Motivation as a Lens for Understanding Information-seeking Behaviors

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Abstract

■ Most prior research characterizes information-seeking behaviors as serving utilitarian purposes, such as whether the obtained information can help solve practical problems. However, information-seeking behaviors are sensitive to different contexts (i.e., threat vs. curiosity), despite having equivalent utility. Furthermore, these search behaviors can be modulated by individuals' life history and personality traits. Yet the emphasis on utilitarian utility has precluded the development of a unified model, which explains when and how individuals actively seek information. To account for this variability and flexibility, we propose a unified information-seeking framework that examines information-seeking through the lens of motivation. This unified model accounts for integration across individuals' internal goal states and the salient features of the environment to influence information-seeking behavior. We propose that information-seeking is determined by motivation for information, invigorated either by instrumental utility or hedonic utility, wherein one's personal or environmental context moderates this relationship. Furthermore, we speculate that the final common denominator in guiding information-seeking is the engagement of different neuromodulatory circuits centered on dopaminergic and noradrenergic tone. Our framework provides a unified framework for information-seeking behaviors and generates several testable predictions for future studies. ■

INTRODUCTION

Information has its own value. Individuals constantly seek information to guide their behaviors (Kelly & Sharot, 2021), sparking researchers to conceptualize these processes as value-based reward-seeking in service of utilitarian purposes. However, simple models of value-based decision-making fall short of describing the variety of information-seeking behaviors seen in everyday life. For example, individuals will often avoid valuable information or seek information that has no obvious value for guiding behaviors, such as trivia answers or learning how magic tricks work (Gruber & Ranganath, 2019). Prior research has begun to explain the diversity of information-seeking and the role of contextual variance (Eschmann, Pereira, Valji, Dehmelt, & Gruber, 2023; Kelly & Sharot, 2021; Soroya, Farooq, Mahmood, Isoaho, & Zara, 2021; Bromberg-Martin & Monosov, 2020; White et al., 2019), yet there has not been a unified model that captures how and when individuals actively seek out information. Here, we propose a framework of information-seeking through the lens of motivation—drawing upon conceptualizations of these processes spanning social psychology, cognitive psychology, and neuroscience—that accounts for both internal drive states and external contextual factors that influence information-seeking behaviors (Figure 1).

Most prior research on information-seeking has focused on the instrumental utility of information—the intrinsic value of information that can be used to guide approach-related decisions (Kelly & Sharot, 2021; Sharot & Sunstein, 2020). For example, individuals actively seek information about Covid-19 or other illnesses so that they can take preventative actions to protect themselves. However, the instrumental utility of information alone cannot explain the variety of information-seeking behaviors. To account for this variability, recent research suggests that individuals seek information because information can also elicit positive affect, which is known as the hedonic utility of information (Kelly & Sharot, 2021). Here, we propose that both instrumental and hedonic utility of information can invigorate a high motivational state to acquire information. By considering motivational drive as the key factor initiating and propagating information-seeking, we can better conceptualize how other cognitive states—such as judgment of learning, curiosity, and perceived agency—drive information-seeking by influencing either instrumental or hedonic utility. In this review, we will summarize the diverse factors that lead to either high or low motivational states to actively acquire information, and we detail how a given contextual state can shape the translation of utility into motivation to execute information-seeking behaviors. Central to this theoretical framework is that utility alone, either instrumental or hedonic, is insufficient to explain information-seeking behaviors. Rather, different contextual states either driven by one's personal history, temperament, or external factors explain variability in information-seeking.

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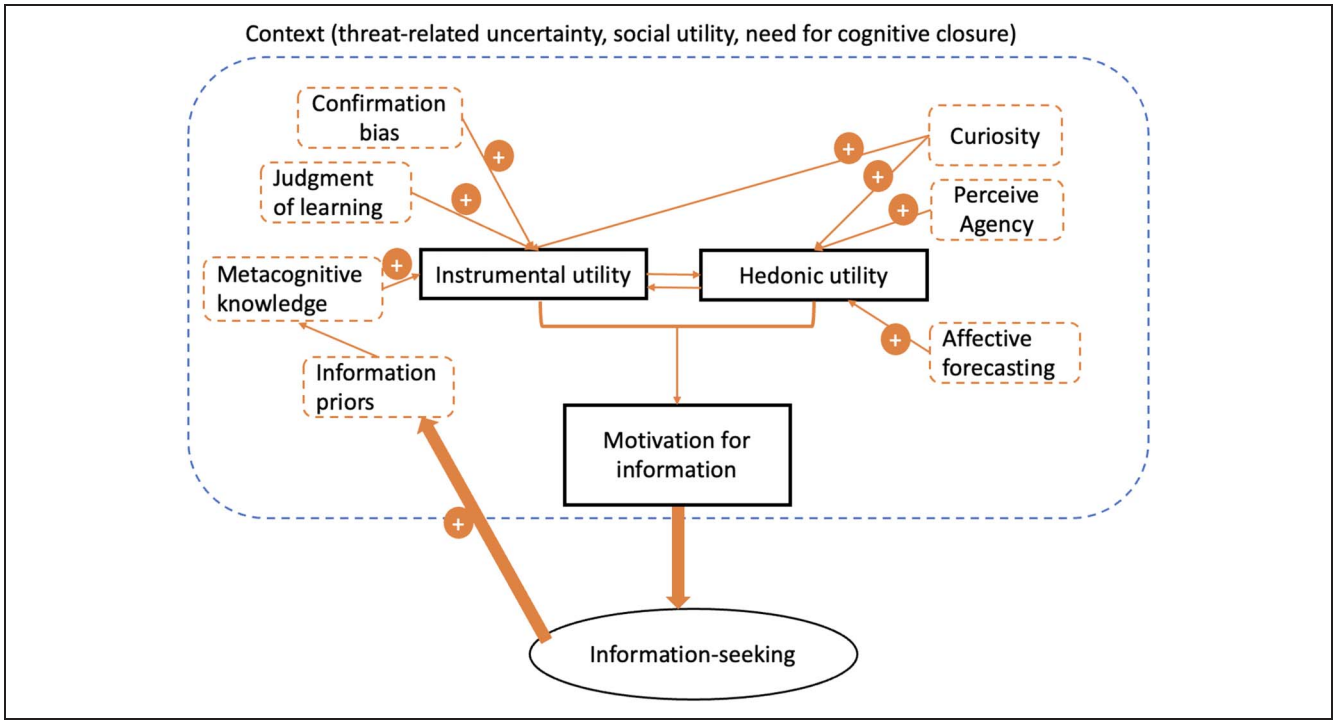

Figure 1. A unified model of information-seeking. We propose an information-seeking framework that integrates individuals' motivational state with contextual factors to determine whether people seek or avoid information. We suggest that the instrumental and hedonic utilities of information are the primary motivational factors influencing information-seeking behaviors and that other factors may influence these utilities positively or negatively.

Finally, to understand the underlying mechanisms of information-seeking, in this review, we will also construe these psychological and behavioral factors through the lens of neuromodulatory systems underlying motivation highlighted in animal models and human neuroimaging (Figure 2). Prior work suggests that motivation-related circuit is involved in information-seeking. It is suggested that midbrain dopamine neurons signal information prediction errors in predicting the opportunity to gain knowledge (Brydevall, Bennett, Murawski, & Bode, 2018). In line with this assertion, research has shown the ventral tegmental area (VTA) and the nucleus

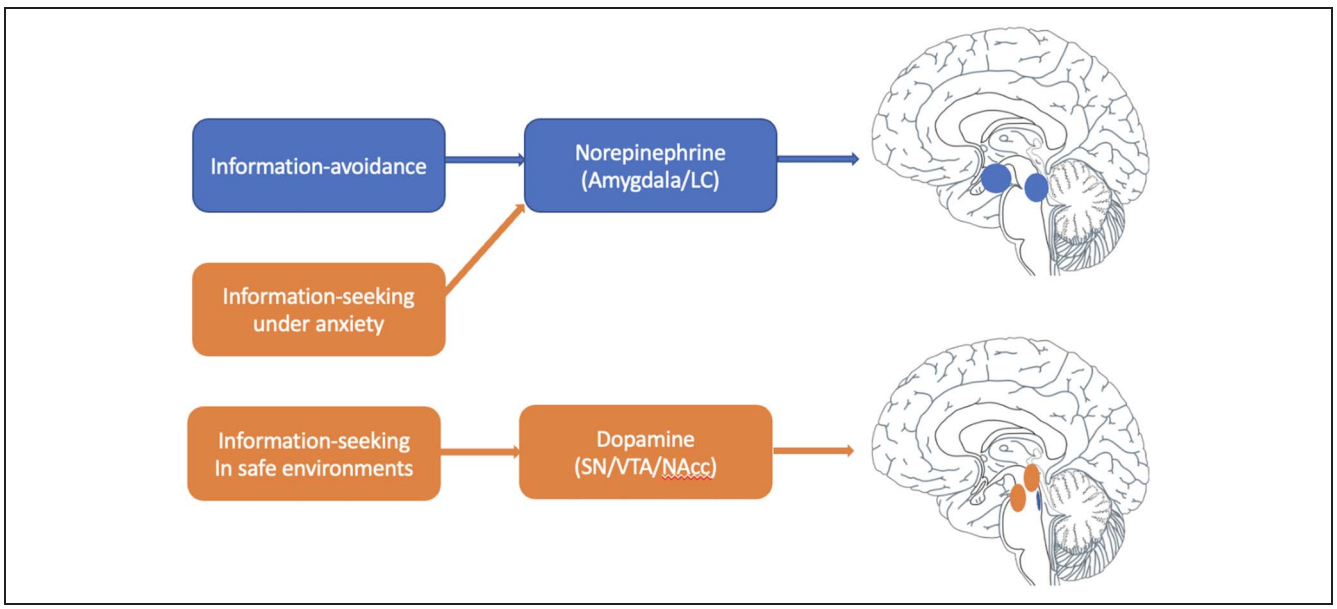

Figure 2. Neuromodulatory system involved in information-seeking. We propose that dopamine is involved in information-seeking whereas norepinephrine is involved in information avoidance.

accumbens (NAcc), core regions within the dopamine circuit, are more active during information-seeking (Bromberg-Martin & Monosov, 2020; Smith, Rigney, & Delgado, 2016). In addition, when presented with a cue that indicates upcoming information, increased functional connectivity between the VTA and NAcc has been observed, suggesting that these regions work together to facilitate decisions related to information-seeking (Eschmann et al., 2023; Bromberg-Martin & Monosov, 2020). Given the large literature that engagement of this system can facilitate instrumental behaviors, we extend this framework to encompass learning as another instrumental behavior subserved by the dopamine system.

