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Feeling-of-Knowing Experiences Breed Curiosity

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A thesis submitted in partial fulfillment of the requirements for the Master of Science degree in Neuroscience

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Abstract

It is well-established that curiosity has benefits for learning. Less is known about potential links between curiosity and memory retrieval. In theoretical work on metacognition it has been argued that retrieval experiences that occur during memory search can exert control over behaviour. States of curiosity, which can be defined as behavioural tendencies to seek out information, may play a critical role in this control function. We conducted two experiments to address this idea, focusing on links between feeling-of knowing (FOK) experiences, memory-search duration, and subsequent information-seeking behaviour. We administered an episodic FOK paradigm that probed memory for previously studied arbitrary face-name pairs and provided a subsequent opportunity to select a subset for restudy. With this set-up, we examined whether unsuccessful retrieval attempts bias restudy choices towards information that received high FOK ratings. Results in Experiment 1 revealed a positive relationship between FOK ratings and the response-times for corresponding judgments. Critically, we observed a similar positive relationship between FOK ratings and restudy choices in both experiments. Moreover, experimental manipulations of cue familiarity, through introduction of entirely novel (Experiment 1) or primed (Experiment 2) faces in the FOK test-phase, had parallel effects on FOKs and information-seeking behaviour. Overall, these findings suggest that metacognitive experiences accompanying unsuccessful retrieval from episodic memory can induce states of curiosity, which exert control over behaviour beyond the immediate retrieval context. As such, curiosity may act as a bond to ensure that memory gaps identified through unsuccessful retrieval adaptively guide future learning.

Keywords

Metacognition, information-seeking; retrieval; metamemory; familiarity

Summary for Lay Audience

The question of what makes us curious is one that captures the attention of scientists and the general public alike. We can easily think of a situation where we were watching a movie and tried to remember the name of an actor for a specific character, but eventually had to admit that we could not recall it. Often present in this scenario is the accompanying feeling that we should have been able to remember this person's name despite being unable to do so at the current time. We can intuitively relate to the idea that such a situation may induce a state of curiosity that motivates us to find out the answer in other ways, perhaps via a Google search. Despite this intuitive appeal, little empirical research on curiosity has investigated its relationship to the subjective feelings that accompany memory retrieval. This link is what the current thesis aimed to address, focusing on a particular subjective experience called a feeling-of-knowing (FOK), in combination with an examination of behavioural expressions of curiosity. A FOK can be defined as the belief that an unrecalable piece of information could be successfully recognized in the future (i.e. "I would know it if I saw it"). Results of the two completed behavioural experiments showed that the degree of an FOK experience for names that had been previously studied in association with faces, but could not be recalled, was closely related to curiosity. Specifically, higher FOK experiences went hand-in-hand with both longer initial memory search and increased tendencies to seek out information about the names in a subsequent restudy phase. Moreover, experimental manipulations of these FOK experiences resulted in parallel effects on memory-search time and information-seeking in the subsequent restudy phase, lending support for a causal role for FOK experiences in driving these behaviours. Overall, the results from this study provide evidence that memory experiences during unsuccessful memory recall can breed curiosity and may facilitate adaptive learning.

Co-Authorship Statement

Dr. Köhler oversaw the project. He assisted in project design, data analysis and interpretation. Additionally, he assisted in the writing of a manuscript based on the two experiments that are included in the current thesis. This manuscript has been submitted for publication and overlaps with some portions of the current thesis document.

Dr. Khan assisted with the planning of follow-up work to be conducted with functional neuroimaging, and he provided access to data-processing pipelines.

Haopei Yang, a Ph.D. candidate in Dr. Köhler's lab, assisted with writing of the manuscript and he provided assistance with the mixed-effects modelling analyses reported in this thesis.

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Introduction

1 Introduction

1.1 Curiosity

Curiosity has become an increasingly studied topic for cognitive psychologists and neuroscientists alike. Contemporary definitions of curiosity emphasize motivational components and suggest that it is a cognitive state characterized by the desire to obtain information through exploration of the environment and through other information-seeking behaviour (Kidd & Hayden, 2015; Gottlieb et al., 2016). This definition depicting state curiosity lends considerable overlap with traditional extrinsic reward processing. Extrinsic reward is known to have motivational consequences (i.e. reward-seeking) that have been suggested to resemble the consequences of information (i.e. information-seeking). Indeed, a recent review (FitzGibbon et al., 2020) highlights the parallels between information and reward, while suggesting that a concept known as incentive salience, which stems from the literature on reward learning (see Berridge, 2012; Anselme & Robinson, 2019), might be a key motivational mechanism behind curiosity. To make this case, the authors present a series of studies that demonstrate how people are willing to sacrifice resources (e.g. money and time) in order to gain access to information about gambling outcomes (Bennett et al., 2016; Rodriguez Cabrero et al., 2019) or answers to trivia questions (Kang et al., 2009), even when this information is non-instrumental, or has no utility. Other findings have shown that people are willing to risk personal harm to receive information that resolves curiosity in a similar manner to which they would take this risk to receive an extrinsic reward (Hsee & Ruan, 2016; Lau et al., 2020). For these reasons the authors posit that information is motivationally salient because, like extrinsic rewards, it carries both hedonic value (i.e. may result in feelings of “liking”) and an incentive salience component. Incentive salience refers to the motivational feeling of “wanting”, which builds up in anticipation of a reward (or information). From this perspective, it is thought that information-seeking and traditional reward-seeking may share overlapping motivational mechanisms.

1.1.1 Curiosity and learning

With the surge in research on curiosity, the close link it shares with learning has become a central topic of investigation. Multiple studies have shown that memory encoding, as well as subsequent consolidation processes, are enhanced when an individual is in a state of curiosity. Studies exploring curiosity-driven memory enhancements do so using a trivia paradigm, with slight variations to better address the specific question in the study. In this general paradigm, participants are presented with trivia questions and are asked if they know the answer, and if not, are asked to indicate their graded level of curiosity for the answer (see Gruber & Ranganath, 2019 for summary of curiosity paradigms and measures). Next, the answer for each question is revealed before the experiment concludes with a final memory test for all the trivia questions. This general set-up allows subsequent test accuracy to be compared to initial curiosity ratings. Findings from a significant number of studies on this topic converge on the result that subsequent memory accuracy is higher for items that were associated with high levels of curiosity, regardless of whether the memory test was given within an hour of encoding (Kang et al., 2009; Gruber et al., 2014; Mullaney et al., 2014; McGillivray et al., 2015; Galli et al., 2018; Ligneul et al., 2018; Stare et al., 2018; Wade & Kidd, 2019), or after a delay spanning from 1 day up to 1 week (Marvin & Shohamy, 2016; McGillivray et al., 2015; Fastrich et al., 2018; Stare et al., 2018). In other words, this convincing evidence supports the suggestion that both encoding and consolidation processes may be enhanced by states of curiosity.

A few of these studies also presented face stimuli, that were not relevant to the trivia task, immediately following the elicitation of curiosity ratings. Subsequent memory for these faces was also probed with an old/new memory test. These studies showed that memory was enhanced for faces that were presented following trivia facts that induced high curiosity, relative to faces that accompanied trivia questions that were given low curiosity ratings (Gruber et al., 2014; Galli et al., 2018; Stare et al., 2018). This finding confirmed that being in a state of curiosity is the critical requirement for memory enhancement, rather than simply being curious about a certain item. Taken together, it is apparent that curiosity and learning share close links. This observation is of particular interest for many

researchers due to its applications for education. Specifically, it is thought that curiosity can be induced in students to better their learning of class material, and thus improve school performance (see Pluck & Johnson, 2011 and Oudeyer et al., 2016 for reviews of the importance of curiosity in education).

At the mechanistic level, there is evidence to suggest that these curiosity dependent effects on learning center on the engagement of reward circuitry, including the substantia nigra/ventral tegmental area (SN/VTA) and the ventral striatum (Kang et al., 2009; Gruber et al., 2014). The seminal study exploring the neural correlates of curiosity with functional magnetic resonance imaging (fMRI) by Kang and colleagues (2009) predicted that engagement of the striatum, a region that was known to track traditional reward signals (Knutson et al., 2000; Knutson et al., 2001; McClure et al., 2004; O'Doherty, 2004; Hare et al., 2008), would also be linked to curiosity. To test this hypothesis, they used a variation of the trivia paradigm described previously. Results showed that activity within the caudate nucleus, a nucleus within the dorsal striatum, increased in response to elevated curiosity. Further, activity within regions related to memory (e.g. the hippocampus) during the time when the answer was revealed, was found to be modulated by curiosity level for questions that were incorrectly guessed. In other words, these regions had higher activity when the participant was being shown a new answer that they had high curiosity for relative to answers they were less curious about.

Building upon this work, Gruber et al (2014) conducted an fMRI study designed to explore curiosity-dependent memory benefits. Results showed that the degree of curiosity was positively correlated with activity within the nucleus accumbens, the main nuclei within the ventral striatum, and within the SN/VTA. Importantly, whether or not a high curiosity item would be later remembered was predicted by activity within the nucleus accumbens, the SN/VTA and the hippocampus. Similarly, inter-individual differences in curiosity-related memory benefits was correlated with the activity in these three regions, along with the functional connectivity between them. Overall, these imaging and behavioural studies provide evidence for a critical link between curiosity and learning, such that memory encoding (and possibly consolidation) is enhanced when someone is in a state of curiosity, likely due to the engagement of the reward circuitry.

