., & Henderson, J. M. (2008). Taking a new look at looking at nothing. *Trends in Cognitive Sciences, 12*, 405–410. http://dx.doi.org/10.1016/j.tics.2008.07.007.

Glaholt, M. G., & Reingold, E. M. (2011). Eye movement monitoring as a process tracing methodology in decision making research. *Journal of Neuroscience, Psychology, and Economics, 4*, 125–146. http://dx.doi.org/10.1037/a0020692.

Hahn, U., & Chater, N. (1998). Similarity and rules: Distinct? Exhaustive? Empirically distinguishable? *Cognition, 65*, 197–230.

Hahn, U., Prat-Sala, M., Pothos, E. M., & Brumby, D. P. (2010). Exemplar similarity and rule application. *Cognition, 114*, 1–18. http://dx.doi.org/10.1016/j.cognition.2009.08.011.

Harries, C., Evans, J. S. B. T., & Dennis, I. (2000). Measuring doctors' self-insight into their treatment decisions. *Applied Cognitive Psychology, 14*, 455–477.

Hintzman, D. L. (1988). Judgments of frequency and recognition memory in a multiple-trace memory model. *Psychological Review, 95*, 528–551.

Hoffmann, J. A., von Helversen, B., & Rieskamp, J. (2013). Deliberation's blindsight: How cognitive load can improve judgments. *Psychological Science, 24*, 869–879. http://dx.doi.org/10.1177/0956797612463581.

Hoffmann, J. A., von Helversen, B., & Rieskamp, J. (2014). Pillars of judgment: How memory abilities affect performance in rule-based and exemplar-based judgments. *Journal of Experimental Psychology: General, 143*, 2242–2261.

Hoover, M. A., & Richardson, D. C. (2008). When facts go down the rabbit hole: Contrasting features and objecthood as indexes to memory. *Cognition, 108*, 533–542. http://dx.doi.org/10.1016/j.cognition.2008.02.011.

Huettig, F., Mishra, R. K., & Olivers, C. N. L. (2012). Mechanisms and representations of language-mediated visual attention. *Frontiers in Psychology, 2*, 1–11. http://dx.doi.org/10.3389/fpsyg.2011.00394.

Huettig, F., Olivers, C. N. L., & Hartsuiker, R. J. (2011). Looking, language, and memory: Bridging research from the visual world and visual search paradigms. *Acta Psychologica, 137*, 138–150. http://dx.doi.org/10.1016/j.actpsy.2010.07.013.

Irwin, D. E. (2004). Fixation location and fixation duration as indices of cognitive processing. In J. M. Henderson & F. Ferreira (Eds.), *The interface of language, vision, and action: Eye movements and the visual world* (pp. 105–133). New York, NY: Psychology Press.

Jahn, G., & Braatz, J. (2014). Memory indexing of sequential symptom processing in diagnostic reasoning. *Cognitive Psychology, 68*, 59–97. http://dx.doi.org/10.1016/j.cogpsych.2013.11.002.

Johansson, R., Holsanova, J., Dewhurst, R., & Holmqvist, K. (2012). Eye movements during scene recollection have a functional role, but they are not reinstatements of those produced during encoding. *Journal of Experimental Psychology: Human Perception and Performance, 38*, 1289–1314. http://dx.doi.org/10.1037/a0026585.

Johansson, R., Holsanova, J., & Holmqvist, K. (2006). Pictures and spoken descriptions elicit similar eye movements during mental imagery, both in light and in complete darkness. *Cognitive Science, 30*, 1053–1079. http://dx.doi.org/10.1207/s15516709cog0000.

Johansson, R., & Johansson, M. (2014). Look here, eye movements play a functional role in memory retrieval. *Psychological Science, 25*, 236–242. http://dx.doi.org/10.1177/0956797613498260.

Johnson, T. R., & Krems, J. F. (2001). Use of current explanations in multicausal abductive reasoning. *Cognitive Science, 25*, 903–939.