However, as we detail above, the drive to seek rewards does not operate in isolation, when factors, such as anxiety and negative affect, outweigh the motivation to seek information, individuals either inhibit information-seeking or actively avoid information (Clewett & Murty, 2019). Norepinephrine (NE) modulates the activity of brain regions such as the amygdala, which is associated with anxiety, suggesting that NE might be involved in information avoidance. Animal and human research suggested that the central nucleus of the amygdala mediates freezing behaviors (Zimmerman, Rabinak, McLachlan, & Maren, 2007; Kalin, 2004), which is a behavioral profile in direct opposition to active information-seeking. Together, we propose that NE and subcortical regions, such as the amygdala, should play important roles in information avoidance.

Below, we first propose a synthesized account of information-seeking that enumerates the different motives underlying the acquisition or avoidance of information. We review factors that influence internal motivation for information and external contextual factors that influence information-seeking. We particularly focus on how internal motivation and external contextual factors together determine information-seeking behaviors. Finally, we discuss neuromodulators involved in the process. This framework therefore brings together these disparate literatures to better understand information-seeking behaviors. This synthesized framework of information-seeking also provides testable predictions for future studies.

AN INTEGRATIVE FRAMEWORK OF INFORMATION-SEEKING

Although most research on information-seeking emphasizes factors that promote information-seeking behaviors, research considering factors that both promote and inhibit information-seeking in their models is relatively understudied. Here, we synthesize prior literature in service of a framework that considers both individuals' motivation for information and their external context. Specifically, we suggest that the integration of motivational state and contextual factors determines information-seeking or avoidance.

Recent research on information-seeking has identified several motives underlying the demand for information. We suggest that the common mechanism of how these different factors moderate information-seeking is by influencing motivational vigor for information. We propose that instrumental utility and hedonic utility of information are the two primary factors that influence the motivational state to actively acquire information. Critically, the variety of other factors that influence information-seeking may do so by either increasing or decreasing perceived instrumental utility or hedonic utility. More specifically, we suggest that metacognitive knowledge, which refers to people's awareness of their own thoughts and cognitive abilities, or a person's knowledge or understanding of their prior knowledge, influences the perceived instrumental utility of information and that curiosity and perceived agency increases the perceived hedonic utility of information.

At the same time, there are many situations in which people actively resist acquiring information, although the utility of acquiring that information is high (Charpentier, Bromberg-Martin, & Sharot, 2018; Sweeny, Melnyk, Miller, & Shepperd, 2010). We propose that different contexts may trigger different information-seeking behaviors even when obtaining the information has the same utility. In other words, the value of information may not necessarily lead to the motivation for information-seeking. The behavior instead depends on the internal and external demands that influence the translation of value into action. Below, we highlight a set of factors centered on anxiety that modulate the relationship between information value and information-seeking behavior, including threat-related avoidance, intolerance of uncertainty, social utility, and the need for cognitive closure. Together, we propose that when contextual factors that inhibit information-seeking are absent, intrinsic motivation to seek information leads to information-seeking. However, increasing levels of anxiety will gradually reduce information-seeking behaviors. Thus, when anxiety reaches a threshold and outweighs intrinsic motivation, individuals may avoid seeking information despite its perceived utility.

RELATIONSHIP TO MODELS OF EXPLORATION/EXPLOITATION

Exploration behavior, particularly in the context of explore–exploit decisions (for a detailed review, see Wilson, Bonawitz, Costa, & Ebitz, 2021), is conceptually related to information-seeking behavior, in that they both provide mechanisms by which individuals engage in learning to reduce uncertainty in the environment. In this framework, exploration refers to actions that aim at acquiring new information in the face of multiple exposures to multiple putative sources of reward, thus expanding one's understanding of the environment with the purpose of facilitating decision-making. This includes learning driven by a specific desire to acquire decision-relevant information (i.e., direct exploration) as well as less goal-driven actions (i.e., random exploration).

Exploration in these contexts is often studied in the context of a trade-off with exploitation, which has participants deciding between accruing rewards from a known source (i.e., exploitation) versus approaching uncertainty to decide whether there are other more valuable sources (i.e., exploration). From a computational perspective, direct exploration behavior exhibits similarities with information-seeking behaviors as we describe; however, the source of what is driving this behavior is quite different. Information bonus, which is the estimated long-term value of information obtained from choosing that option, increases the value of exploratory options given its role in reducing uncertainty (Wilson et al., 2021). In this computational framework, the direct explorer will continue to explore when there is still an information bonus for reducing uncertainty (Wilson et al., 2021). Similarly, as we discussed in our information-seeking framework, instrumental utility of information increases motivation for information, which drives information-seeking behaviors.

However, despite these similarities, the key distinction between information-seeking in our framework and exploration behaviors in explore–exploit frameworks is that the latter is often driven by feedback, particularly in the context of explicit reinforcement (e.g., a four-armed bandit gambling task, naturalistic foraging paradigms). In our information-seeking framework, behaviors are internally motivated by specific goals and intentions that do not necessitate feedback. These goals and intentions can either be instrumental (acquiring information because it is useful for guiding future behaviors) or hedonic (acquiring information because of the positive affect induced by information-seeking). Thus, the drives for information-seeking are purely anticipatory in our framework and agnostic to iterative feedback. Therefore, although both information-seeking and exploration share certain commonalities, their underlying driving forces are divergent.

There have also been other information-seeking frameworks that aim to integrate diverse drives of information-seeking behavior. Sharot and Sunstein (2020) proposed that instrumental utility, hedonic utility, and cognitive utility are the three main drives for information-seeking. Similar to our proposed information-seeking framework, instrumental utility refers to "the ability to use information to select actions that increase extrinsic rewards and help evade losses" (Sharot & Sunstein, 2020) and hedonic utility refers to the positive affect induced by knowledge and information. Moreover, cognitive utility refers to the idea that information can enhance or reduce people's sense that they understand the world around them. We suggest that the main difference between our model and Sharot and Sunstein's model is our model of information-seeking emphasizes different drives and the motivation for information, whereas Sharot and Sunstein's model discusses the outcomes of information-seeking.

UNPACKING THE FACTORS THAT INFLUENCE INDIVIDUALS' UTILITY FOR INFORMATION

Our framework of information-seeking suggests that motivation for information is a key predictor of information-seeking behaviors and that several factors can influence individuals' motivational state for information. We argue that instrumental utility and hedonic utility are the two main factors that affect individuals' motivation to actively seek information. In this section, we highlight different factors that affect individuals' internal motivational state for information by affecting either the perceived instrumental utility or hedonic utility of information.

Instrumental Utility

In an extrinsically motivated environment, in which individuals are driven to perform a behavior based on external factors, such as rewards and punishments, agents perform actions based on reinforcement learning rules, and actions that lead to rewards are reinforced in memory (Subramanian, Chitlangia, & Baths, 2022; Leong, Radulescu, Daniel, DeWoskin, & Niv, 2017). Therefore, individuals are motivated to select actions to maximize extrinsic rewards, such as food and money, and to minimize losses (Subramanian et al., 2022). Obtaining and accumulating information can be useful to resolve uncertainty about the connections between actions and rewards, and to help achieve a goal-oriented behavior (Gottlieb, Oudeyer, Lopes, & Baranes, 2013). For example, information obtained from the stock market can aid in making investment decisions, enabling us to increase gains and reduce potential losses. Information about Covid-19 or other viruses can help us prevent disease spread. The ability to use information to make decisions to achieve goals is known as the instrumental utility of information (Sharot & Sunstein, 2020).

Instrumental utility of information is known as an important driver of information-seeking behaviors. Recent research found that individuals seek information based on the utility of said information (Abir et al., 2022). When other contextual factors are held constant, individuals prefer information of high utility, compared with information of low utility (Abir et al., 2022; Sharot & Sunstein, 2020). For example, in a recent study examining information-seeking behaviors during Covid-19, participants rated the usefulness of either Covid-19-related questions or general questions, and also rated their willingness to wait to see the answers. Results showed that individuals who were more concerned about Covid-19 gave higher usefulness ratings to Covid-19-related questions than the general questions and spent longer time waiting for Covid-19 answers—a key measure of motivation to seek information. This is confirmatory evidence that higher perceived utility leads to higher motivation for information.

One of the main factors that we believe influences the perceived instrumental utility of information is metacognitive knowledge and awareness. It is suggested that there is an inverted U-shaped relationship between utility and metacognitive knowledge. Information that individuals feel they know but actually not is of the highest utility to reduce uncertainty or guide decisions (Metcalfe & Kornell, 2003). However, there are many facets of prior knowledge that can influence how it changes information-seeking. This includes the amount of prior knowledge, metacognitive awareness, and confirmation biases. We next detail how these factors influence instrumental utility and thus information-seeking.