1.1.2 Memory retrieval and curiosity

In contrast with this behavioural and mechanistic evidence showing how curiosity can drive learning, little is known about whether there might also be links between memory retrieval and curiosity. An important question to ask in this context is whether retrieval-related processes or experiences can induce a state of curiosity that shapes subsequent information-seeking behaviour. In the present study we aim to address this possibility by examining the relationship between metacognitive retrieval experiences, specifically FOKs, immediate memory search duration, and subsequent information-seeking behaviour.

1.2 Metacognition

In order to understand the links between memory retrieval and curiosity, it is important to turn to the domain of metacognition. This is because research on metacognition has established that unsuccessful retrieval can be experienced in different ways and that such experiences have behavioural relevance. A well-studied example of an experience unique to memory retrieval is the tip-of-the-tongue (TOT) phenomenon (Brown & McNeill, 1966). Another example is the feeling that we might be able to recognize the answer that we cannot recall among multiple alternatives, an experience that is referred to as a feeling-of-knowing (FOK) in the memory literature (Hart, 1965). Such FOK states have been documented in relation to retrieval of semantic information (e.g. “What is the capital city of Ghana?”), as well as retrieval of information from episodic memory (e.g. “What is the name of the boisterous individual I encountered at the party last night?”). Both TOT and FOK experiences have been suggested to guide decisions about when to stop memory search in situations that are characterized by a lack of recall success (e.g. Schwartz, 2001; Singer & Tiede, 2008). Critically, it has also been proposed that they shape subsequent decisions about whether to seek out the information that could not be recalled (Litman et al., 2005, Metcalfe, et al., 2017, Hanczakowski et al., 2014). For example, when a familiar person whose name we cannot recall is a celebrity, we may decide to Google the answer based on the context in which the person was encountered (e.g. a movie). This illustration highlights a potential role for metacognitive experiences

during unsuccessful retrieval in motivating the type of information-seeking behaviour that defines curiosity, both during and after memory search.

Theoretical approaches to metacognition have made an important distinction between its monitoring and control functions (see Koriat, 2007 and Moulin & Souchay, 2014, for review). Extant research of both functions has focused on various retrieval experiences, including, but not limited to, FOK and TOT states (see e.g. DeCaro & Thomas, 2019 for judgements-of-learning, JOL). In the context of retrieval, the monitoring aspect encompasses processes related to assessing the progress and outcome of memory search. Metacognitive control, by contrast, pertains to how the experiences that emerge during monitoring guide behavioural choices during and following memory search.

1.2.1 Monitoring function of metacognition

Empirical research on metacognition, and in particular metacognition of memory (termed metamemory) has focused mostly on the monitoring aspect. This work has confirmed that judgements related to monitoring hold validity (e.g. Nelson, 1984), and has also explored what processes contribute to the monitoring of memory. In regards to the latter, early views proposed that monitoring could tap into a lingering memory trace, and the strength of this trace informed the resulting judgements (Hart, 1965; Hart, 1967; see Koriat, 2007 for review of this “direct-access view”). More recent work, however, has provided convincing evidence supporting the notion that FOKs are actually based on heuristic inferences, rather than a direct-access to a memory trace (e.g. Schwartz & Metcalfe, 1992; Koriat & Levy-Sadot 2001; see Koriat, 2007 for review of this “experience-based monitoring”). Specifically, it has been observed that two main heuristic cues inform people’s monitoring-related judgements of metamemory: cue familiarity and target accessibility. Studies have shown that when cues are made to be more familiar, typically by priming of a cue prior to study, subsequent FOK ratings are higher relative to unprimed cues (Reder, 1987; Reder & Ritter, 1992, Schwartz & Metcalfe, 1992; Metcalfe et al., 1993). Related work has demonstrated that FOKs increase as the amount of partial information about a target that is recalled increases (i.e. remembering that someone’s name begins with “M”), a variable termed target accessibility (Koriat & Levy-Sadot, 2001).

1.2.2 Control function of metacognition

Decisions about the termination of memory search, and about subsequent information-seeking, speak to the control function of metacognitive retrieval experiences, which, to date, have been less frequently studied.

One domain in which control functions of metacognitive retrieval experiences have been studied concerns the duration of unsuccessful memory search. The outcome from numerous studies converges on the finding that these variables are positively correlated. Of most relevance for the current research are studies that revealed this relationship in FOK paradigms (but see e.g. Schwartz, 2001 for similar results in research on TOT). These studies have typically focused on the relationship between FOK experiences and memory search during retrieval of semantic information. Gruneberg et al. (1977) first demonstrated that response times for the report of unsuccessful recall were longer for items for which participants indicated the presence of an FOK experience relative to items where such an experience was absent. Subsequent work also revealed that this relationship holds when a graded scale is used to probe for FOK experiences (Costermans et al., 1992). In other research on this topic, Nelson and colleagues showed that even response times for incorrect answers in response to factual questions were positively correlated with the strength of FOK experiences (Nelson & Narens, 1980; Nelson et al., 1984). Although it is difficult to disentangle cause and effect in the relationship between the duration of memory search and FOKs (see Metcalfe, 2009), the findings reviewed are compatible with the view that FOK experiences exert control on behaviour at the level of gating the extent of memory search.

In discussions of the functional role of metacognitive retrieval experiences it has also been suggested that they may contribute to the control of behaviour outside of the context of the memory judgment at hand (Koriat, 2007). One behavioural domain in which their control functions may play out is in guiding subsequent information-seeking behaviour in the external environment as a reflection of curiosity.

Although this idea has intuitive appeal, extant research that speaks to it directly is limited. The few studies that addresses the idea that metacognitive experiences can guide

information-seeking, primarily do so with a focus on the TOT state. Litman et al. (2005) presented participants with general knowledge questions and asked them to indicate whether they knew or did not know the answer, or whether they were in a TOT state (i.e. “The answer is on the tip-of-my-tongue”). Following these questions, participants provided a curiosity rating for each fact and, in a final phase of the experiment, they were allowed to explore the answers to any of the questions that had been presented earlier. Results showed that facts which induced a TOT experience received higher curiosity ratings and were more frequently explored, relative to those participants knew or did not know. Similar results were obtained by Metcalfe et al. (2017) when they probed information-seeking immediately following a TOT experience for semantic facts.

To our knowledge, only a single study (Hanczakowski et al., 2014) has explored the guiding of information-seeking behaviour in relation to FOK experiences. This study focused on restudy-choices that immediately followed FOK judgments in an episodic-memory paradigm for arbitrary paired words that had been encountered in an initial study-phase. Results showed that participants’ restudy choices were correlated with FOK judgement on an item-by-item basis, such that items with unsuccessful recall of the associate and higher FOK ratings were selected for restudy more frequently than those with lower ratings. This finding suggests that the control function of FOKs may indeed include information-seeking behaviour. Given that behavioural choices directly followed the memory judgments on an item-by-item basis in this study, however, its results do not speak to whether information-seeking is influenced by prior FOK experiences in lasting ways. More specifically, it does not provide insight into situations where the behavioural decision is made outside of the context of an immediately preceding unsuccessful memory search. Moreover, it also does not address any potential relationship between control functions of FOK that pertain to duration of internal memory search and those that pertain to information-seeking behaviour in the external environment. To the extent that memory search in itself can be considered to be a type of information-seeking behaviour, it is possible that both control functions rely on shared mechanisms related to curiosity.

1.3 Current Study

In the current study we aimed to explore the relationship between FOK experiences and curiosity, by assessing participants' memory search duration during FOK judgement phase and by examining subsequent information-seeking choices. To address these relationships, we adopted a behavioural paradigm previously employed in our research on experiential aspects of episodic FOKs (Fiacconi et al., 2017). This paradigm makes use of face-name pairs, rather than word-pairs, to assess FOKs. This modification in stimuli is important as face-name associations arguably have more ecological validity than word-pairs. FOKs and other metacognitive retrieval experiences, such as impressions of familiarity, are frequently triggered in everyday life by the faces or names of people we encounter.

In the paradigm employed in the current study, participants were tasked with attempting to recall a target name that had been paired with the image of a person's face in an initial memorization phase. Following this recall attempt, they were asked to provide a graded FOK judgement. Once they had completed this FOK test phase for each face-name pair, participants were exposed to the face cues once again, and were given the opportunity to seek out a limited number of the associated names for restudy. This study design allowed us to assess immediate and longer-lasting effects of FOKs on information-seeking behaviour. We anticipated to find that the strength of FOK experiences would not only be correlated with participants' immediate memory search duration, but that they would also predict participants' subsequent choice behaviour when offered opportunities for restudy.

In order to provide support for a potential causal role of FOK experiences in shaping curiosity, we also sought to influence these FOK experiences by experimentally manipulating cue familiarity. Towards this end, we included entirely novel face cues in combination with previously studied faces in Experiment 1 and primed versus unprimed face cues in Experiment 2. We predicted that the well-documented boost of FOK experiences through increased cue familiarity would lead to corresponding increases in immediate memory-search duration and in subsequent information-seeking.

Methods and Results

2 Experiment 1

In Experiment 1, we assessed the relationship of FOK experiences to the control of behaviour, employing previously studied and novel face stimuli during the FOK test phase. We offered unlimited time for recall so as to optimize evaluation of the relationship between FOKs and response times at the time of a retrieval attempt, as well as between response times and subsequent information-seeking behavior. In this experiment, we predicted that participant FOK ratings would correlate with both their response times and information-seeking decisions. Further, we predicted that novel faces would receive lower FOK ratings, and that this would be paralleled by shorter response times and less frequent restudy.

