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Subjective judgments on direct and generative retrieval of autobiographical memory: The role of interoceptive sensibility and emotion

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Abstract
Autobiographical remembering is a subjective experience, and whether retrieval is perceived to occur through involuntary or voluntary, direct or generative cognitive processes is also based on subjective intuition. The present study examined factors that may contribute to the subjective judgment that occurs when we perceive memories as being retrieved directly (i.e., a memory comes to mind directly and immediately) or through generative processes (i.e., recalling a memory with effort or by using additional information). We examined the hypothesis that internal awareness (interoceptive sensibility and mindfulness traits) contributes to the physical reaction and emotional impact of memories at retrieval, which then influence the subjective judgment that memories are retrieved directly. In two online experiments, participants were asked to recall specific memories following verbal cues and to judge the retrieval process (i.e., direct or generative). We demonstrated that emotional awareness, an interoceptive sensibility scale factor, consistently predicted a high probability of direct retrieval judgments independent of other predictors of direct retrieval, such as retrieval latency and cue concreteness. This effect was especially common for concrete cues. In Experiment 2 we demonstrated that emotional awareness predicted direct retrieval judgments through the mediation of retrieval impact (physical reaction and emotional impact). These results indicate the involvement of interoceptive processing in the direct retrieval of autobiographical memories. We discuss the role of interoception in memory retrieval and present interoceptive prediction error as a novel and potentially integrative account of our findings.

Keywords Autobiographical memory · Retrieval process · Involuntary memory · Interoception · Mindfulness

Introduction

Autobiographical memory refers to the collection of past events that we have experienced in our lives. Previous research has focused on how we retrieve our autobiographical past (Berntsen, 1996, 2010; Conway, 2005; Conway & Pleydell-Pearce, 2000) and memory retrieval has generally been discussed as taking one of three forms: (voluntary) generative, (voluntary) direct, or involuntary retrieval (Barzykowski & Staugaard, 2016). These forms of retrieval can be differentiated on the basis of the presence or absence of recall intention and on whether the memory came to mind immediately or not. Voluntary retrieval occurs when we deliberately try to recall a memory (i.e., following an explicit memory prompt during an experiment), while involuntary retrieval occurs when a memory spontaneously comes to mind without any intention (i.e., in the absence of an explicit memory prompt). Direct retrieval following an explicit memory prompt and involuntary retrieval occur when a memory comes to mind directly and immediately, while generative retrieval occurs when recalling a memory with effort or using additional information beyond the original cue (Uzer et al., 2012). Several studies have shown that memory properties, such as vividness and clarity, elicited

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by involuntary retrieval and direct retrieval are similar (Barzykowski & Staugaard, 2016).

Autobiographical remembering is a subjective experience (Tulving, 2002), and whether retrieval is perceived to occur through involuntary or voluntary, direct or generative processes also involves a subjective component. In this sense, understanding factors that inform our subjective judgment of how memories are retrieved can potentially inform our understanding of consciousness (Berntsen, 2021), can address questions about what it means to *deliberately* recall our past, and the psychological mechanisms underlying autonoetic consciousness (Tulving, 2002). Exploring the mechanisms and individual difference factors that underpin memory retrieval will allow us to elucidate memory experiences such as intrusive images and flashbacks that occur through direct or involuntary retrieval and are commonly associated with psychological disorder (Brewin et al., 2010). In the present study, we focus on direct and generative retrieval processes and experimentally examine the subjective component of retrieval judgments.

Distinguishing between direct and generative retrieval

Direct and generative modes of retrieval have been distinguished and examined from three perspectives: (a) latency (reaction time), (b) cue concreteness/imageability, and (c) subjective judgment. In studies measuring retrieval latency (Conway, 2005; Haque & Conway, 2001), short retrieval latencies have been regarded as indexing direct retrieval, while long retrieval latencies have been regarded as indexing generative retrieval. In studies manipulating cue concreteness or imageability (Anderson et al., 2012, 2017; Hauer et al., 2008; Rasmussen & Berntsen, 2014; Sanson et al., 2020; Williams et al., 1999; Eade et al., 2006), researchers hypothesized that concrete/highly imaginable cues are more likely to elicit memories through mechanisms of direct retrieval, and that abstract/less imaginable cues are more likely to elicit memories through generative retrieval mechanisms. These studies showed that concrete/highly imaginable cues elicited memories with shorter retrieval latencies than did abstract/less imaginable cues (Anderson et al., 2012, 2017; Rasmussen & Berntsen, 2014; Williams et al., 1999). In addition, concrete cues produced more specific memories, whereas abstract cues produced more general memories (Anderson et al., 2012, 2017; Hauer et al., 2008; Rasmussen & Berntsen, 2014; Williams et al., 1999; Eade et al., 2006).

In studies investigating subjective judgments of retrieval mode, participants were explicitly asked to report on whether their memories came to mind through direct or generative processes (Harris & Berntsen, 2019; Janssen et al., 2021; Matsumoto et al., 2020; Uzer et al., 2012; Uzer, 2016; Uzer & Brown, 2017) or voluntary or involuntary retrieval processes (Barzykowski et al., 2021; Sanson et al., 2020). This method revealed that memories that came to mind following concrete cues and with short retrieval latencies, averaging approximately 5 s or less, were judged as having been retrieved directly while memories with relatively long retrieval latencies, averaging approximately 10 s (Uzer et al., 2012) were judged as having been retrieved through generative processes. However, some memories judged to be retrieved directly were observed following a long latency and in response to abstract cues. Conversely, memories judged to be retrieved through generative retrieval were also observed with short latencies and following concrete cues. According to Uzer et al. (2012), Uzer and Brown (2017), approximately 40–50% of direct retrieval judgments occur for abstract cues, and approximately 40% of generative retrieval judgments occur for concrete cues.