Information Priors, Judgment of Learning, and Confirmation Bias

Information priors refer to one's knowledge state before acquiring new information. Individuals use metacognitive knowledge to decide if additional information is needed before making a decision, which is known as judgment of learning. In other words, the ability to think about what you know and your confidence in that knowledge can dramatically influence information-seeking behavior. More specifically, we propose that individuals prefer seeking information that they have prior knowledge about but are not confident about, primarily based on the region of proximal learning (RPL) theory (Metcalfe & Kornell, 2003, 2005). RPL suggests that when given free choice, people allocate their time selectively to study items of intermediate difficulty, rather than items that are easiest or most difficult. For example, one study (Atkinson, 1972) examining optimal learning strategies suggested that the most effective learning algorithm involved having people selectively study the partially learned items compared with items that were easily remembered and unlearned. This pattern of results suggests that studying items that are neither too difficult nor too easy to learn is most important for achieving study goals, indicating high instrumental utility. Relatedly, results of two behavioral experiments found that people tended to seek more information about face–name associations in a subsequent restudy phase for names with feeling of knowing experience (Brooks, Yang, & Köhler, 2021), suggesting the role of feeling of knowing experiences in driving information-seeking behaviors. This further supports the hypothesis that judgment of learning drives information-seeking and that information in the RPL is of the highest instrumental utility in guiding decisions.

The above model suggests that beliefs about prior knowledge can target information-seeking toward more adaptive ends. However, prior beliefs might also bias information-seeking in ways that counter pure instrumental utility. Previous research has found that participants value incongruent information less, a phenomenon called confirmation bias (Vedejová & Čavojová, 2022; Schultz, 1974). A similar bias might exist during information-seeking. Individuals are known to assign higher values to information that is consistent with their prior beliefs and are more motivated to seek that information relative to disconfirming evidence. In one study examining information-seeking using four controversial topics, it was found that people were biased to seek more information confirming their positions on a given topic (Vedejová & Čavojová, 2022). These results suggest individuals value information consistent with prior beliefs and that this valuation drives information-seeking behaviors. One reason for this may be that confirming prior beliefs elicits positive feelings, which is known as the hedonic utility of information (see section below). Prior knowledge can influence the hedonic utility of information by inducing curiosity. It is suggested that detection of knowledge gaps elicits curiosity (Gruber & Ranganath, 2019). A recent study investigating prior knowledge and curiosity using a trivia paradigm showed that curiosity is predicted by people's estimate of their current knowledge (Wade & Kidd, 2019). Thus, prior beliefs highlight the importance of assessing multiple types of utility in guiding motivation to seek information.

Together, we suggest that the instrumental utility of information is a motivational factor that drives information-seeking behaviors. Factors such as judgment of learning and confirmation bias influence information-seeking behaviors by affecting the perceived instrumental utility of information. Furthermore, acquired information updates our prior beliefs over time and thus guides further information-seeking.

Hedonic Utility

Individuals do not make rational information-seeking decisions all the time. Often, individuals seek information of no instrumental utility, such as answers to trivia questions or knowledge of how magic clips work. Hedonic utility, the amount of positive feeling and relief that information induces, could explain why and when information-seeking behaviors persist even when they are not driven by instrumental utility (Kelly & Sharot, 2021; Sharot & Sunstein, 2020). Information can induce both positive and negative affect, and individuals prefer seeking information that evokes positive affect over negative affect (van Lieshout, Traast, de Lange, & Cools, 2021). Earlier studies have indicated that humans tend to be more inclined to spend money on information when they anticipate positive outcomes, such as information indicating financial gains, and may even be willing to pay to avoid information that suggests negative outcomes, such as information indicating financial loss (Sharot & Sunstein, 2020). This is notable, as both sources of information in this case have no prominent instrumental utility. In another study, participants showed a greater preference for information on gain trials than loss trials, suggesting individuals seek information that elicits positive emotions (Levy, 2018).

We further propose that individuals might also be motivated to seek information that they anticipate information would elicit positive affect. This process of simulating future emotional states is known as affective forecasting (Wilson & Gilbert, 2005). Individuals have the ability to envision their emotional state in various scenarios, despite not having encountered them previously, but it has been found that people often overestimate the effect that an upcoming event will have on their happiness and the intensity of their emotional responses (Gilbert, Driver-Linn, & Wilson, 2002). We propose that the overestimated positive affect may drive information-seeking behaviors. For example, a person might spend a significant amount of time and resources researching a particular vacation destination, imagining that the experience will bring them an extreme amount of joy and satisfaction. However, when they actually go on vacation, they may find their level of happiness is not as high as they had anticipated. Despite this, the initial overestimation of the positive affect may have still motivated more information-seeking behavior.

Given that hedonic utility of information is a key driver of information-seeking behaviors, it is predicted that individuals with depression, who are less likely to maintain positive affect, are likely to engage in atypical information-seeking behaviors. This pattern of predicted findings was recently confirmed in research that found that greater depression symptoms was associated with a reduced tendency to seek information (Smith et al., 2022). This is indirect evidence that hedonic utility of information is a key driver of information-seeking behaviors.

Hedonic utility also includes relief induced by information-seeking. According to the uncertainty reduction theory, uncertainty is accompanied by negative affect states, such as stress and anxiety (Berger & Calabrese, 1975). Individuals are motivated to reduce uncertainty because they believe uncertainty reduction will result in favorable outcomes and alleviate stress. Recent work demonstrated the relationship between uncertainty and information-seeking (van Lieshout et al., 2021). Using a non-instrumental lottery task, it has been found that people were more curious and more willing to wait for trials with higher uncertainty about the outcome. Moreover, it was suggested that acquiring information about a highly uncertain environment led to the largest uncertainty reduction. We propose that relief accompanied by uncertainty reduction drives these information-seeking behaviors. Similarly, anxiety drives information-seeking as seeking information reduces uncertainty, which induces relief and increases perceived hedonic utility of information (Aberg, Toren, & Paz, 2022). We will discuss more about the effect of anxiety on information-seeking as a context factor in the section below (see Threat-related Avoidance section).

Curiosity

Curiosity is defined as the intrinsic motivation to close information gaps and acquire information (Gruber & Ranganath, 2019). Curiosity can be elicited both because of its instrumental utility and its hedonic utility. We focus here on the hedonic utility of curiosity, as its instrumental utility can be accounted for by the factors related to information priors detailed above. For how curiosity enhances perceived instrumental utility, which drives information-seeking, see Gruber and Ranganath (2019). We operationalize curiosity as a desire for knowledge for its own sake, even in the absence of instrumental utility. According to a recent review of curiosity and information-seeking (Gruber & Ranganath, 2019), curiosity is elicited when we become aware of gaps in our knowledge or encounter prediction errors. We are motivated to fill these gaps or resolve prediction errors with information, the receipt of which can be rewarding (Bromberg-Martin & Hikosaka, 2009, 2011). In one study, individuals could choose whether to know the value of their own portfolio, which was of no instrumental utility. Results showed that participants were willing to pay for information about their portfolio, although this information could not influence the outcome of their investments (Levy, 2018), confirming that instrumental utility is not the only drive for information. Recent research also suggested that curiosity and information-seeking behavior are associated with the size of information gap. People were more curious and willing to wait for outcomes with higher uncertainty, which leads to the highest reduction in uncertainty and increase in positive feeling (hedonic utility), suggesting that curiosity-driven information-seeking reduces uncertainty, and increases both the perceived hedonic utility of information and motivation for information. Consistently, animal work suggested that monkeys prefer options with information indicating upcoming primary rewards (such as water or juice) over uninformative options, although this choice did not change the reward outcomes (Bromberg-Martin & Hikosaka, 2009, 2011). More strikingly, monkeys were even willing to give up a substantial portion of their reward to get this information. Together, we propose that when instrumental utility alone cannot determine information-seeking behaviors, curiosity might be another explanatory factor (Eschmann et al., 2023; Abir et al., 2022; van Lieshout et al., 2021; Gruber & Ranganath, 2019; Gottlieb et al., 2013).

Curiosity-driven information-seeking not only reduces uncertainty but also elicits positive feelings. A study using trivia question paradigms found that curiosity level was higher for positive questions than negative ones (van Lieshout, de Lange, & Cools, 2020), suggesting people are more curious about positive information than negative information. Another study using a lottery task found that people were more curious about gains than losses (Marvin & Shohamy, 2016). Moreover, individuals also seek information out of interest. For example, individuals are curious about magic clips, which are not associated with information gaps or prediction errors. Taken together, we suggest that curiosity increases information-seeking behaviors that either reduce uncertainty or elicit positive

feelings, suggesting that curiosity leads to information-seeking by increasing perceived hedonic utility of information.

Perceived Agency

Perceived agency refers to belief in one's ability to have control over the external environment and achieve desired goals (Leotti & Delgado, 2011, 2014; Leotti, Iyengar, & Ochsner, 2010). Prior animal and human research suggests a preference for choice, even when that choice could not alter outcomes (Wang & Delgado, 2019; Murty, DuBrow, & Davachi, 2015; Leotti & Delgado, 2011, 2014; Fujiwara et al., 2013). For example, in one study (Bown, Read, & Summers, 2003), it was found that when choosing between two options, humans tend to choose options that lead to a subsequent choice (Bown et al., 2003), suggesting a preference for having choices. In another study investigating how perceived agency influences information valuation (Jiwa, Cooper, Chong, & Bode, 2021), it was found that participants placed higher bids to learn outcomes of trials that they had agency than lotteries that were randomly assigned (Jiwa et al., 2021), suggesting that people value outcomes reflect agency more than outcomes that reflect unchosen actions.