2.1 Methods

2.1.1 Participants

In Experiment 1, 45 undergraduate and graduate student participants were recruited from Western University to take part in the study in exchange for monetary compensation. The data of 36 participants (26 female; age range 18 – 25) were included in our final analyses, with the remaining 9 excluded due to insufficient distribution of FOK values (i.e. less than 5 instances for 2 of the 5 scale values on unsuccessful recall trials). This exclusion criterion was introduced to ensure a sufficient number of trials in each participant for correlation analyses. All experimental procedures were approved by the Non-Medical Research Ethics Board at the University of Western Ontario.

2.1.2 Materials

All face stimuli used in this paradigm were taken from the Chicago Face Database (Ma et al., 2015) and were screened using the published norming data to ensure uniformity in terms of neutral emotional expression and perceived attractiveness. Selection criteria included a rating below 3.5 (on a 7-point scale) on all emotional expressions (afraid, angry, happy, sad, surprised, disgusted, and threatening), and attractiveness ratings

between 2 and 5 on the 7-point scale. Of the faces that met these criteria, a total of 78 faces were randomly selected for experimental use.

For this study, 156 English names were selected from the U.S. Census Bureau 1990 (<https://catalog.data.gov/dataset/names-from-census-1990>) for use in the study and recognition phases of the experiment. The total set was composed of 78 male first names, 78 female first names, and 156 surnames of medium frequency in the population (frequency rates between 0.15% and .5% for first names, and between 0.05% and 0.5% for surnames, respectively). Explicit efforts were made to avoid any overlap in pronunciation or spelling between the names selected (e.g. Julie and Julia or Robert and Roberts), and to avoid any reference to celebrities. First and last names were then paired to create 156 different full names of comparable length (11 to 17 characters; $M = 12.9$, $SD = 1$), and comparable syllable count (3 to 5).

For the purpose of counterbalancing, 78 faces were paired with two sets of names, with each participant assigned to one set. Assignment of names to faces was pseudo-random, with the restriction that sex be matched. The remaining non-assigned 78 names served as novel lures in the forced choice recognition memory test. Of the 78 matched face-name pairs, 52 were randomly assigned to be memorized (20 Caucasian females, 20 Caucasian males, 6 African-American females and 6 African-American males), and the remaining 26 (10 Caucasian males, 10 Caucasian females, 3 African-American males and 3 African-American females) were used as novel stimuli in the FOK test phase.

2.1.3 Procedure

The experiment was administered using Psychophysics Toolbox Version-3 (<http://www.psychtoolbox.org/>) and MATLAB R2018b (The MathWorks, Natick, MA) with a 14-inch laptop. It included four different phases (Figure 1), taking approximately 35 minutes for completion.

In the first part, participants were asked to memorize a set of 52 face-name pairs. Each pair appeared on the screen for 3 s with the face appearing above the name. Following a

500 ms interstimulus interval (ISI), the next pair was presented. Participants were offered a break halfway through this study phase.

The second phase served for memory testing and began immediately after completion of the study phase. Here, participants saw the 52 previously studied faces, along with 26 novel ones, for an unlimited duration, and they were instructed to try and recall the name associated with each face. On each trial, they responded to two self-paced memory judgement prompts. The first judgment required a yes/no response concerning the perceived success of their attempted name recall. The second judgement required FOK ratings; participants were asked to estimate the likelihood that they would be able to recognize the name associated with the face prompt, if provided, on a 5-point Likert scale (from 1/very unlikely to 5/very likely). As per the suggestion of Koriat (1993), this judgement was elicited for all faces presented, regardless of the participants' indication of perceived success on any given trial. Following these two judgements, the next face would appear on the screen after a 500 ms ISI.

After the FOK test phase was completed, participants entered the restudy phase. Here they were given an opportunity to select up to 39 of the 78 faces previously used as prompts in the FOK test phase for exposure to the associated name. Note that, unbeknownst to participants, 52 of the 78 faces would have been memorized initially, with the other 26 only having served as lures in the FOK test phase. Thus, this exposure constituted a restudy or a first study opportunity, respectively. If the participant chose to see the name for a given prompt, the face-name pair would appear on the screen for 3 s. After this interval, or if they chose not to see the name, the next face would appear, following a 500 ms ISI. Throughout this phase, participants were also exposed, in the corner of the screen, to a countdown of how many more face-name pairs were still available for exposure. If the participant reached the maximum of 39 possible exposures, they were forced to respond 'no' to the restudy prompt for the remainder of trials.

In the fourth and last phase of the experiment, participants completed a self-paced forced-choice recognition test for the names of all 78 faces used in the FOK test phase, which could constitute faces initially memorized as well as faces employed as lures, regardless

of whether they had been selected for exposure in the restudy phase or not. In this recognition test, three name options were presented for each face, namely the name corresponding to the face, a previously seen name that belonged to one of the other previously studied faces, and an entirely novel name. The three choices were matched for sex and were presented randomly in one of three positions.

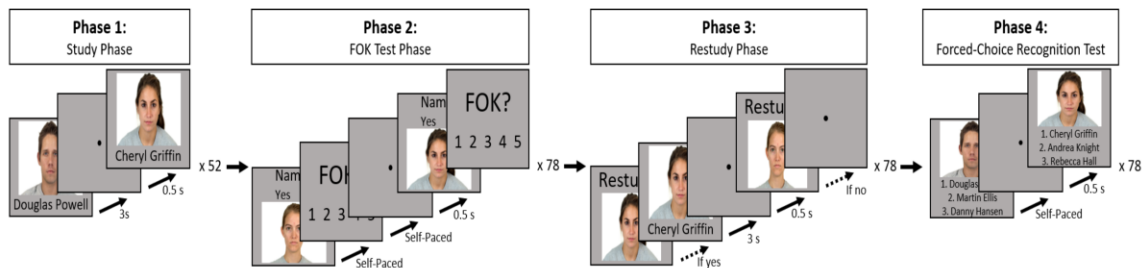


Figure 1: Behavioural paradigm in Experiment 1. The experiment consisted of 4 consecutive phases. In the study phase participants memorized face-name pairs. In the FOK test phase, participants were asked to recall the names associated with previously studied and novel face cues, and provide corresponding FOK ratings. In the restudy phase, participants selected a subset of the faces encountered in the FOK test phase for further study of the associated names. In the final phase, participants completed a 3-alternative forced-choice recognition-memory test for face-name associations.

2.1.4 Mixed-Effects Modelling

The first mixed-effects model employed in Experiment 1 was one that was used to model participant response times in the FOK test phase. To do this, a null hypothesis model that included random intercept terms for subject and item (i.e. face-name pair) was constructed. This null model was compared to the most maximal model that was able to converge successfully, as per the recommendation of Barr et al. (2013). This model featured, in addition to the random intercept terms, fixed effect terms for item status (previously studied versus novel), FOK rating and the interaction between these factors. Additionally, a random slope variance term for FOK dependent on subject was included as an additional random term. This full model significantly reduced deviance compared to the null model, $\chi^2(4) = 388.82, p < 0.001$. Next, we assessed whether any terms could

be trimmed from this model. To do this we compared the Bayesian Information Criteria (BIC) for a trimmed model with the BIC value for an untrimmed model. We used a BIC decrease of 2 units (which constitutes an improvement in model fit) as the minimum standard to justify trimming a term, as recommended by Raftery (1995), and done by similar studies in this area (DeCaro and Thomas, 2019). Following this guideline, we were unable to trim any of the terms from the model, thus making the model described previously the final model that was used to predict response times in Experiment 1.

To develop the restudy choice model, we conducted the same procedure we performed while modelling response times. Again, the null hypothesis model included only random intercept terms for subject and item. This null model was compared to a maximal model that featured, in addition to the random intercept terms, fixed effect terms for item status (previously studied versus novel) and FOK rating, along with interaction terms between these factors. In addition, random slope variances for FOK, status and the interaction were included dependent on both subject and items (i.e. 6 random slope terms). The complete model significantly reduced deviance compared to the null model, $\chi^2(17) = 96.63, p < 0.001$. We then trimmed non-significant effects (see above for criterion) allowing for a more parsimonious final model. The first term we trimmed, was the random slope variance for the interaction on subject ($\Delta\text{BIC}_{df=3} = 17$). Next, the random slope variance for the interaction term between FOK and item status on item was trimmed ($\Delta\text{BIC}_{df=3} = 23.6$). Finally, the random intercept for subject was trimmed ($\Delta\text{BIC}_{df=1} = 7.9$), leaving our final mixed-effects model for restudy choices in Experiment 1.

2.2 Results

2.2.1 Do FOK ratings show validity in the current experimental paradigm?

In our first analysis we examined whether the FOK ratings obtained in our experiment carried validity by virtue of being sensitive to the study manipulation. This analysis leveraged the fact that not all faces for which FOK ratings were obtained had been studied during the memorization of face-name pairs. Indeed, the average FOK ratings

were significantly higher for previously studied than for novel face cues (see Table 1 for mean FOK ratings), $t(35) = 12.20$, $p < 0.001$, $d = 2.03$.

A second way to confirm the validity of FOK ratings is to show that they have predictive value for subsequent accuracy in recognition-memory judgments of names. Towards this end, we computed gamma correlations for individual participants between their FOK ratings and performance on the recognition memory test (Nelson, 1984). Importantly, in order to control for any influence of repeated study, this calculation was completed only for trials in which names had not been selected for restudy. The average gamma correlation between FOK rating and recognition memory performance for all trials (*Mean gamma* = 0.14, *SD* = 0.34) was significantly greater than zero, $t(34) = 2.46$, $p = 0.019$, $d = 0.42$. This significant relationship was also present when only initially studied face name-pairs were considered in the correlation (*Mean gamma* = 0.18, *SD* = 0.33), $t(34) = 3.20$, $p = 0.003$, $d = 0.54$. These results provide further support for the validity of the FOK ratings provided by participants.