Johnson, E. J., Schulte-Mecklenbeck, M., & Willemsen, M. C. (2008). Process models deserve process data: Comment on Brandstätter, Gigerenzer, and Hertwig (2006). *Psychological Review, 115*, 263–273. http://dx.doi.org/10.1037/0033-295X.115.1.263.

Juslin, P., Karlsson, L., & Olsson, H. (2008). Information integration in multiple cue judgment: A division of labor hypothesis. *Cognition, 106*, 259–298. http://dx.doi.org/10.1016/j.cognition.2007.02.003.

Juslin, P., Olsson, H., & Olsson, A.-C. (2003). Exemplar effects in categorization and multiple-cue judgment. *Journal of Experimental Psychology: General, 132*, 133–156. http://dx.doi.org/10.1037/0096-3445.132.1.133.

Juslin, P., & Persson, M. (2002). PROBabilities from EXemplars (PROBEX): A "lazy" algorithm for probabilistic inference from generic knowledge. *Cognitive Science, 26*, 563–607. http://dx.doi.org/10.1207/s15516709cog2605_2.

Karlsson, L., Juslin, P., & Olsson, H. (2007). Adaptive changes between cue abstraction and exemplar memory in a multiple-cue judgment. *Psychonomic Bulletin & Review, 14*, 1140–1146.

Karlsson, L., Juslin, P., & Olsson, H. (2008). Exemplar-based inference in multi-attribute decision making: Contingent, not automatic, strategy shifts? *Judgment and Decision Making, 3*, 244–260.

Laeng, B., Bloem, I. M., D'Ascenzo, S., & Tommasi, L. (2014). Scrutinizing visual images: The role of gaze in mental imagery and memory. *Cognition, 131*, 263–283. http://dx.doi.org/10.1016/j.cognition.2014.01.003.

Laeng, B., & Teodorescu, D. (2002). Eye scanpaths during visual imagery reenact those of perception of the same visual scene. *Cognitive Science, 26*, 207–231. http://dx.doi.org/10.1207/s15516709cog2602.

Lagnado, D. A., Newell, B. R., Kahan, S., & Shanks, D. R. (2006). Insight and strategy in multiple-cue learning. *Journal of Experimental Psychology: General, 135*, 162–183. http://dx.doi.org/10.1037/0096-3445.135.2.162.

Lewandowsky, S., & Farrell, S. (2011). *Computational modeling in cognition: Principles and practice*. Thousand Oaks, CA: Sage.

Markman, A. B., Blok, S., Kim, K., Larkey, L., Narvaez, L. R., Stilwell, C. H., et al. (2005). Digging beneath rules and similarity. *Behavioral and Brain Sciences, 28*, 29–30.

Martarelli, C. S., & Mast, F. W. (2013). Eye movements during long-term pictorial recall. *Psychological Research Psychologische Forschung, 77*, 303–309. http://dx.doi.org/10.1007/s00426-012-0439-7.

Mata, R., von Helversen, B., Karlsson, L., & Küpper, L. (2012). Adult age differences in categorization and multiple-cue judgment. *Developmental Psychology, 48*, 1188–1201. http://dx.doi.org/10.1037/a0026084.

Mehlhorn, K., Taatgen, N. A., Lebiere, C., & Krems, J. F. (2011). Memory activation and the availability of explanations in sequential diagnostic reasoning. *Journal of Experimental Psychology: Learning, Memory and Cognition, 37*, 1391–1411. http://dx.doi.org/10.1037/a0023920.

Milton, F., Wills, A. J., & Hodgson, T. L. (2009). The neural basis of overall similarity and single-dimension sorting. *NeuroImage, 46*, 319–326. http://dx.doi.org/10.1016/j.neuroimage.2009.01.043.

Nelson, J. D., & Cottrell, G. W. (2007). A probabilistic model of eye movements in concept formation. *Neurocomputing, 70*, 2256–2272. http://dx.doi.org/10.1016/j.neucom.2006.02.026.

Nosofsky, R. M., & Bergert, F. B. (2007). Limitations of exemplar models of multi-attribute probabilistic inference. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 33*, 999–1019. http://dx.doi.org/10.1037/0278-7393.33.6.999.