It is suggested that there is a positive relationship between feelings of control and positive affect (Li, Zhao, & Yu, 2021; Leotti et al., 2010; Abelson, Khan, Liberzon, Erickson, & Young, 2008). People gave more positive ratings for items that they chose (Fujiwara et al., 2013). Moreover, most studies examining whether perceived agency influences participants' self-reported affective states found that opportunities to enact agency elicited positive emotions (Hökkä, Vähäsantanen, Paloniemi, & Eteläpelto, 2017). Overall, these findings suggest that increased perceived agency is associated with increased positive affect (Kaiser, Buciuman, Gigl, Gentsch, & Schütz-Bosbach, 2021), suggesting that perceived agency increases hedonic utility of information and thus drives information-seeking behaviors.

So far, we have discussed factors that either influence the instrumental utility or hedonic utility of information. However, instrumental utility and hedonic utility are not exclusive to each other. Instead, they influence each other. Instrumental utility can affect hedonic utility. Obtaining information of high instrumental utility will be more likely to elicit a positive affect. For example, information that is consistent with prior beliefs has higher instrumental utility. Confirming those beliefs also elicit positive feeling. On the other hand, hedonic utility could also affect instrumental utility. For example, the anticipation of pleasure experiences during a vacation trip can increase the motivation to gather travel information and make travel arrangements.

To summarize, we discussed several factors that drive information-seeking behaviors, and we suggest that the common mechanism of how these factors promote information-seeking behaviors is by increasing the motivational state for information. People are motivated to obtain information with high instrumental utility because such information helps maximize rewards and achieve goals. Information also evokes positive affect, and individuals are motivated to seek that information to promote life well-being. We further suggest that factors such as judgment of learning, curiosity, and perceived agency promote information-seeking behaviors by either increasing perceived instrumental or hedonic utility of information.

SUMMARY OF CONTEXTUAL FACTORS INFLUENCING INFORMATION-SEEKING BEHAVIORS

All of the evidence noted thus far illustrates that information-seeking behaviors are propagated by increased motivation for information, predominately driven by its instrumental or hedonic utility. Individuals differ in their information-seeking behaviors, however, even if they have equal utility for obtaining that information. Emerging research has shown the importance of context in influencing information-seeking behavior, but few have elaborated on how contextual factors interact with internal motivation for information and influence information-seeking. Therefore, in this section, we highlight individual difference factors and factors from external contexts that can modify information-seeking behaviors. We also summarize how these external factors, together with motivation for information, influence individuals' information-seeking behaviors.

Threat-related Avoidance

Prior research on information-seeking has mostly investigated these processes in neutral contexts. However, information-seeking behaviors have been shown to be quite malleable, especially when individuals are in uncertain, aversive environments. For example, individuals may want to know if they will test positive for Covid-19 when they feel sick, although they might be highly anxious about the test results. According to the Prediction, Appraisal, Curiosity, and Exploration (PACE) framework (Gruber & Ranganath, 2019), an uncertain environment could trigger curiosity and exploration if one feels capable of resolving the uncertainty. However, uncertainty could instead trigger anxiety and lead to behavioral inhibition if one believes that one has no ability to cope with the situation. However, contrary to predictions made by the PACE framework, recent research on information-seeking during Covid-19 showed mixed findings regarding anxiety and information-seeking. One study investigating information-seeking during the Covid-19 pandemic found no relationship between anxiety and information-seeking (Eschmann et al., 2023). It was suggested that curiosity, but not anxiety, correlated with information-seeking around Covid-19 (Eschmann et al., 2023). Another study showed a quadratic relationship between the strength of

anticipated feelings, such as negative emotions, and choice for COVID-19 headlines (Niehoff, Mittenbühler, & Oosterwijk, 2023). Other research (Charpentier et al., 2022) suggests that seeking information when anxious may help reduce uncertainty and guide decision-making. Therefore, it is possible that information gathered under anxiety may be beneficial and that, in some contexts, anxiety may increase information-seeking. Indeed, in one recent study, participants who were more anxious about Covid-19 sought more Covid-19-related information (Charpentier et al., 2022). Several recent findings have also shown that both trait and state-induced anxiety increased information-seeking by reducing anxiety (Aberg et al., 2022; Charpentier et al., 2022; Loosen, Skvortsova, & Hauser, 2021; Sharot & Sunstein, 2020; Myrick & Willoughby, 2019).

One of the goals of our framework is to reconcile the discrepancy between predictions from the PACE framework and the reviewed findings on anxiety-increased information-seeking. We propose that anxiety moderates perceived instrumental utility and hedonic utility of information and that whether an individual seeks information depends on the integration of one's motivation for information and present anxiety level.

More specifically, we propose that threat decreases both the perceived instrumental and hedonic utility of information and thus plays a critical role in reducing the motivation to seek information. Decreased motivation for information-seeking could be adaptive under an anxiety state. Although speculative, it is suggested that when individuals are in high states of anxiety, cognitive capacity is limited, which can undermine motivation to seek information. Information-seeking under anxiety could lead to information overload (Soroya et al., 2021); therefore, anxiety may reduce the perceived instrumental utility of information and information-seeking behaviors. For example, during Covid-19, a large amount of information is accessible online. The available information on Covid-19 could be overwhelming and conflicting, which further triggers stress and anxiety. In this situation, instrumental utility of information may be reduced and people may start avoiding information regarding Covid-19 (Soroya et al., 2021).

Importantly, threat not only causes negative emotions but also diminishes positive feelings. Threat elicits stress, which is a well-established risk factor for different mental disorders. Investigations on emotional responses during threatening situations have revealed that threat reduces positive affect. In addition, previous studies suggested that individuals who are more vulnerable to intense negative emotions during naturalistic stress have a higher probability of developing anxiety and depression in the future (Rackoff & Newman, 2020). Thus, the normal sources of hedonic utility that might emerge from situations like curiosity and agency may be absent when individuals are experiencing high states of anxiety.

In our model of information-seeking, we propose that integration of context and motivation for information determines information-seeking behaviors. If the motivation for information is much higher than anxiety from the environment, then individuals will still seek information. However, in some situations, when their anxiety level is higher than motivation for information, individuals will avoid information. Future studies that examine information-seeking behaviors as a function of anxiety are needed to confirm this hypothesis.

Intolerance of Uncertainty

Intolerance of uncertainty (IU) is a personality trait that a person's inclination to struggle with managing uncertain and vague information (Carleton, Norton, & Asmundson, 2007). Prior work has identified that high levels of IU increased the risk of developing anxiety disorder and several other mental disorders (Jensen, Cohen, Mennin, Fresco, & Heimberg, 2016). Individuals who have a high IU rating are more likely to perceive ambiguous situations as threatening (Bartoszek, Ranney, Curanovic, Costello, & Behar, 2022). For example, prolonged anxiety triggered by high IU might compromise one's ability to seek useful information under threat-related uncertainty.

The Covid-19 pandemic has led to a high level of uncertainty environment, resulting in large-scale studies investigating IU and information-seeking in an ecologically valid setting. However, results in this research domain—as in many ecologically valid studies—have been mixed. Some research suggests that seeking Covid-19-related information can lead to high stress levels for people with high IU (Baerg & Bruchmann, 2022). Consistent with this account, prior work found that high IU evoked anxiety and reduced information-seeking behaviors (Smith et al., 2022). However, similar to the contrasting findings reviewed above regarding threat and information-seeking (Charpentier et al., 2022), recent research also suggests that high IU individuals seek information to reduce uncertainty (Bartoszek et al., 2022). It has been shown that higher IU is associated with higher health monitoring, suggesting high information-seeking on threat-relevant information regarding health (Bartoszek et al., 2022; Rosen, Knäuper, & Sammut, 2007). To summarize, based on previous research, high IU could decrease or increase information-seeking behaviors, depending on whether high IU evoked excessive anxiety or higher motivation to reduce uncertainty.

Again, to resolve the conflicts in the literature, we propose that whether IU decreases or increases information-seeking depends on the level of uncertainty relative to motivation for information. If the anxiety level triggered by high IU is higher than motivation for information, individuals will avoid information-seeking; otherwise, individuals might still seek information. Other individual difference factors, such as negative and positive affect and trait anxiety, are expected to influence information-seeking behaviors same as IU.

Need for Cognitive Closure

Need for cognitive closure refers to a preference for definite information over ambiguous information (Kruglanski, 1989). Similar to IU, the need for cognitive closure differs across individuals, such that some people make decisions easily based on limited information whereas others continue to seek information without making a final decision (Webster & Kruglanski, 1994). Individuals with a high need for cognitive closure tend to avoid uncertainty by relying more on past knowledge to make decisions (Webster & Kruglanski, 1994). We propose that a high versus low need for cognitive closure leads to different information-seeking behaviors, such that individuals with a high need for cognitive closure tend to seek less information than individuals with a low need for cognitive closure.

Social Utility

Humans are social beings. Their behaviors are usually influenced by others' emotions and actions (Vries, Backbier, Kok, & Dijkstra, 1995). The presence of other individuals has been shown to play an important role in shaping individuals' behaviors (Asch, 1956). In situations where there is high uncertainty, people tend to seek cues from others to determine what is appropriate behavior. When people perceive that no one else is performing a particular behavior, they may feel social pressure to conform and avoid performing that behavior, such as refusing to drink alcohol at a party where everyone else is drinking. Although no one is forcing the individual to drink, they may feel pressure to conform to the social norm of drinking and avoid being seen as different. Social pressure can even lead individuals to change their opinions or behaviors to conform with their peers (Asch, 1956), including information-seeking behavior. For example, a student in a classroom who has a clarification question may hesitate to ask if they believe that no one else has the same question and fear appearing unintelligent. A recent study has shown that students' decisions to use Wikipedia were influenced by their peers, confirming the important role of peer pressure in influencing information-seeking behaviors (Chung, 2012). Combined with our model of information-seeking, we suggest that social pressure decreases information-seeking when the pressure is higher than individual motivation for information. On the contrary, if motivation for information is still higher than perceived social pressure, people will continue seeking information regardless of social pressure.