Table 1: Summary of behavioural data for Experiments 1 and 2. Data are shown as Mean (SD). Recognition accuracy is for trials not selected for restudy

		Experiment 1		
		No Perceived Recall Success	Perceived Recall Success	All Trials
Previously Studied	Proportion of trials	0.92 (0.12)	0.08 (0.12)	
	FOK rating	2.26 (0.49)	4.51 (0.65)	2.42 (0.51)
	Proportion restudied	0.48 (0.10)	0.68 (0.38)	0.49 (0.09)
	Subsequent accuracy	0.47 (0.12)	0.56 (0.36)	0.48 (0.12)
	Response time (ms)	4441 (2372)	6981 (3860)	4493 (2308)
Novel	Proportion of trials	0.98 (0.05)	0.02 (0.05)	
	FOK rating	1.54 (0.36)	4.36 (0.72)	1.59 (0.41)
	Proportion restudied	0.41 (0.15)	0.59 (0.45)	0.41 (0.14)
	Subsequent accuracy	0.36 (0.12)	0 (0)	0.36 (0.12)
	Response time (ms)	4097 (2312)	6092 (4273)	4101 (2309)
Total	Proportion of trials	0.94 (0.09)	0.06 (0.09)	
		Experiment 2		
		No Perceived Recall Success	Perceived Recall Success	All Trials
Primed	Proportion of trials	0.76 (0.17)	0.24 (0.17)	
	FOK rating	2.68 (0.48)	4.30 (0.53)	3.08 (0.45)
	Proportion restudied	0.50 (0.11)	0.67 (0.26)	0.54 (0.10)
	Subsequent accuracy	0.45 (0.18)	0.58 (0.43)	0.47 (0.18)
Unprimed	Proportion of trials	0.86 (0.11)	0.14 (0.11)	
	FOK rating	2.24 (0.34)	4.26 (0.52)	2.49 (0.35)
	Proportion restudied	0.38 (0.11)	0.67 (0.28)	0.42 (0.09)
	Subsequent accuracy	0.48 (0.14)	0.70 (0.33)	0.49 (0.14)
Total	Proportion of trials	0.83 (0.12)	0.17 (0.12)	

2.2.2 Are FOK ratings related to response times during attempts to recall the names corresponding to face cues?

The first marker of motivated information-seeking that we examined was that of response times for the initial memory-recall attempts. Specifically, to calculate response times, we focused on the combined duration of the pair of judgments (perceived success of recall and FOK ratings) participants were asked to provide on each trial in the FOK test phase. To assess the relationship between FOK ratings and response times (Figure 2A) we calculated Spearman correlations for each participant, between values on both dimensions. We found a positive correlation when all trials were included ($Mean\ rho = 0.35, SD = 0.21$), but also when trials without perceived successful recall were excluded ($Mean\ rho = 0.35, SD = 0.19$; note that in the large majority of trials, recall was perceived to be unsuccessful, as evident in Table 1). In both cases, the mean Spearman correlation was found to be larger than zero, $t(35) = 9.96, p < 0.001, d = 1.66$ and $t(35) = 10.98, p < 0.001, d = 1.83$, respectively (Figure 2B).

Comparing the average response times for the memory judgements for unsuccessful recall trials between face cues that had previously been encountered and those that were novel, we found significantly longer response times for the former set of trials (see Table 1 for mean response times), $t(35) = 2.40, p = 0.02, d = 0.40$. Taken together, these results suggest, in line with prior findings (e.g. Costermans et al., 1992), that the duration of search during memory judgments is related to the resulting FOK ratings, and is affected by prior exposure to the cues and the information that is to be recalled.

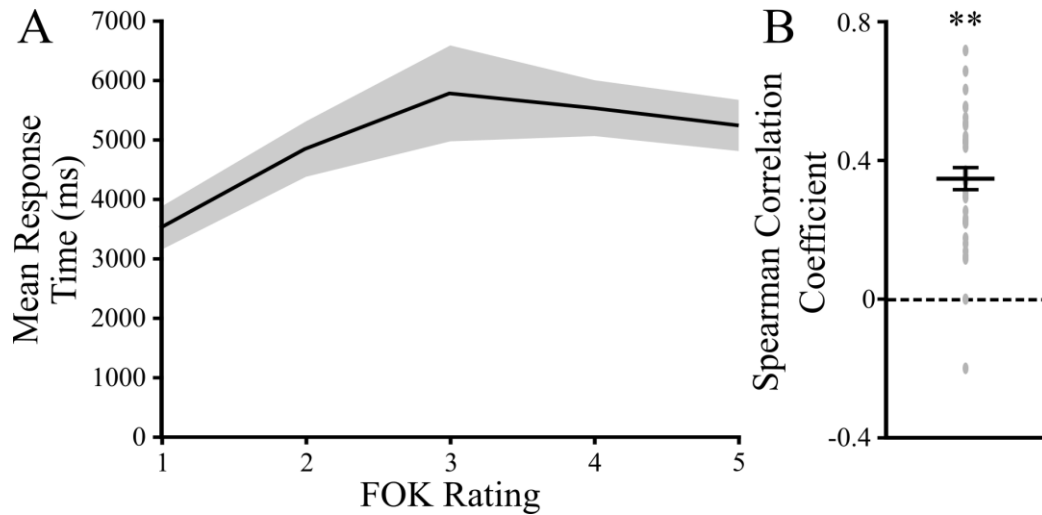


Figure 2: Response times for judgements without perceived recall success during the FOK test phase in Experiment 1. A) Mean response times as a function of ratings on the 5-point FOK scale. B) Spearman correlations between FOK ratings and response times calculated across items for individual participants. The mean Spearman correlation, shown by the black bar, was significantly greater than zero.

Shaded area = ± 1 SEM. Error bars = ± 1 SEM. ** $p < 0.001$.

2.2.3 Is the impact of prior exposure on response times during recall attempts tied to FOK ratings?

While the analyses just summarized suggest that response times for search during memory judgements are related to prior exposure of the face cues, they do not provide an indication as to whether this relationship is tied to FOK ratings or independent. To address this question, we conducted a generalized mixed-effects model procedure on response times in R (R Core Team, 2013).

The selected model we used for our analysis contained fixed effect terms representing FOK rating, item status (whether it had been initially studied or not) and the interaction between these variables. Details about the development of this model, such as the trimming of non-significant effects, and the random effect terms included in it, are described in section 2.1.4. Importantly, as we were particularly interested in situations in which recall was ultimately unsuccessful (and where there was no natural endpoint to

memory search), trials with perceived successful recall during the FOK test phase were excluded from this analysis.

With this modelling, we found that, for cues that were not studied in the initial study phase, participants' FOK ratings positively predicted the response time during their memory judgements (see Table 2). For items that had been studied initially, FOK ratings still predicted response times, albeit with a weaker relationship, as evident by the significantly negative interaction between FOK rating and item status. Critically, the non-significant effect of item status indicated that there was no contribution of prior cue exposure on response times that was independent of FOK ratings.

Table 2: Results of the mixed-effects model used to predict the response times during the FOK test phase in Experiment 1.

Fixed Effects		β (SE)	t	p
Intercept		3.02 (0.44)	6.89	< 0.001
FOK		1.33 (0.18)	7.28	< 0.001
Cue Status		0.20 (0.16)	1.21	0.23
FOK x Cue Status (Initially Studied)		-0.20 (0.087)	-2.33	0.02
Random Effects		Variance (SD)		
Intercept	Item	0.10 (0.32)		
	Subject	1.37 (1.17)		
Slope - Subject	FOK	0.23 (0.48)		
Residual		0.15 (0.38)		

2.2.4 Are FOK ratings related to subsequent information-seeking?

As a marker of information-seeking, we focused on participants' choices to study select face-names pairs in the restudy phase that followed the FOK test phase. In this part, participants were given an opportunity to select a limited number of face-name pairs when provided with faces as cues. The corresponding names had either been memorized initially during the study phase or had not been encountered yet (in the case of faces that were novel in the FOK test phase). Our primary interest was to determine whether these choices in information-seeking behaviour could be predicted by the ratings provided in

the FOK test phase, and whether they were affected by prior study. If the relationship between FOK experiences and information-seeking extends (Figure 3A) beyond the time of a recall attempt, as we hypothesized, then gamma correlation coefficients between FOK experiences and information-seeking choices should be positive, paralleling the relationship observed between FOK ratings and memory search time. We found that the mean gamma between FOK and restudy choices for all trials (*Mean gamma* = 0.27, *SD* = 0.40) was significantly greater than zero, $t(35) = 4.13$, $p < 0.001$, $d = 0.69$. When the correlation was performed only for trials without successful perceived recall (*Mean gamma* = 0.26, *SD* = 0.37) the relationship remained significantly positive, $t(35) = 4.24$, $p < 0.001$, $d = 0.71$ (Figure 3B). These results confirm that an increase in FOK experiences is associated with a subsequent increased tendency to seek out the information that could not be recalled.