Nosofsky, R. M., & Palmeri, T. J. (1997). An exemplar-based random walk model of speeded classification. *Psychological Review, 104*, 266–300.

Nosofsky, R. M., & Palmeri, T. J. (1998). A rule-plus-exception model for classifying objects in continuous-dimension spaces. *Psychonomic Bulletin & Review, 5*, 345–369.

Nosofsky, R. M., Palmeri, T. J., & McKinley, S. C. (1994). Rule-plus-exception model of classification learning. *Psychological Review, 101*, 53–79.

Orquin, J. L., & Mueller Loose, S. (2013). Attention and choice: A review on eye movements in decision making. *Acta Psychologica, 144*, 190–206. http://dx.doi.org/10.1016/j.actpsy.2013.06.003.

Pachur, T., & Olsson, H. (2012). Type of learning task impacts performance and strategy selection in decision making. *Cognitive Psychology, 65*, 207–240. http://dx.doi.org/10.1016/j.cogpsych.2012.03.003.

Payne, J. W., Bettman, J. R., & Johnson, E. J. (1993). *The adaptive decision maker*. New York, NY: Cambridge University Press.

Persson, M., & Rieskamp, J. (2009). Inferences from memory: Strategy- and exemplar-based judgment models compared. *Acta Psychologica, 130*, 25–37. http://dx.doi.org/10.1016/j.actpsy.2008.09.010.

Peterson, M. S., & Beck, M. R. (2011). Eye movements and memory. In S. P. Liversedge, I. D. Gilchrist, & S. Everling (Eds.), *The Oxford handbook of eye movements* (pp. 579–592). New York, NY: Oxford University Press.

Pinker, S., & Prince, A. (1988). On language processing and connectionism: Analysis of a parallel distributed processing model of language acquisition. *Cognition, 28*, 73–193.

Platzer, C., & Bröder, A. (2012). Most people do not ignore salient invalid cues in memory-based decisions. *Psychonomic Bulletin & Review, 19*, 654–661. http://dx.doi.org/10.3758/s13423-012-0248-4.

Platzer, C., & Bröder, A. (2013). When the rule is ruled out: Exemplars and rules in decisions from memory. *Journal of Behavioral Decision Making, 26*, 429–441. http://dx.doi.org/10.1002/bdm.

Platzer, C., Bröder, A., & Heck, D. W. (2014). Deciding with the eye: How the visually manipulated accessibility of information in memory influences decision behavior. *Memory & Cognition, 42*, 595–608. http://dx.doi.org/10.3758/s13421-013-0380-z.

Pothos, E. M. (2005). The rules versus similarity distinction. *Behavioral and Brain Sciences, 28*, 1–49.

Pothos, E. M., & Hahn, U. (2000). So concepts aren't definitions, but do they have necessary *or* sufficient features? *British Journal of Psychology, 91*, 439–450.

Rayner, K. (2009). Eye movements and attention in reading, scene perception, and visual search. *Quarterly Journal of Experimental Psychology, 62*, 1457–1506. http://dx.doi.org/10.1080/17470210902816461.

Rehder, B., & Hoffman, J. E. (2005). Eyetracking and selective attention in category learning. *Cognitive Psychology, 51*, 1–41. http://dx.doi.org/10.1016/j.cogpsych.2004.11.001.

Renkewitz, F., & Jahn, G. (2012). Memory indexing: A novel method for tracing memory processes in complex cognitive tasks. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 38*, 1622–1639. http://dx.doi.org/10.1037/a0028073.

Renkewitz, F., & Jahn, G. (2010). Tracking memory search for cue information. In A. Glöckner & C. Witteman (Eds.), *Foundations for tracing intuition: Challenges and methods* (pp. 199–218). New York, NY: Psychology Press.

Richardson, D. C., Altmann, G. T. M., Spivey, M. J., & Hoover, M. A. (2009). Much ado about eye movements to nothing: A response to Ferreira et al.: Taking a new look at looking at nothing. *Trends in Cognitive Sciences, 13*, 235–236. http://dx.doi.org/10.1016/j.tics.2009.02.006.