There are other social factors, such as in-group/out-group identity, that could also influence information-seeking behaviors. In-group and out-group identities can sometimes inhibit information-seeking behavior by influencing individuals' perceptions and attitudes toward members of different social groups. Social identity theory (Tajfel & Turner, 1979) suggests that people tend to categorize themselves and others into social groups and derive part of their self-esteem from the positive distinctiveness of their in-group compared with out-groups. This desire for positive distinctiveness can lead to biases and prejudices against out-groups, affecting information-seeking behavior. Individuals may be less inclined to seek information from or about out-group members because of a perceived threat to their own group identity or a fear of cognitive dissonance resulting from information that challenges their in-group's superiority (Hornsey & Hogg, 2000). Such identity-driven biases can hinder the acquisition of diverse perspectives and information, potentially leading to misunderstandings and reinforcing stereotypes (Dovidio, Love, Schellhaas, & Hewstone, 2017).

To summarize, prior research indicates that contextual factors, such as threat, IU, social pressure, and need for cognitive closure might inhibit information-seeking, but context does not solely determine information-seeking behaviors. Context instead moderates motivation for information, and the joint integration of context and motivation for information determines information-seeking behaviors. We propose that the moderation effect of context could occur at different stages of information-seeking. However, future studies are needed to confirm the model.

NEUROMODULATORS SYSTEMS INVOLVED IN INFORMATION-SEEKING

So far, we summarized factors influencing the internal motivation for information, and the moderating effect of external contexts, and reviewed how both factors together may determine information-seeking behaviors. Although all of the work that we have reviewed thus far was behavioral and conducted in humans, parallel work using animal models of motivated behavior and human neuroimaging have meaningfully illuminated the neural mechanisms underlying information-seeking. To integrate these two often siloed fields of information-seeking, we conclude by identifying plausible neuromodulatory systems involved in information-seeking and examining how motivation may influence neural processes. We suggest that our central premise—that motivation for information and context together influence information-seeking behavior—is underlaid by a common denominator: systematic influence of the neuromodulatory systems that invigorate and inhibit goal-oriented, motivated behavior.

Motivation, the desire to take action, is a complex process that is critical for survival and involves multiple behavioral functions mediated by an array of interacting neural circuits. The neural circuits underlying motivated behavior are not completely understood (Abir et al., 2022; Gottlieb, Lopes, & Oudeyer, 2016; Sescousse, Li, & Dreher, 2015; Düzel, Bunzeck, Guitart-Masip, & Düzel, 2010). However, pharmacological and genetic approaches have clearly established that dopamine is essential for motivated behavior (Düzel et al., 2010; Dayan, 2009). Direct evidence from animal studies showed that mice

with elevated dopamine exhibit enhanced motivation (Cagniard, Balsam, Brunner, & Zhuang, 2006). Key subcortical regions in the motivation-related circuitry—the VTA, the substantia nigra (SN), and the dopaminergic (DA) system—are hypothesized to be involved in exploration behaviors. According to the NOvelty-related Motivation of Anticipation and exploration by Dopamine model, novel environments lead to a high motivational state. Anticipating novel and rewarding environments has a similar motivational effect, which leads to high tonic SN/VTA activation and promotes exploratory behavior. Additional animal research suggested that midbrain dopamine neurons are capable of signaling preference for advance information about future rewards (Düzel et al., 2010). This suggests that the motivational circuit (SN/VTA) is involved in information-seeking. Prior human research also found that information-seeking is associated with increases in activity and functional connectivity within the mesolimbic DA system (Lau, Ozono, Kuratomi, Komiya, & Murayama, 2020; Brydevall et al., 2018; Charpentier et al., 2018). Specifically, increased functional connectivity between the VTA and NAcc has been for information cues, suggesting that the DA system is important for information-seeking behaviors (Charpentier et al., 2018). Increased activation in the SN/VTA and ventral striatum has also been found for information about upcoming gains (Charpentier et al., 2018).

Critically, some of the cognitive factors we have highlighted as driving the hedonic value of information-seeking also reliably engage the mesolimbic system. Research on curiosity found increased DA midbrain (SN/VTA) activity for high curiosity items (Eschmann et al., 2023; Gruber & Ranganath, 2019; Charpentier et al., 2018; Oosterwijk, 2017; Gruber, Gelman, & Ranganath, 2014). Similarly, research on perceived agency suggests that having the opportunity to make choices modulates the mesolimbic dopamine system (Murty et al., 2015; Leotti & Delgado, 2011). For example, in a memory encoding task where participants' sense of agency was manipulated, such that, during encoding, participants either had agency to choose information to encode or were given forced choices, researchers found that the DA midbrain (i.e., the VTA) showed greater activation for encoding with choices than encoding without choices (Murty et al., 2015). Additional research suggests that anticipation of making choices is associated with increased activity in the ventral striatum (Wang & Delgado, 2019). This is further evidence that the DA pathway plays an important role in information-seeking behaviors. Research investigating the sense of agency in personality and substance users also confirms the hypothesis that dopamine plays a crucial role in the perception of agency. Recent work found that narcissism and substance use were associated with a weaker sense of agency compared with controls (Render & Jansen, 2019) and it was suggested that higher dopamine accessibility increases the sense of agency and vice versa for lower dopamine accessibility (Render & Jansen, 2019).

More direct evidence for the role of mesolimbic engagement in information-seeking comes from studies examining patients with alterations in DA functions, such as Parkinson's disease, schizophrenia, and depression (Meder, Herz, Rowe, Lehéricy, & Siebner, 2019; Brisch et al., 2014). Given that dopamine function is thought to play a role in information-seeking, abnormal DA function may lead to atypical information-seeking behaviors. Consistent with this hypothesis, patients with depression displayed atypical information-seeking behaviors (Sharot & Sunstein, 2020; Camp, 1986), potentially confirming the role of the DA system in information-seeking. Another study directly tested the role of dopamine in information-seeking by administration of an antagonist that showed that levodopa altered non-instrumental information-seeking about potential losses, which further confirms that dopamine is important for information-seeking (Vellani, de Vries, Gaule, & Sharot, 2020).

Relatedly, multiple studies explore the roles played by neuromodulators, primarily NE and dopamine (DA), in the dynamics of explore–exploit behaviors, which often show contradictory findings as how we described these systems contribute to information-seeking through the lens of anticipation. Chen, Mueller, Knep, Ebitz, and Grissom (2023) used DA and NE receptor agonists and antagonists and found that the DA activity has an inverse relationship with exploration (Chen et al., 2023). Similarly, Chakroun, Mathar, Wiehler, Ganzer, and Peters (2020) investigated the role of DA in human exploration, and they found that levodopa diminishes directed exploration, which is contrary to the predictions of our framework of information-seeking wherein DA facilitates information-seeking behavior (Chakroun et al., 2020). As we detailed above, our framework emphasizes motivations for information-seeking, instead of feedback-driven learning. The above-referenced studies focus on the role of DA at the outcome phase of exploration, such as expected rewards or reward uncertainty, which explains the discrepancy between the finding and our proposed framework and parallels the differences in information-seeking in our model versus those addressed by exploration–exploitation trade-offs.

Consistent with our framework, Cremer, Kalbe, Müller, Wiedemann, and Schwabe (2023) found an increase in exploration behaviors at the beginning of the task for the amisulpride group compared with the placebo group, which is when the influence of feedback-driven learning is at its lowest and individuals may rely more on anticipatory/intrinsic signals (Cremer et al., 2023). In terms of NE, Dubois et al. (2021) found NE's role in random exploration, such that NE facilitates random exploration (Dubois et al., 2021). We speculate that in the context of information-seeking, DA is involved in information-seeking under a safe environment whereas NE is more involved in information-seeking under anxiety.

We also acknowledge the interplay between phasic and tonic locus coeruleus (LC) activity is important during

information-seeking. Phasic bursts of NE release can signal the need to explore and gather new information when unexpected or salient events occur. Meanwhile, tonic LC activity helps maintain a state of alertness and readiness for ongoing information-seeking and decision-making. However, studies supporting this trade-off have mainly been studied in the context of explore–exploit decisions and future work is necessary to determine whether similar effects would be present in our information-seeking framework.

NEUROMODULATORY SYSTEMS INVOLVED IN INFORMATION AVOIDANCE

Prior research found that animals either freeze or activate fight-or-flight reactions in threatening environments (Roelofs, 2017). We propose that this behavioral inhibition such as information avoidance under high anxiety is similar to freezing under stress. Freezing refers to behavioral inhibition accompanied by heart rate deceleration. Studies in rodents have found that the amygdala is involved in freezing behaviors, such that stimulation of the central nucleus of the amygdala results in freezing (Kapp, Frysinger, Gallagher, & Haselton, 1979). On the basis of our model of information-seeking, under a high anxiety context (i.e., when anxiety outweighs motivation for information), individuals will inhibit information-seeking. Given that prior research has suggested that the amygdala plays a role in freezing behaviors under stress, we propose that the amygdala might also be involved in the inhibition of information-seeking behaviors.