Next, we asked whether information-seeking in the restudy phase was affected by whether the information that could not be recalled in the FOK test phase had in fact been studied previously. To address this question, we compared the proportion of initially studied pairs selected for restudy to the proportion of novel pairs selected for study. This comparison, when performed for all trials, revealed that previously studied face-name pairs were selected for restudy at a significantly greater rate than novel pairs (see Table 1 for proportions), $t(35) = 2.83$, $p = 0.008$, $d = 0.47$. This difference remained significant when the comparison was restricted to trials in which prior recall of names was perceived to be unsuccessful (see Table 1 for proportions), $t(35) = 2.81$, $p = 0.008$, $d = 0.47$. These findings support our hypothesis that FOK ratings are related to the information that participants subsequently choose to seek. Moreover, they suggest that pertinent choices are impacted by the familiarity of the cues, biasing behavioural choices towards previously studied information. Overall, these results highlight parallels in the relationship between FOK experiences and search behaviour during memory retrieval, and that between FOK experiences and subsequent information-seeking behaviour.

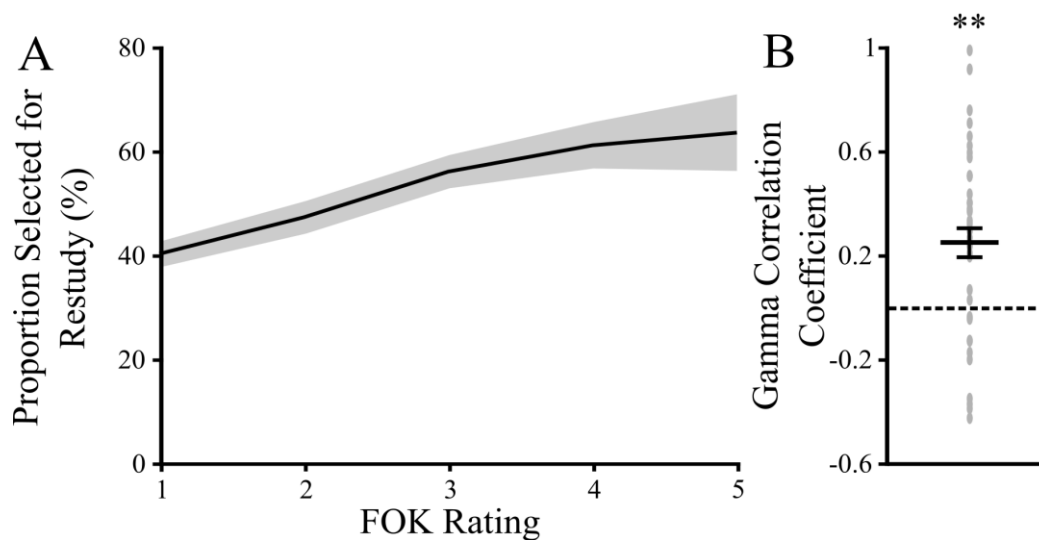


Figure 3: Selection of items without prior perceived recall success during the restudy phase in Experiment 1. A) Mean proportion of trials selected in the restudy phase as a function of ratings on the 5-point FOK scale. B) Gamma correlations between FOK ratings and choices for restudy calculated across items for individual participants. The mean gamma correlation, shown by the black bar, was significantly greater than zero. Shaded area = ± 1 SEM. Error bars = ± 1 SEM. ** $p < 0.001$.

2.2.5 Is the impact of prior exposure to face cues on subsequent information-seeking tied to FOK ratings?

As in our analyses of response time data, the analyses focusing on the relationship between prior exposure and subsequent restudy choices do not provide information as to whether this effect is tied to FOK ratings or independent. To address this question, we conducted another mixed-effects modelling analysis, similar to the one performed with response times. As before, only trials in which recall was perceived to be unsuccessful were included.

The selected model contained fixed effect terms representing item familiarity, FOK rating and the interaction between these factors (see section 2.1.4 for further methodological detail on model selection). This mixed-effect model revealed that participants' FOK rating positively predicted subsequent restudy choices for items that were initially studied but not those encountered for the first time during the FOK test phase (see Table 3). For

previously studied items, the log-odds of restudying the name associated with a face cue increased by 0.36 for each rating point on the 5-point FOK rating scale. In simpler terms, this means that for a face cue that was rated one point higher on the FOK rating scale than another item, the odds of restudying the higher-rated cue were 1.43 times as large. Critically, the effect of item status was non-significant in these analyses, indicating that there was no contribution of prior cue exposure on subsequent information-seeking behaviour that was independent of FOK ratings.

Table 3: Results of the mixed-effects model used to predict subsequent information-seeking choices in Experiment 1.

Fixed Effects		β (SE)	z	p
Intercept		-0.61 (0.19)	-3.20	0.0014
FOK		0.14 (0.095)	1.43	0.15
Cue Status		-0.24 (0.21)	-1.12	0.26
FOK x Cue Status (Initially Studied)		0.22 (0.10)	2.16	0.030
Random Effects		Variance (SD)		
Intercept	Item	0.013 (0.11)		
Slope - Item	Cue Status (Novel)	0.014 (0.12)		
	Cue Status (Initially Studied)	0.095 (0.31)		
	FOK	0.00 (0.00)		
Slope - Subject	Cue Status (Novel)	0.38 (0.62)		
	Cue Status (Initially Studied)	0.091 (0.30)		
	FOK	0.025 (0.16)		

2.2.6 Is information-seeking related to response times during prior recall attempts?

Inasmuch as our results point to a link between FOK ratings and response times during the memory decisions, as well as between FOK ratings and subsequent information-seeking behaviour, an important question that remains to be answered is whether participants showed an increased tendency towards studying items for which they spent more time searching for an answer. A comparison of the average response time for memory judgements during the FOK test phase for faces later chosen for restudy ($M =$

4635 ms, $SD = 2278$ ms) and those not chosen for restudy ($M = 4167$ ms, $SD = 2355$ ms) revealed significantly longer search times for items that were later restudied, $t(35) = 2.81$, $p = 0.008$, $d = 0.47$. This relationship between search times and subsequent restudy choices also held when analyses were restricted to cues that had previously been encountered with associated names during memorization ($M = 4730.53$ ms, $SD = 2251.50$ ms versus $M = 4252.80$ ms, $SD = 2555.68$ ms), $t(35) = 2.15$, $p = 0.04$, $d = 0.36$., and when trials with perceived successful recall were excluded as well ($M = 4711$ ms, $SD = 2283$ ms versus $M = 4236$ ms, $SD = 2659$ ms), $t(35) = 2.14$, $p = 0.04$, $d = 0.36$. This pattern of results suggests that the mechanisms through which FOKs shape immediate memory search and those through which they guide subsequent information-seeking may be overlapping.

3 Experiment 2

We conducted a second experiment with two main goals in mind. Our first goal was to replicate the predictive relationship between FOK ratings and subsequent information-seeking we observed in Experiment 1. Our second goal was to assess the impact of cue familiarity on the relationship between FOK ratings and subsequent information-seeking behaviour in a more selective manner. In Experiment 1 we manipulated whether items encountered during the FOK test phase had previously been studied in association with corresponding names or not. As such the behavioural differences we observed in relation to this manipulation could be due to prior exposure to the face cues, the memorization of corresponding names, or a combination of these two factors. A consideration of the role of cue familiarity in and of itself is important because an extensive literature suggests that this familiarity can serve as one of the sources for the inferential heuristic process that has been proposed to underlie FOK judgments (see Schwartz & Metcalfe, 1992; Koriat & Levy-Sadot, 2001). We predicted that priming of face cues would enhance cue familiarity and inflate FOK ratings. As in Experiment 1, we predicted that this effect on FOK ratings would be paralleled in the restudy choices, leading to more frequent subsequent information-seeking for primed items.

3.1 Methods

3.1.1 Participants

Thirty-three English-speaking undergraduate participants from Western University took part in Experiment 2 in exchange for course credit. The data of 29 participants (15 female; age range 17 – 22) were used in all analyses, with the remaining 4 participants being excluded due to an insufficient distribution of FOK values across the scale (see exclusion criterion from Experiment 1). Again, all experimental procedures were approved by the Non-Medical Research Ethics Board at the University of Western Ontario.

3.1.2 Materials

The same set of 78 face stimuli from Experiment 1 was used in Experiment 2, along with 52 additional faces that still met the criteria detailed for Experiment 1. Once again, two sets of pseudo-randomly matched face-name pairs were created. In each set, 78 face-name pairs (30 Caucasian males, 30 Caucasian females, 9 African American males and 9 African-American females) were randomly selected to be studied in the study phase. The remaining 78 unmatched names served as novel lures in the forced-choice recognition test. Of the 78 faces to be memorized, 26 were chosen to be primed in the priming phase (a third of each demographic). The priming phase also featured the remaining 52 unpaired faces as distractors (20 Caucasian males, 20 Caucasian females, 6 African American males, 6 African-American females). Note that the rationale for this counterbalancing parallels that employed in Experiment 1. Participants were randomly assigned to one of the two stimuli sets prior to beginning the experiment.

3.1.3 Procedure

The behavioural paradigm employed was very similar to the one used in Experiment 1. This time, however, the paradigm, which was administered on a 15.6-inch laptop, proceeded through five different phases and took approximately 45 minutes to complete (Figure 4). In the added first phase (i.e. the priming phase) participants were exposed to 26 of the faces that would later reappear in the study phase, alongside 52 distractor faces. During this self-paced part, participants were instructed to rate the likeability of the person in each image on a 5-point scale. The phase structure of the remaining parts of Experiment 2 was identical to that in Experiment 1, including a study phase, an FOK test phase, a restudy phase, and a final forced-choice recognition test.