Richardson, D. C., & Kirkham, N. Z. (2004). Multimodal events and moving locations: Eye movements of adults and 6-month-olds reveal dynamic spatial indexing. *Journal of Experimental Psychology: General, 133*, 46–62. http://dx.doi.org/10.1037/0096-3445.133.1.46.

Richardson, D. C., & Spivey, M. J. (2000). Representation, space and Hollywood Squares: Looking at things that aren't there anymore. *Cognition, 76*, 269–295. http://dx.doi.org/10.1016/S0010-0277(00)00084-6.

Rieskamp, J., & Otto, P. E. (2006). SSL: A theory of how people learn to select strategies. *Journal of Experimental Psychology: General, 135*, 207–236. http://dx.doi.org/10.1037/0096-3445.135.2.207.

Russo, J. E., Johnson, E. J., & Stephens, D. L. (1989). The validity of verbal protocols. *Memory & Cognition, 17*, 759–769.

Scheibehenne, B., Rieskamp, J., & Wagenmakers, E.-J. (2013). Testing adaptive toolbox models: A Bayesian hierarchical approach. *Psychological Review, 120*, 39–64. http://dx.doi.org/10.1037/a0030777.

Scholz, A., Mehlhorn, K., & Krems, J. F. (in press). Listen up, eye movements play a role in verbal memory retrieval. *Psychological Research*.

Schulte-Mecklenbeck, M., Kühberger, A., & Ranyard, R. (2011). The role of process data in the development and testing of process models of judgment and decision making. *Judgment and Decision Making, 6*, 733–739.

Smith, E. E., Langston, C., & Nisbett, R. E. (1992). The case for rules in reasoning. *Cognitive Science, 16*, 1–40.

Spivey, M. J., & Dale, R. (2011). Eye movements both reveal and influence problem solving. In S. P. Liversedge, I. D. Gilchrist, & S. Everling (Eds.), *The Oxford handbook of eye movements* (pp. 551–562). New York, NY: Oxford University Press.

Spivey, M. J., & Geng, J. J. (2001). Oculomotor mechanisms activated by imagery and memory: Eye movements to absent objects. *Psychological Research Psychologische Forschung, 65*, 235–241. http://dx.doi.org/10.1007/s004260100059.

Tanenhaus, M. K., Spivey-Knowlton, M. J., Eberhard, K. M., & Sedivy, J. C. (1995). Integration of visual and linguistic information in spoken language comprehension. *Science, 268*, 1632–1634.

van Gompel, R. P. G., Fischer, M. H., Murray, W. S., & Hill, R. L. (2007). *Eye movements: A window on mind and brain*. Amsterdam, The Netherlands: Elsevier.

von Helversen, B., Herzog, S. M., & Rieskamp, J. (2014). Haunted by a doppelgänger: Irrelevant facial similarity affects rule-based judgments. *Experimental Psychology, 61*, 12–22. http://dx.doi.org/10.1027/1618-3169/a000221.

von Helversen, B., Karlsson, L., Mata, R., & Wilke, A. (2013). Why does cue polarity information provide benefits in inference problems? The role of strategy selection and knowledge of cue importance. *Acta Psychologica, 144*, 73–82. http://dx.doi.org/10.1016/j.actpsy.2013.05.007.

von Helversen, B., Mata, R., & Olsson, H. (2010). Do children profit from looking beyond looks? From similarity-based to cue abstraction processes in multiple-cue judgment. *Developmental Psychology, 46*, 220–229. http://dx.doi.org/10.1037/a0016690.

von Helversen, B., & Rieskamp, J. (2008). The mapping model: A cognitive theory of quantitative estimation. *Journal of Experimental Psychology: General, 137*, 73–96. http://dx.doi.org/10.1037/0096-3445.137.1.73.

von Helversen, B., & Rieskamp, J. (2009). Models of quantitative estimations: Rule-based and exemplar-based processes compared. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 35*, 867–889. http://dx.doi.org/10.1037/a0015501.