NE plays a critical role in regulating behaviors under threat, such as behavioral inhibition. The noradrenergic neurons are present in the LC and amygdala (McCall et al., 2017). Prior research showed that noradrenaline-depleted animals performed an avoidance task faster than controls (Mason & Fibiger, 1979), suggesting that NE is important for inhibition. Other stress hormones, such as stress-induced cortisol levels and glucocorticoids also play an important role in freezing behaviors (Buss, Davidson, Kalin, & Goldsmith, 2004; Kalin, Shelton, Rickman, & Davidson, 1998). Therefore, we propose that NE and other stress hormones might be important during information inhibition and avoidance. Future studies are needed to confirm the role of NE during information avoidance.

What is more, prioritization and selection are essential for adaptive behavior under threat, which is the opposite of exploration and information-seeking observed in a safe environment. NE has been suggested to be involved in attentional narrowing to process only threat-related information (Clewett & Murty, 2019), which is at odds with increases in information-seeking and exploration. Furthermore, pharmacological studies have supported the attention-narrowing view by showing that NE facilitates top–down selective attention (Robbins & Arnsten, 2009). Although speculative, it could be inferred that under threat, attention narrowing caused by NE release could prevent information-seeking, which leads to inhibition of information-seeking.

In terms of NE, Dubois et al. (2021) found NE's role in random exploration, such that NE facilitates random exploration. We speculate that in the context of information-seeking, DA is involved in information-seeking under a safe environment whereas NE is more involved in information-seeking under anxiety.

We also acknowledge the interplay between phasic and tonic LC activity is important during information-seeking. Phasic bursts of NE release can signal the need to explore and gather new information when unexpected or salient events occur. Meanwhile, tonic LC activity helps maintain a state of alertness and readiness for ongoing information-seeking and decision-making. However, studies supporting this trade-off have mainly been studied in the context of explore–exploit decisions and future work is necessary to determine whether similar effects would be present in our information-seeking framework.

CONCLUSION

We propose that information-seeking behavior is determined by both an individual's internal motivation for information and their external context. We further propose that instrumental utility and hedonic utility of information are two main factors that influence motivation for information. Several factors, such as judgment of learning, curiosity, and perceived agency, influence motivation for information by affecting either instrumental utility or hedonic utility of information. We summarized contextual factors, including threat-related avoidance and social influence, and individual differences, such as IU and the need for cognitive closure, that might inhibit information-seeking. More importantly, we showed how our integrated framework of information-seeking explains the mixed findings regarding anxiety and information-seeking.

Our framework generates several testable predictions for future work. Different from prior models of information-seeking, our framework emphasizes on dynamic balance between internal motivation for information and contexts. It will be necessary for future work to examine if information-seeking behaviors decrease as a function of anxiety in the environment given the same motivation for information. Similarly, it would also be interesting to confirm given the same context, whether information-seeking behaviors increase as a function of motivation for information. Given that information-seeking enhances memory encoding, it is also predicted that factors that influence information-seeking could have downstream effects on memory. Future studies in memory are needed to test this framework of information-seeking.

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Diversity in Citation Practices

Retrospective analysis of the citations in every article published in this journal from 2010 to 2021 reveals a persistent pattern of gender imbalance: Although the proportions of authorship teams (categorized by estimated gender identification of first author/last author) publishing in the *Journal of Cognitive Neuroscience* (*JoCN*) during this period were M(an)/M = .407, W(oman)/M = .32, M/W = .115, and W/W = .159, the comparable proportions for the articles that these authorship teams cited were M/M = .549, W/M = .257, M/W = .109, and W/W = .085 (Postle and Fulvio, *JoCN*, 34:1, pp. 1–3). Consequently, *JoCN* encourages all authors to consider gender balance explicitly when selecting which articles to cite and gives them the opportunity to report their article's gender citation balance.

REFERENCES

Abelson, J. L., Khan, S., Liberzon, I., Erickson, T. M., & Young, E. A. (2008). Effects of perceived control and cognitive coping on endocrine stress responses to pharmacological activation. *Biological Psychiatry*, *64*, 701–707. https://doi.org/10.1016/j.biopsych.2008.05.007, PubMed: 18571624

Aberg, K. C., Toren, I., & Paz, R. (2022). A neural and behavioral trade-off between value and uncertainty underlies exploratory decisions in normative anxiety. *Molecular Psychiatry*, *27*, 1573–1587. https://doi.org/10.1038/s41380-021-01363-z, PubMed: 34725456

Abir, Y., Marvin, C. B., van Geen, C., Leshkowitz, M., Hassin, R. R., & Shohamy, D. (2022). An energizing role for motivation in information-seeking during the early phase of the COVID-19 pandemic. *Nature Communications*, *13*, 2310. https://doi.org/10.1038/s41467-022-30011-5, PubMed: 35484153

Asch, S. E. (1956). Studies of independence and conformity: I. A minority of one against a unanimous majority. *Psychological Monographs: General and Applied*, *70*, 1–70. https://doi.org/10.1037/h0093718

Atkinson, R. C. (1972). Optimizing the learning of a second-language vocabulary. *Journal of Experimental Psychology*, *96*, 124–129. https://doi.org/10.1037/h0033475

Baerg, L., & Bruchmann, K. (2022). COVID-19 information overload: Intolerance of uncertainty moderates the relationship between frequency of internet searching and fear of COVID-19. *Acta Psychologica*, *224*, 103534. https://doi.org/10.1016/j.actpsy.2022.103534, PubMed: 35189539

Bartoszek, G., Ranney, R. M., Curanovic, I., Costello, S. J., & Behar, E. (2022). Intolerance of uncertainty and information-seeking behavior: Experimental manipulation of threat relevance. *Behaviour Research and Therapy*, *154*, 104125. https://doi.org/10.1016/j.brat.2022.104125, PubMed: 35642992

Berger, C. R., & Calabrese, R. J. (1975). Some explorations in initial interaction and beyond: Toward a developmental theory of interpersonal communication. *Human Communication Research*, *1*, 99–112. https://doi.org/10.1111/j.1468-2958.1975.tb00258.x

Bown, N. J., Read, D., & Summers, B. (2003). The lure of choice. *Journal of Behavioral Decision Making*, *16*, 297–308. https://doi.org/10.1002/bdm.447

Brisch, R., Saniotis, A., Wolf, R., Bielau, H., Bernstein, H.-G., Steiner, J., et al. (2014). The role of dopamine in schizophrenia from a neurobiological and evolutionary perspective: Old fashioned, but still in vogue. *Frontiers in Psychiatry*, *5*, 47. https://doi.org/10.3389/fpsyt.2014.00047, PubMed: 24904434

Bromberg-Martin, E. S., & Hikosaka, O. (2009). Midbrain dopamine neurons signal preference for advance information about upcoming rewards. *Neuron*, *63*, 119–126. https://doi.org/10.1016/j.neuron.2009.06.009, PubMed: 19607797

Bromberg-Martin, E. S., & Hikosaka, O. (2011). Lateral habenula neurons signal errors in the prediction of reward information. *Nature Neuroscience*, *14*, 1209–1216. https://doi.org/10.1038/nn.2902, PubMed: 21857659

Bromberg-Martin, E., & Monosov, I. E. (2020). Neural circuitry of information seeking. *Current Opinion in Behavioral Sciences*, *35*, 62–70. https://doi.org/10.1016/j.cobeha.2020.07.006, PubMed: 33681428

Brooks, G., Yang, H., & Köhler, S. (2021). Feeling-of-knowing experiences breed curiosity. *Memory*, *29*, 153–167. https://doi.org/10.1080/09658211.2020.1867746, PubMed: 33480318

Brydevall, M., Bennett, D., Murawski, C., & Bode, S. (2018). The neural encoding of information prediction errors during non-instrumental information seeking. *Scientific Reports*, *8*, 6134. https://doi.org/10.1038/s41598-018-24566-x, PubMed: 29666461

Buss, K. A., Davidson, R. J., Kalin, N. H., & Goldsmith, H. H. (2004). Context-specific freezing and associated physiological reactivity as a dysregulated fear response. *Developmental Psychology*, *40*, 583–594. https://doi.org/10.1037/0012-1649.40.4.583, PubMed: 15238045

Cagniard, B., Balsam, P. D., Brunner, D., & Zhuang, X. (2006). Mice with chronically elevated dopamine exhibit enhanced motivation, but not learning, for a food reward. *Neuropsychopharmacology*, *31*, 1362–1370. https://doi.org/10.1038/sj.npp.1300966, PubMed: 16319913

Camp, C. J. (1986). I am curious-grey: Information seeking and depression across the adult lifespan. *Educational Gerontology*, *12*, 375–384. https://doi.org/10.1080/0380127860120412

Carleton, R. N., Norton, M. A. P. J., & Asmundson, G. J. G. (2007). Fearing the unknown: A short version of the Intolerance of Uncertainty Scale. *Journal of Anxiety Disorders*, *21*, 105–117. https://doi.org/10.1016/j.janxdis.2006.03.014, PubMed: 16647833

Chakroun, K., Mathar, D., Wiehler, A., Ganzer, F., & Peters, J. (2020). Dopaminergic modulation of the exploration/exploitation trade-off in human decision-making. *eLife*, *9*, e51260. https://doi.org/10.7554/eLife.51260, PubMed: 32484779

Charpentier, C. J., Bromberg-Martin, E. S., & Sharot, T. (2018). Valuation of knowledge and ignorance in mesolimbic reward circuitry. *Proceedings of the National Academy of Sciences, U.S.A.*, *115*, E7255–E7264. https://doi.org/10.1073/pnas.1800547115, PubMed: 29954865