The procedural details of phases two to five were identical to those in Experiment 1 except for the inclusion of primed and unprimed items in the study phase (78 face-name pairs, 26 being primed), and two modifications in the FOK test phase. One modification was related to the composition of the list of face cues. Instead of being presented with previously studied and non-studied face cues (i.e. our manipulation in Experiment 1), participants were only exposed to faces that had previously been studied, with a third of

items having been primed prior to study. Participants were not explicitly told that some phases from the priming phase would reappear in subsequent phases. A second modification concerned a more controlled timing of trials in the FOK test phase. Specifically, participants were exposed to each face cue for 3 s, rather than for an unlimited duration, before being directed to the subsequent memory-judgement prompts.

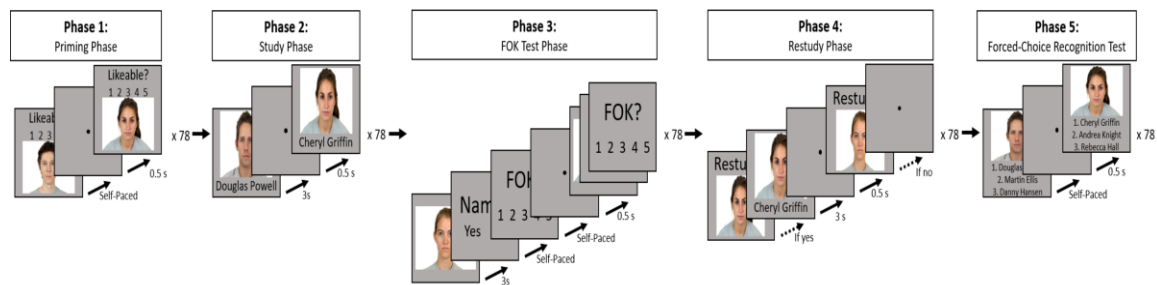


Figure 4: Behavioural paradigm in Experiment 2. The experimental design was similar to Experiment 1 with several notable exceptions. It included an additional priming phase for a subset of faces to be memorized, but no introduction of novel face cues in the FOK test phase or the restudy phase. There was also restricted presentation times for the face cues in the FOK test phase.

3.1.4 Mixed-Effects Modelling

To develop a mixed-effects model for Experiment 2, a similar procedure was used to that to develop the restudy choice model in Experiment 1. Adding all the fixed effect parameters and interaction term, plus all 6 additional slope variance terms (see Experiment 1 methods for the specific terms), improved the fit of the model relative to a null model with only random intercept terms, $\chi^2(7) = 109.12, p < 0.001$. Next, the random slope variance for the FOK and status interaction on subject ($\Delta\text{BIC}_{df=3} = 22.4$) and on item ($\Delta\text{BIC}_{df=3} = 22.6$) were both trimmed from the model. Finally, the random intercept for subject was trimmed from the model ($\Delta\text{BIC}_{df=1} = 7.4$), leaving the model to be used in the final analysis.

3.2 Results

3.2.1 Are FOK ratings and final recognition-memory judgments sensitive to the manipulation of familiarity of the face cues through priming?

In the first analyses for this experiment, we compared the FOK ratings and subsequent forced-choice recognition memory performance for primed faces with those for unprimed faces, to ensure that our priming manipulation had the expected effects. As expected, average FOK ratings for primed cues were significantly greater than average FOK ratings for unprimed cues (see Table 1 for mean FOK ratings), $t(28) = 8.53$, $p < 0.001$, $d = 1.58$. Also as expected, forced-choice recognition-memory accuracy for primed faces was no different than the accuracy for unprimed faces (see Table 1 for recognition memory accuracies), $t(28) = 0.83$, $p = 0.41$, $d = 0.15$. Like in Experiment 1, this comparison only considered pairs that were not selected for restudy ($M = 54.02\%$ of all trials, $SD = 5.87\%$), to ensure that participants had equal exposure to the primed and unprimed face-name pairs. This pattern is in line with the basic notion that priming of face cues, without concurrent presentation of associated names, increases the familiarity of the face cue, which in turn inflates FOK ratings, but does not provide additional information for subsequent recognition of face name pairs. In other words, these findings confirm that our priming procedure was successful in manipulating familiarity as a cue that ‘drives’ FOK ratings (Reder, 1987; Reder & Ritter, 1992, Schwartz & Metcalfe, 1992; Metcalfe et al., 1993; Koriat & Levy-Sadot, 2001).

3.2.2 Do FOK ratings show validity in the current experimental paradigm?

If participants’ FOK ratings hold predictive validity, they should be related to future memory performance, as they were in Experiment 1. Again, we computed a gamma correlation coefficient, for each participant, between FOK ratings and subsequent recognition-memory accuracy, focusing only trials that were not selected for restudy. As expected, and as observed in Experiment 1, we found that the mean of these gamma correlations ($Mean\ gamma = 0.17$, $SD = 0.27$) was significantly greater than zero, $t(28) = 3.48$, $p = 0.0017$, $d = 0.65$.

3.2.3 Are FOK ratings related to subsequent information-seeking?

Next, we examined whether the relationship between FOK experiences and subsequent information-seeking behaviour that we observed in Experiment 1 could be replicated even when variability in response times for FOK judgments was limited through restriction of exposure to the face cues. Again, we assessed the relationship of FOK ratings with restudy choices (Figure 5A) through the computation of gamma correlations between these variables for individual participants. When this calculation was performed for all trials, the mean gamma correlation was significantly greater than zero (*Mean gamma* = 0.41, *SD* = 0.32), $t(28) = 6.81$, $p < 0.001$, $d = 1.27$, and it remained significantly greater than zero when trials with perceived recall success were excluded from the calculation (*Mean gamma* = 0.36, *SD* = 0.27; note that in the majority of trials, recall was perceived to be unsuccessful, see Table 1 for perceived success frequency), $t(28) = 7.17$, $p < 0.001$, $d = 1.33$ (Figure 5B). Furthermore, we found no significant difference in response times for unsuccessfully recalled items that were subsequently restudied relative to those that were not, although there remained a trend ($M = 2994$ ms, $SD = 1106$ ms versus $M = 2820$ ms, $SD = 1080$ ms, respectively), $t(28) = 1.99$, $p = 0.06$, $d = 0.37$. As expected, the overall variability in response time was significantly reduced in Experiment 2 (*mean SD* = 2018 ms, $SD = 726$ ms) relative to Experiment 1 (*mean SD* = 2940 ms, $SD = 1598$ ms), $t(51.06) = 3.09$, $p = 0.003$, $d = 0.74$. Together, these analyses show that despite reductions in the variability in response times, FOK ratings remained closely tied to restudy choices, such that cues evoking greater FOK were restudied more often.

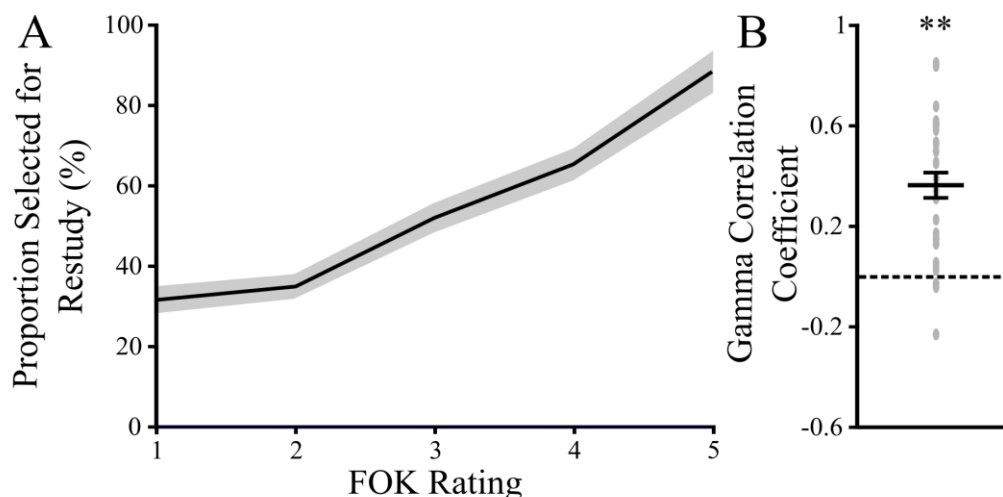


Figure 5: Selection of items without prior perceived recall success during the restudy phase in Experiment 2. A) Mean proportion of trials selected in the restudy phase as a function of ratings on the 5-point FOK scale. B) Gamma correlations between FOK ratings and choices for restudy calculated across items for individual participants. The mean gamma correlation, shown by the black bar, was significantly greater than zero. Shaded areas = ± 1 SEM. Error bars = ± 1 SEM. ** $p < 0.001$.

3.2.4 Is information-seeking influenced by priming of face cues?

In order to investigate our second goal of the study, we compared the proportion of face-name pairs with primed face cues that were selected for restudy, with the proportion of pairs with unprimed face cues that were restudied. This comparison closely paralleled how we examined the impact of prior memorization of face name-pairs on information-seeking behaviour in Experiment 1 but addressed the impact of cue familiarity more directly. Our analysis revealed that participants chose to restudy the names associated with primed faces at a more frequent rate than the names corresponding to unprimed faces (see Table 1 for restudy proportions), $t(28) = 4.36$, $p < 0.001$, $d = 0.81$. This pattern also held when we restricted the analysis to trials in which perceived recall was unsuccessful in the FOK test phase (see Table 1 for restudy proportions), $t(28) = 4.44$, $p < 0.001$, $d = 0.82$. Taken together these results suggest that cue familiarity, a factor that has previously been shown to influence FOKs in numerous studies (e.g. Schwartz and

Metcalf, 1992; Metcalfe et al., 1993; Koriat & Levy-Sadot, 2001), also influenced subsequent information-seeking behaviour.

3.2.5 Is the relationship between priming and information-seeking tied to FOK ratings?

The analyses presented on the relationship between priming and subsequent restudy choices so far do not provide information as to whether this effect is tied to FOK ratings or independent. To address this question, a mixed-effects modelling analysis was performed. A similar procedure was used to develop the model as in Experiment 1. Specifically, it included fixed effect terms for FOK rating, cue familiarity and the interaction between these factors (see section 3.1.4 for details of model development). With this model, we found that restudy choices were predicted by FOK ratings for all items, regardless of the level of familiarity of the cue (see Table 4). For unprimed items, the odds that an item with a given FOK rating would be selected for restudy increased to almost 1.5 times that of an item with a FOK rating 1-point less. For primed items, the odds increased by 1.75 for each FOK rating. The odds, however, were not significantly different for primed as compared to unprimed items, as evident by the non-significant interaction between priming and FOK. Finally, there was no significant difference in the odds that highly familiar cues would be restudied compared to those with low familiarity, independent of FOK rating. Overall, these results suggest that the influence of cue familiarity on information-seeking is closely tied to FOK ratings.

Table 4: Results of the mixed-effects model used to predict subsequent information-seeking choices in Experiment 2.

Fixed Effects		β (SE)	z	p
Intercept		-1.39 (0.18)	-7.86	< 0.001
FOK		0.38 (0.065)	5.75	< 0.001
Cue Status		-0.058 (0.30)	-0.20	0.84
FOK x Status (Primed)		0.18 (0.11)	1.65	0.010
Random Effects		Variance (SD)		
Intercept	Item	0.0056 (0.075)		
Slope - Item	Cue Status (Unprimed)	0.040 (0.20)		
	Cue Status (Primed)	0.031 (0.18)		
	FOK	0.022 (0.15)		
Slope - Subject	Cue Status (Unprimed)	0.19 (0.44)		
	Cue Status (Primed)	0.060 (0.25)		
	FOK	0.00 (0.00)		

Discussion

4 Discussion

4.1 Summary

We conducted two experiments that aimed to elucidate links between experiential aspects of memory retrieval and curiosity. Specifically, we examined links between metacognitive FOK experiences and duration of ongoing memory search, subsequent information-seeking, and their relationship. In each experiment we employed an episodic FOK paradigm with face-name pairs that was followed by a restudy phase, which provided means to determine whether FOK experiences bias subsequent information-seeking behaviour towards information that participants could not recall but that they expected to be able to recognize.

Results in Experiment 1 replicated the well-established positive relationship between the FOK ratings participants provided and corresponding response times. Critically, we observed a similar positive relationship between FOK ratings and subsequent information-seeking, as reflected in restudy choices under conditions in which such opportunities were limited. This finding was replicated in Experiment 2 under conditions in which the duration participants were allowed to view a memory cue during the retrieval attempt was constrained. Moreover, our experimental manipulations of FOK experiences through alterations in cue familiarity also had parallel effects on information-seeking behaviour in both experiments. In Experiment 1, participants showed higher FOKs for previously studied than novel face cues. This effect on FOKs went hand in hand with longer response times and a bias in subsequent information-seeking for faces that were initially studied compared to those that were novel. In Experiment 2, faces that had been primed prior to initial study were given higher FOK ratings, and were also selected more frequently for subsequent restudy than unprimed faces. Mixed-effects modelling revealed that the observed differences in search time (in Experiment 1) and information-seeking behaviour (i.e. away from novel items in Experiment 1 and toward primed items in Experiment 2) that resulted from our experimental manipulations were indeed tied to the effects they exerted on FOK ratings. Overall, these findings suggest

that FOK experiences at retrieval have pervasive motivational consequences on information seeking that reflect state curiosity and that can be understood within the theoretical framework of metacognition that emphasize its control function.

4.2 Relation to research on metacognitive control functions

The present results replicate and extend the outcome of prior research that has addressed the control function of FOKs as metacognitive experiences. As discussed in section 1.2.2, numerous studies have reported correlations between FOK experiences and the duration of attempted recall in semantic FOK paradigms (Gruneberg et al., 1977; Nelson & Narens, 1980; Nelson et al., 1984; Costermans et al., 1992). Experiment 1 shows that this relationship also holds for episodic FOK experiences. Further, past research has also revealed a relationship between FOK experiences and information-seeking behaviour as reflected in restudy choices in an episodic FOK paradigm (Hanczakowski et al., 2014). Notably, however, this relationship was previously demonstrated under conditions in which these choices immediately followed an initial recall attempt for the same item. The current experiments reveal that this motivational consequence of FOK experiences is lasting and continues to shape information-seeking behaviour even outside of the immediate context of an unsuccessful memory search. Similar to Hanczakowski et al. (2014), the current experiments also show that the impact of cue familiarity on FOKs, particularly with the more selective priming manipulation in Experiment 2, is paralleled by an increase in subsequent restudy choices. Notably, in Experiment 1, the initially studied items that participants chose to seek out more often were the majority of items. In Experiment 2, however, participants chose primed items more frequently for restudy, and these were the minority of items during the FOK test phase. This pattern of results across experiments lends support to the conclusion that the manipulation of cue familiarity, rather than the composition of the list, is the factor that drives the observed biases in information-seeking. The mixed-effects models we conducted add to this evidence by suggesting that the experiential aspect of FOKs plays a critical role in the control of behaviour.

4.3 Relationship to research on curiosity

Although on the surface decisions to terminate memory search reflect behaviour that is clearly different from decisions that pertain to seeking out opportunities for further study, the present results suggest that there may be shared motivational mechanisms underlying both of these seemingly distinct behaviours. Of most relevance, Experiment 1 revealed strong parallels in the effects of the cue-familiarity manipulation on search time and restudy choices, with both effects being tied to FOK experiences. Moreover, items chosen for restudy had longer memory-search durations than those not chosen. While this pattern of results does not establish the presence of shared mechanisms with certainty, they invite this interpretation when considered in the context of work on curiosity.

State curiosity is defined in direct relation to information-seeking and is thought to motivate behaviour that resolves uncertainty, with successful access to critical information providing a reward (Kidd & Hayden, 2015; Gottlieb et al., 2016; Gottlieb & Oudeyer 2018; Gruber & Ranganath, 2019; FitzGibbon et al., 2020). Although curiosity is typically defined with reference to exploration of the external environment in an attempt to acquire information or knowledge (Berlyne, 1966; Gottlieb et al., 2013), such a definition could also be applied to ‘internal’ memory search. In a nutshell, memory search also involves information-seeking that aims to resolve uncertainty. Metacognitive retrieval experiences that arise during this search may trigger motivational mechanisms that could drive ongoing retrieval efforts as well as future behaviour geared towards further exploration of the external environment. Future research may build on this curiosity-based framework so as to identify the suggested shared motivational mechanisms. For example, future imaging studies could determine whether the engagement of reward circuitry predicts both types of information-seeking behaviour (see section 4.4.2 for further discussion on this future direction).

4.3.1 Links to other work on curiosity and metacognition

4.3.1.1 Tip-of-the-tongue (TOT) state

Other findings from research on metacognition indicate that the reported links between retrieval experiences and curiosity may not be limited to FOKs. Indeed, a similar relationship has been documented for the TOT phenomenon (Litman et al., 2005; Metcalfe et al., 2017). As previously detailed in section 1.2.2, these studies both report higher curiosity and more frequent exploration for items that had induced a TOT state. While these prior findings on TOT align with our findings on FOK, there are critical differences between these metacognitive experiences. Namely, TOT studies typically employ a semantic memory paradigm with binary options for participants to indicate their metacognitive experience (i.e. “I’m having a TOT” versus “I’m not having a TOT”), whereas our studies utilize episodic FOK paradigm with a graded metacognitive scale. The semantic versus episodic distinction is important as studies have found evidence in support of the suggestion that metacognitive experiences for these memories differ. Specifically, studies of patients with Alzheimer’s Disease, schizophrenia and frontal lobe lesions have shown that episodic metacognition is impaired while semantic metacognition remains intact (Bacon et al., 2001; Schnyer et al., 2004; Souchay et al., 2006; Souchay, 2007). Imaging studies have shown that differing patterns of brain activity support each metacognitive experience (Reggev et al., 2011; Elman et al., 2012). Finally, behavioural work has shown dissociations in metacognitive efficiency between each domain within individual participants (e.g. Mazancieux et al., 2020).

Beyond the episodic versus semantic distinction, theorists also emphasize that there are important differences between TOT and FOK experiences (see Brown, 1991 for review). In particular, FOKs assess the likelihood of future recognition, while TOT probes for one’s confidence of eventual free recall. This divergence may explain research that has observed both high FOK ratings for items that did not induce a TOT state and a presence of a TOT experience despite a low FOK rating (Yaniv & Meyer, 1987). Due to this discrepancy, metacognitive researchers emphasize the importance of examining the control functions of both FOK and TOT. The parallel findings of relationships between metacognition and curiosity, between past studies on TOT and ours on FOK, suggest that

information-seeking can be found, not just following a TOT experience but also subsequent to the report of a high FOK.