Charpentier, C. J., Cogliati Dezza, I., Vellani, V., Globig, L. K., Gädeke, M., & Sharot, T. (2022). Anxiety selectively increases information-seeking in response to large changes. *Scientific Reports*, *12*, 7385. https://doi.org/10.1038/s41598-022-10813-9, PubMed: 35513397

Chen, C. S., Mueller, D., Knep, E., Ebitz, R. B., & Grissom, N. M. (2023). Dopamine and norepinephrine differentially mediate the exploration–exploitation tradeoff. *bioRxiv*. https://doi.org/10.1101/2023.01.09.523322, PubMed: 36711959

Chung, S. (2012). Cognitive and social factors affecting the use of Wikipedia and information seeking / Les facteurs cognitifs et sociaux déterminant l'utilisation de Wikipedia et la recherche d'information. *Canadian Journal of Learning and Technology / La Revue Canadienne de l'apprentissage et de la Technologie*, *38*. https://doi.org/10.21432/T25K59

Clewett, D., & Murty, V. P. (2019). Echoes of emotions past: How neuromodulators determine what we recollect. *eNeuro*, *6*. https://doi.org/10.1523/ENEURO.0108-18.2019, PubMed: 30923742

Cremer, A., Kalbe, F., Müller, J. C., Wiedemann, K., & Schwabe, L. (2023). Disentangling the roles of dopamine and noradrenaline in the exploration–exploitation tradeoff during human decision-making. *Neuropsychopharmacology*, *48*, 1078–1086. https://doi.org/10.1038/s41386-022-01517-9, PubMed: 36522404

Dayan, P. (2009). Dopamine, reinforcement learning, and addiction. *Pharmacopsychiatry*, *42*, S56–S65. https://doi.org/10.1055/s-0028-1124107, PubMed: 19434556

Dovidio, J. F., Love, A., Schellhaas, F. M. H., & Hewstone, M. (2017). Reducing intergroup bias through intergroup contact: Twenty years of progress and future directions. *Group Processes & Intergroup Relations*, *20*, 606–620. https://doi.org/10.1177/1368430217712052

Dubois, M., Habicht, J., Michely, J., Moran, R., Dolan, R. J., & Hauser, T. U. (2021). Human complex exploration strategies are enriched by noradrenaline-modulated heuristics. *eLife*, *10*, e59907. https://doi.org/10.7554/eLife.59907, PubMed: 33393461

Düzel, E., Bunzeck, N., Guitart-Masip, M., & Düzel, S. (2010). NOvelty-related Motivation of Anticipation and exploration by Dopamine (NOMAD): Implications for healthy aging. *Neuroscience & Biobehavioral Reviews*, *34*, 660–669. https://doi.org/10.1016/j.neubiorev.2009.08.006, PubMed: 19715723

Eschmann, K. C. J., Pereira, D. F. M. M., Valji, A., Dehmelt, V., & Gruber, M. J. (2023). Curiosity and mesolimbic functional connectivity drive information seeking in real life. *Social Cognitive and Affective Neuroscience*, *18*, nsac050. https://doi.org/10.1093/scan/nsac050, PubMed: 35975900

Fujiwara, J., Usui, N., Park, S. Q., Williams, T., Iijima, T., Taira, M., et al. (2013). Value of freedom to choose encoded by the human brain. *Journal of Neurophysiology*, *110*, 1915–1929. https://doi.org/10.1152/jn.01057.2012, PubMed: 23864380

Gilbert, D. T., Driver-Linn, E., & Wilson, T. D. (2002). The trouble with Vronsky: Impact bias in the forecasting of future affective states. In L. F. Barrett & P. Salovey (Eds.), *The wisdom in feeling: Psychological processes in emotional intelligence* (pp. 114–143). Guilford Press.

Gottlieb, J., Lopes, M., & Oudeyer, P.-Y. (2016). Motivated cognition: Neural and computational mechanisms of curiosity, attention, and intrinsic motivation. In S. Kim, J. Reeve, & M. Bong (Eds.), *Advances in motivation and achievement* (Vol. 19, pp. 149–172). Emerald Group Publishing Limited. https://doi.org/10.1108/S0749-742320160000019017

Gottlieb, J., Oudeyer, P.-Y., Lopes, M., & Baranes, A. (2013). Information-seeking, curiosity, and attention: Computational and neural mechanisms. *Trends in Cognitive Sciences*, *17*, 585–593. https://doi.org/10.1016/j.tics.2013.09.001, PubMed: 24126129

Gruber, M. J., Gelman, B. D., & Ranganath, C. (2014). States of curiosity modulate hippocampus-dependent learning via the dopaminergic circuit. *Neuron*, *84*, 486–496. https://doi.org/10.1016/j.neuron.2014.08.060, PubMed: 25284006

Gruber, M., & Ranganath, C. (2019). How curiosity enhances hippocampus-dependent memory: The Prediction-Appraisal-Curiosity-Exploration (PACE) framework. *Trends in Cognitive Sciences*, *23*, 1014–1025. https://doi.org/10.1016/j.tics.2019.10.003, PubMed: 31706791

Hökkä, P. K., Vähäsantanen, K., Paloniemi, S., & Eteläpelto, A. (2017). The reciprocal relationship between emotions and agency in the workplace. In M. Goller & S. Paloniemi (Eds.), *Agency at work* (Vol. 20, pp. 161–181). Springer International Publishing. https://doi.org/10.1007/978-3-319-60943-0_9

Hornsey, M. J., & Hogg, M. A. (2000). Assimilation and diversity: An integrative model of subgroup relations. *Personality and Social Psychology Review*, *4*, 143–156. https://doi.org/10.1207/S15327957PSPR0402_03

Jensen, D., Cohen, J. N., Mennin, D. S., Fresco, D. M., & Heimberg, R. G. (2016). Clarifying the unique associations among intolerance of uncertainty, anxiety, and depression. *Cognitive Behaviour Therapy*, *45*, 431–444. https://doi.org/10.1080/16506073.2016.1197308, PubMed: 27314213

Jiwa, M., Cooper, P. S., Chong, T. T.-J., & Bode, S. (2021). Choosing increases the value of non-instrumental information. *Scientific Reports*, *11*, 8780. https://doi.org/10.1038/s41598-021-88031-y, PubMed: 33888764

Kaiser, J., Buciuman, M., Gigl, S., Gentsch, A., & Schütz-Bosbach, S. (2021). The interplay between affective processing and sense of agency during action regulation: A review. *Frontiers in Psychology*, *12*, 716220. https://doi.org/10.3389/fpsyg.2021.716220, PubMed: 34603140

Kalin, N. H. (2004). The role of the central nucleus of the amygdala in mediating fear and anxiety in the primate. *Journal of Neuroscience*, *24*, 5506–5515. https://doi.org/10.1523/JNEUROSCI.0292-04.2004, PubMed: 15201323

Kalin, N. H., Shelton, S. E., Rickman, M., & Davidson, R. J. (1998). Individual differences in freezing and cortisol in infant and mother rhesus monkeys. *Behavioral Neuroscience*, *112*, 251–254. https://doi.org/10.1037/0735-7044.112.1.251, PubMed: 9517832

Kapp, B. S., Frysinger, R. C., Gallagher, M., & Haselton, J. R. (1979). Amygdala central nucleus lesions: Effect on heart rate conditioning in the rabbit. *Physiology & Behavior*, *23*, 1109–1117. https://doi.org/10.1016/0031-9384(79)90304-4, PubMed: 542522

Kelly, C. A., & Sharot, T. (2021). Individual differences in information-seeking. *Nature Communications*, *12*, 7062. https://doi.org/10.1038/s41467-021-27046-5, PubMed: 34862360

Kruglanski, A. W. (1989). *Lay epistemics and human knowledge: Cognitive and motivational bases*. Plenum Press. https://doi.org/10.1007/978-1-4899-0924-4

Lau, J. K. L., Ozono, H., Kuratomi, K., Komiya, A., & Murayama, K. (2020). Shared striatal activity in decisions to satisfy curiosity and hunger at the risk of electric shocks. *Nature Human Behaviour*, *4*, 531–543. https://doi.org/10.1038/s41562-020-0848-3, PubMed: 32231281

Leong, Y. C., Radulescu, A., Daniel, R., DeWoskin, V., & Niv, Y. (2017). Dynamic interaction between reinforcement learning and attention in multidimensional environments. *Neuron*, *93*, 451–463. https://doi.org/10.1016/j.neuron.2016.12.040, PubMed: 28103483

Leotti, L. A., & Delgado, M. R. (2011). The inherent reward of choice. *Psychological Science*, *22*, 1310–1318. https://doi.org/10.1177/0956797611417005, PubMed: 21931157

Leotti, L. A., & Delgado, M. R. (2014). The value of exercising control over monetary gains and losses. *Psychological Science*, *25*, 596–604. https://doi.org/10.1177/0956797613514589, PubMed: 24390827

Leotti, L. A., Iyengar, S. S., & Ochsner, K. N. (2010). Born to choose: The origins and value of the need for control. *Trends in Cognitive Sciences*, *14*, 457–463. https://doi.org/10.1016/j.tics.2010.08.001, PubMed: 20817592

Levy, I. (2018). Information utility in the human brain. *Proceedings of the National Academy of Sciences, U.S.A.*, *115*, 7846–7848. https://doi.org/10.1073/pnas.1809865115, PubMed: 29980646

Li, T., Zhao, F., & Yu, G. (2021). Who is more utilitarian? Negative affect mediates the relation between control deprivation and moral judgment. *Current Psychology*, *40*, 4024–4030. https://doi.org/10.1007/s12144-019-00301-1

Loosen, A. M., Skvortsova, V., & Hauser, T. U. (2021). Obsessive–compulsive symptoms and information seeking

during the Covid-19 pandemic. *Translational Psychiatry*, *11*, 309. https://doi.org/10.1038/s41398-021-01410-x, PubMed: 34021112
Marvin, C. B., & Shohamy, D. (2016). Curiosity and reward: Valence predicts choice and information prediction errors enhance learning. *Journal of Experimental Psychology: General*, *145*, 266–272. https://doi.org/10.1037/xge0000140, PubMed: 26783880
Mason, S. T., & Fibiger, H. C. (1979). Noradrenaline and avoidance learning in the rat. *Brain Research*, *161*, 321–333. https://doi.org/10.1016/0006-8993(79)90073-8, PubMed: 758978
McCall, J. G., Siuda, E. R., Bhatti, D. L., Lawson, L. A., McElligott, Z. A., Stuber, G. D., et al. (2017). Locus coeruleus to basolateral amygdala noradrenergic projections promote anxiety-like behavior. *eLife*, *6*, e18247. https://doi.org/10.7554/eLife.18247, PubMed: 28708061
Meder, D., Herz, D. M., Rowe, J. B., Lehéricy, S., & Siebner, H. R. (2019). The role of dopamine in the brain—Lessons learned from Parkinson's disease. *Neuroimage*, *190*, 79–93. https://doi.org/10.1016/j.neuroimage.2018.11.021, PubMed: 30465864
Metcalfe, J., & Kornell, N. (2003). The dynamics of learning and allocation of study time to a region of proximal learning. *Journal of Experimental Psychology: General*, *132*, 530–542. https://doi.org/10.1037/0096-3445.132.4.530, PubMed: 14640846
Metcalfe, J., & Kornell, N. (2005). A Region of Proximal Learning model of study time allocation. *Journal of Memory and Language*, *52*, 463–477. https://doi.org/10.1016/j.jml.2004.12.001
Murty, V. P., DuBrow, S., & Davachi, L. (2015). The simple act of choosing influences declarative memory. *Journal of Neuroscience*, *35*, 6255–6264. https://doi.org/10.1523/JNEUROSCI.4181-14.2015, PubMed: 25904779
Myrick, J. G., & Willoughby, J. F. (2019). Educated but anxious: How emotional states and education levels combine to influence online health information seeking. *Health Informatics Journal*, *25*, 649–660. https://doi.org/10.1177/1460458217719561, PubMed: 28728457
Niehoff, E., Mittenbühler, M., & Oosterwijk, S. (2023). To read or not to read? Motives for reading negative COVID-19 news. *American Psychologist*. https://doi.org/10.31234/osf.io/df6ye, PubMed: 37971843
Oosterwijk, S. (2017). Choosing the negative: A behavioral demonstration of morbid curiosity. *PLoS One*, *12*, e0178399. https://doi.org/10.1371/journal.pone.0178399, PubMed: 28683147
Rackoff, G. N., & Newman, M. G. (2020). Reduced positive affect on days with stress exposure predicts depression, anxiety disorders, and low trait positive affect 7 years later. *Journal of Abnormal Psychology*, *129*, 799–809. https://doi.org/10.1037/abn0000639, PubMed: 32914995
Render, A., & Jansen, P. (2019). Dopamine and sense of agency: Determinants in personality and substance use. *PLoS One*, *14*, e0214069. https://doi.org/10.1371/journal.pone.0214069, PubMed: 30889224
Robbins, T. W., & Arnsten, A. F. T. (2009). The neuropsychopharmacology of fronto-executive function: Monoaminergic modulation. *Annual Review of Neuroscience*, *32*, 267–287. https://doi.org/10.1146/annurev.neuro.051508.135535, PubMed: 19555290
Roelofs, K. (2017). Freeze for action: Neurobiological mechanisms in animal and human freezing. *Philosophical Transactions of the Royal Society of London, Series B: Biological Sciences*, *372*, 20160206. https://doi.org/10.1098/rstb.2016.0206, PubMed: 28242739
Rosen, N. O., Knäuper, B., & Sammut, J. (2007). Do individual differences in intolerance of uncertainty affect health monitoring? *Psychology & Health*, *22*, 413–430. https://doi.org/10.1080/14768320600941038
Schultz, C. B. (1974). Information seeking following the confirmation or contradiction of beliefs. *Journal of Educational Psychology*, *66*, 903–910. https://doi.org/10.1037/h0021534
Sescousse, G., Li, Y., & Dreher, J.-C. (2015). A common currency for the computation of motivational values in the human striatum. *Social Cognitive and Affective Neuroscience*, *10*, 467–473. https://doi.org/10.1093/scan/nsu074, PubMed: 24837478
Sharot, T., & Sunstein, C. R. (2020). How people decide what they want to know. *Nature Human Behaviour*, *4*, 14–19. https://doi.org/10.1038/s41562-019-0793-1, PubMed: 31932690
Smith, D. V., Rigney, A. E., & Delgado, M. R. (2016). Distinct reward properties are encoded via corticostriatal interactions. *Scientific Reports*, *6*, 20093. https://doi.org/10.1038/srep20093, PubMed: 26831208
Smith, R., Taylor, S., Wilson, R. C., Chuning, A. E., Persich, M. R., Wang, S., et al. (2022). Lower levels of directed exploration and reflective thinking are associated with greater anxiety and depression. *Frontiers in Psychiatry*, *12*, 782136. https://doi.org/10.3389/fpsyt.2021.782136, PubMed: 35126200
Soroya, S. H., Farooq, A., Mahmood, K., Isoaho, J., & Zara, S. (2021). From information seeking to information avoidance: Understanding the health information behavior during a global health crisis. *Information Processing & Management*, *58*, 102440. https://doi.org/10.1016/j.ipm.2020.102440, PubMed: 33281273
Subramanian, A., Chitlangia, S., & Baths, V. (2022). Reinforcement learning and its connections with neuroscience and psychology. *Neural Networks*, *145*, 271–287. https://doi.org/10.1016/j.neunet.2021.10.003, PubMed: 34781215
Sweeny, K., Melnyk, D., Miller, W., & Shepperd, J. A. (2010). Information avoidance: Who, what, when, and why. *Review of General Psychology*, *14*, 340–353. https://doi.org/10.1037/a0021288
Tajfel, H., & Turner, J. (1979). An integrative theory of intergroup conflict. In W. G. Austin & S. Worchel (Eds.), *The social psychology of intergroup relations* (pp. 33–37). Monterey, CA: Brooks/Cole.
van Lieshout, L. L., de Lange, F. P., & Cools, R. (2020). Why so curious? Quantifying mechanisms of information seeking. *Current Opinion in Behavioral Sciences*, *35*, 112–117. https://doi.org/10.1016/j.cobeha.2020.08.005
van Lieshout, L. L. F., Traast, I. J., de Lange, F. P., & Cools, R. (2021). Curiosity or savouring? Information seeking is modulated by both uncertainty and valence. *PLoS One*, *16*, e0257011. https://doi.org/10.1371/journal.pone.0257011, PubMed: 34559816
Vedejová, D., & Čavojová, V. (2022). Confirmation bias in information search, interpretation, and memory recall: Evidence from reasoning about four controversial topics. *Thinking & Reasoning*, *28*, 1–28. https://doi.org/10.1080/13546783.2021.1891967
Vellani, V., de Vries, L. P., Gaule, A., & Sharot, T. (2020). A selective effect of dopamine on information-seeking. *eLife*, *9*, e59152. https://doi.org/10.7554/eLife.59152, PubMed: 33295870
Vries, H. D., Backbier, E., Kok, G., & Dijkstra, M. (1995). The impact of social influences in the context of attitude, self-efficacy, intention, and previous behavior as predictors of smoking onset. *Journal of Applied Social Psychology*, *25*, 237–257. https://doi.org/10.1111/j.1559-1816.1995.tb01593.x
Wade, S., & Kidd, C. (2019). The role of prior knowledge and curiosity in learning. *Psychonomic Bulletin & Review*, *26*,

1377–1387. https://doi.org/10.3758/s13423-019-01598-6, PubMed: 31079309

Wang, K. S., & Delgado, M. R. (2019). Corticostriatal circuits encode the subjective value of perceived control. *Cerebral Cortex*, *29*, 5049–5060. https://doi.org/10.1093/cercor/bhz045, PubMed: 30877791

Webster, D. M., & Kruglanski, A. W. (1994). Individual differences in need for cognitive closure. *Journal of Personality and Social Psychology*, *67*, 1049–1062. https://doi.org/10.1037/0022-3514.67.6.1049, PubMed: 7815301

White, J. K., Bromberg-Martin, E. S., Heilbronner, S. R., Zhang, K., Pai, J., Haber, S. N., et al. (2019). A neural network for information seeking. *Nature Communications*, *10*, 5168. https://doi.org/10.1038/s41467-019-13135-z, PubMed: 31727893

Wilson, R. C., Bonawitz, E., Costa, V. D., & Ebitz, R. B. (2021). Balancing exploration and exploitation with information and randomization. *Current Opinion in Behavioral Sciences*, *38*, 49–56. https://doi.org/10.1016/j.cobeha.2020.10.001, PubMed: 33184605

Wilson, T. D., & Gilbert, D. T. (2005). Affective forecasting: Knowing what to want. *Current Directions in Psychological Science*, *14*, 131–134. https://doi.org/10.1111/j.0963-7214.2005.00355.x

Zimmerman, J. M., Rabinak, C. A., McLachlan, I. G., & Maren, S. (2007). The central nucleus of the amygdala is essential for acquiring and expressing conditional fear after overtraining. *Learning & Memory*, *14*, 634–644. https://doi.org/10.1101/lm.607207, PubMed: 17848503