4.3.1.2 Judgements-of-learning (JOL)

Research on judgements-of-learning (JOL) suggests that a positive relationship between metacognitive experiences and curiosity is, however, not ubiquitous across all metacognitive judgements. DeCaro & Thomas (2019) had participants attempt to recall members of previously studied word-pairs, using the other pair-members as cues.

Following this recall attempt, participants provided a JOL rating, in response to a JOL prompt, that required participants to estimate the likelihood that they could successfully learn a word-pair during a future study phase. The experiment also included a restudy phase that required participants to select a subset of items for further memorization.

Results revealed a significant correlation between reported JOL experiences and restudy choices. Unlike in the current study and in research on TOTs, however, the correlation between metacognitive ratings and restudy choices was found to be negative, such that items with lower JOL ratings were restudied more frequently than those with higher ratings. This pattern of findings across studies raises the interesting question as to what component-processes trigger the motivational mechanisms that increase subsequent information-seeking behaviour (see section 4.4.3 for speculation about promising candidate processes). This question deserves careful consideration in future research involving the examination of information-seeking following systematic manipulation of different types of memory judgments.

4.3.2 Interpretation of results within theories of curiosity

Within the broader literature on curiosity, the current findings can be interpreted in the recently proposed Prediction, Appraisal, Curiosity and Exploration (PACE) framework, which aims to provide a theoretical foundation for understanding links between curiosity and memory in terms of cognitive processes and their underlying neural mechanisms (Gruber & Ranganath, 2019). Most relevant for the current findings is the proposal that curiosity is driven by prediction errors, which can take the form of either the detection of a novel context or the detection of an information gap. The proposed link between

information gaps and curiosity dates back to Loewenstein's influential work, which emphasized that information gaps can increase curiosity (Loewenstein, 1994). Recent work has added to this notion by suggesting that curiosity is highest when this information gap is small enough to be judged as possible to be closed, a state known as the Region of Proximal Learning (Metcalf & Kornell, 2003; Metcalf & Kornell, 2005; Metcalf et al., 2017). In the context of FOK judgments, the unsuccessful recall that typically precedes them may also be considered an instance of identifying an information gap, or within the PACE framework, as an instance of a prediction error. The degree of the FOK experience may reflect the perceived size of this information gap. Our observation that the tendency to restudy items was largest for those that induced high FOKs is in line with the idea that curiosity may peak when an item is in the Region of Proximal Learning.

The PACE framework also suggests that the detection of a novel context can fill the role of a prediction error that drives curiosity (Gruber & Ranganath, 2019). In line with this suggestion is a significant literature showing that humans tend to preferentially seek out novelty in the environment (Smock & Holt, 1962; Althoff & Cohen, 1999; Ryan et al., 2000; Ryan & Cohen, 2004; Wittmann et al., 2007; Hannula et al., 2012). This effect is so salient it forms the basis of the Visual-Paired Comparison (VPC) task (Fantz, 1964), a paradigm commonly used to assess memory in non-verbal populations (e.g. infants or non-human primates). An interesting consequence of the way the behavioural paradigm from Experiment 1 in the current study was structured, is that we were able to examine response times and subsequent information-seeking behaviour in relation to whether an item had been previously studied or was novel. Results showed both behavioural markers were biased away from novelty and towards familiar items (i.e. longer response times and more frequent restudy for studied items). This finding suggests that novelty may not always be the most powerful driver of information-seeking. Specifically, in situations where small information gaps and outright novelty are present, our results indicate that the presence of information gaps may trigger curiosity to a greater extent than the detection of novelty.

4.4 Limitations and Future Directions

4.4.1 Difficulties in disentangling cause and effect

While we provide evidence in support of a relationship between FOK experiences and the control of behaviour as reflected in response time during memory search and in subsequent restudy choices, we recognize that it remains difficult to establish causality in this observed relationship. Notably, it has been suggested that response times may not necessarily be the consequence of FOKs but could also be a heuristic clue that informs them (see Koriat, 2007 and Metcalfe, 2009, for discussion). For restudy choices, concerns about cause and effect may be less pressing in the current study, given that they followed the expression of FOKs in a separate experimental phase. The results of our experimental manipulation of FOKs provides additional evidence that gives credence to a causal interpretation, again particularly for information-seeking behaviour during restudy. By virtue of introducing entirely novel (Experiment 1) or primed faces (Experiment 2) in the FOK test phase, we were able to decrease or increase FOKs, respectively, and influence information-seeking in a parallel fashion. Definitive evidence for a casual role could be established through direct manipulations of the neural mechanisms that drive information-seeking behaviour. As noted, interactions between brain regions that form the reward circuitry, which involve dopamine as their primary neurotransmitter, are closely tied to curiosity. As such, pharmacological manipulations of dopamine may allow for the assessment of a causal relationship between FOKs and the information-seeking behaviour probed in the current study. A related prediction is that the pharmacological alteration of dopamine levels (e.g. through the dopamine D2 receptor antagonist haloperidol) would lead to a decoupling between FOKs, search times, and subsequent restudy choice behaviour (see Clos et al., 2019, for a suitable study design).

4.4.2 Establishing that shared mechanisms may drive the behaviours

The pattern of findings in the current study suggests the possibility, but does not provide definitive evidence, that memory search and subsequent information-seeking are driven by overlapping motivational mechanisms, as previously discussed. To address this question, we propose a future fMRI study designed to explore the neural correlates of

these behaviours. Specifically, we suggest that a comparable behavioural paradigm could be administered to a participant in the MR scanner. Critically, functional data could be collected during the FOK test phase and analysed to see whether the engagement of any regions predicts both the duration of the FOK judgement (including the preceding recall attempt), and the subsequent restudy choice. In line with the curiosity-based framework we outlined previously, we hypothesize that increasing metacognitive FOK experiences be tied to an increasing engagement of areas that compose the reward circuitry in the brain (i.e. the ventral striatum and the VTA), which prior studies have already shown to track curiosity in other task contexts (Kang et al., 2009; Gruber et al., 2014). If this prediction holds true, activity in regions might in turn also drive ongoing memory search (as a form of ‘internal’ information-seeking) and predict subsequent exploration of the external environment.

4.4.3 Uncovering the specific processes in an FOK judgement responsible for inducing curiosity

Another avenue of research building upon these findings could focus on uncovering which aspect of the FOK test phase is necessary to induce curiosity, as observed in the present study. To explore this idea, participants could perform a phase structure similar to the behavioural paradigm used in the present study but make differing judgements in the phase that required FOK judgments preceding restudy. The bias in information-seeking towards studied items demonstrated here could be used as a marker for increased curiosity across different judgements (e.g. simply judging the familiarity of the face as opposed to judging whether one could recognize the corresponding name in a recognition test). Possible candidate processes include the recall attempt, the prospective nature of a FOK experience, or the retrieval-related processes involved in making memory judgments more broadly. The recall attempt might be a critical component for triggering curiosity as it is related to the identification of an information gap, a known driver of curiosity (Loewenstein, 1994). Another process that has been shown to generate curiosity is the process of making a prediction (Brod & Breitwieser, 2019), something involved in an FOK judgement due to its prospective nature. Thus, these two aspects of our current paradigm are promising candidates for triggering curiosity in memory judgments that

deserve further empirical investigation. Specifically, a future study could task participants with either providing FOK judgements with or without a preceding recall attempt or providing a retrospective memory judgement (e.g. judging familiarity) with or without a recall attempt. Assessing the degree of bias towards seeking previously studied as opposed to novel information across task conditions could provide evidence that would speak to which component processes trigger curiosity in the manner we observed.

4.5 Implications for education

The results of the current study have implications for education. Current work in the area of metacognitively-guided learning emphasizes that people can use JOLs to help decide what items (i.e. parts of the to-be-learned material) would benefit from further study (see Metcalfe, 2009 and Metcalfe, 2014 for review). Evidence from some studies have revealed negative correlations between JOLs and restudy choices (e.g. DeCaro & Thomas, 2019), while theoretical work points to further study of items in the RPL as the optimal strategy to see maximum learning benefits (e.g. Metcalfe & Kornell, 2003). In other words, extant evidence indicates that studying items with high JOLs, that are not yet learned, may be the optimal study focus for students, as these topics are the ones that are likely to be the most easily mastered.

This type of learning strategy, however, may fail to make optimal use of students' states of curiosity. In light of the well-documented benefits that dopamine increases have for encoding and consolidation of memories (Lisman & Grace, 2009; Shohamy & Adcock, 2010; Lisman et al., 2011), and the evidence demonstrating the involvement of dopaminergic regions in curiosity (Kang et al., 2009; Gruber et al., 2014), the importance of being able to stimulate students' curiosity to improve their learning is critical. Results from the current study indicate that inducing FOK experiences may be a good way to stimulate curiosity and the information-seeking behaviours that define it. Thus, by encouraging students to seek out the study material based on FOKs within a particular range, rather than JOL experiences, may lead to increased curiosity, and in turn to improved learning. This learning improvement could be attributed to the dopamine-dependent encoding benefits that are tied to states of curiosity induced by metacognitive retrieval experiences.

4.6 Conclusion

In conclusion, the present study revealed that curiosity is not only intimately tied to learning but also has links to episodic memory retrieval. The evidence presented argues in favour of the general notion that metacognitive experiences accompanying unsuccessful retrieval from episodic memory can induce states of curiosity that exert control over information-seeking behaviour beyond the immediate retrieval context. From this perspective, curiosity may act as a bond that ensures that memory gaps identified through unsuccessful retrieval can adaptively guide future learning.

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