These findings highlight an important question then as to how people formulate these subjective distinctions during the retrieval process. Some previous studies showed that individual differences or states influence subjective retrieval judgments (Barzykowski et al., 2021; Matsumoto et al., 2020; Sanson et al., 2020). Sanson et al. (2020) showed that retrieval fluency during voluntary retrieval led to subjective feelings of involuntary retrieval rather than voluntary retrieval, and Barzykowski et al. (2021) showed that less subjective effort led to judgments of involuntary retrieval. To further understand the subjective nature of the retrieval judgment, we need to consider additional factors that may contribute to the subjective components of retrieval judgments during in the retrieval process.

Interoception and the subjective retrieval process

Theoretical and neuropsychological research suggests that while generative or voluntary memory retrieval is driven by top-down processes that involve cognitive control and brain regions associated with executive function, involuntary or direct retrieval is understood to be driven more heavily by bottom-up associative processing where event retrieval is constrained by contextual factors (Berntsen, 2021; Conway & Pleydell-Pearce, 2000; Hall et al., 2008). While there is a difference between direct and involuntary retrieval in terms of the presence or absence of intention of recall, the overlap between direct and involuntary modes of retrieval in terms of the immediacy suggests that our knowledge of involuntary retrieval is helpful in understanding the mechanisms underlying direct retrieval. Distinct features of the cueing context, overlap between cue context and memory content, and individual difference factors such as the emotional well-being or regulatory style of an individual have been found to be involved in involuntary memory retrieval (see Berntsen, 2021, for a review).

One consistent difference between involuntary and voluntary memory retrieval is that involuntary memories are associated with more extreme emotional valence (Barzykowski et al., 2019; Barzykowski & Staugaard, 2016) and elicit stronger emotional responses than memories retrieved voluntarily (Berntsen & Hall, 2004; Del Palacio-Gonzalez et al., 2017; Watson et al., 2012). It is well known that emotion is often brought about by autobiographical recall (Damasio et al., 2000; Rainville et al., 2006), and changes in the internal state during this process are associated with subjectively feeling emotion (Damasio et al., 2000). Due to the strong relationship between contextual factors at retrieval and features of direct and involuntary memories, we hypothesize here that perceived interoception, defined as the perception of internal bodily experiences (Garfinkel et al., 2015), may influence the subjective judgments and emotional impact of direct and involuntary autobiographical memories.

During direct and involuntary retrieval, information in the external or internal environment may lead to alterations in bodily systems, or cue-induced interoceptions, which are then transmitted through the insular cortex (Craig, 2002, 2009). Memories appropriate to explain the sensory inputs and associated emotions may be constructed (Craig, 2009; Critchley & Garfinkel, 2017; Khalsa et al., 2018). For example, consider individuals who have a traumatic experience. When patients are presented with the cue "blood," an increase in heart rate could be observed as an autonomic response (Ehlers et al., 2010). This physical reaction would then be sent to the brain via afferent nerves and interoception would occur at the neural level (Craig, 2009). Based on past experiences associated with similar environmental (the cue blood) and interoceptive cues (increase in heart rate), a memory that best aligns with the incoming sensory experience is then retrieved, "I saw a man covered in blood following a car accident," and simultaneously emotion is constructed by the inference of the incoming sensory experiences as they relate to the memory content. Memory recall may occur spontaneously with a bodily sensation (Umeda et al., 2016) like an automatic process, or it may be brought about by active inference regarding the causes of the interoception (Barrett, 2017; Barrett et al., 2016; Paulus et al., 2019). Umeda et al. (2016) showed that spontaneous retrieval in prospective memory tasks was brought about by interoception, and since involuntary memory is a subtype of spontaneous retrieval (Kvavilashvili et al., 2020), it seems plausible that involuntary or direct retrieval is also supported by interoception.

Further support for this hypothesis extends from predictive processing models of interoception (Barrett, 2017; Barrett & Simmons, 2015; Critchley & Garfinkel, 2017; Seth & Friston, 2016). This line of research suggests that humans constantly make predictions about incoming sensory signals and create cognitions and emotions based on the prediction error between these predictions and actual sensory input. In other words, our cognitions and emotions are constructed by interpreting why the interoceptive experiences have arisen. Prediction error may explain why emotions evoked in voluntary generative retrieval are generally less intense, while those evoked in involuntary and direct retrieval are generally strong. When an autobiographical memory is retrieved on the basis of strong incoming sensory signals (i.e., interoceptive prediction error), emotions are simultaneously perceived on the basis of prediction error referring to the memory content, and greater retrieval (emotional) impact may be perceived. The likelihood of an involuntary or direct retrieval judgment may be increased if the judgments of retrieval process are based on a subjective sense of "sudden recall" derived from a large prediction error. Thus, in subjectively perceived involuntary or direct retrieval, the evoked emotion is also greater (Barzykowski et al., 2019; Barzykowski & Staugaard, 2016). Conversely, and in line with the definition of generative retrieval, when retrieval occurs with intention and involves cognitive effort (Barzykowski et al., 2021), memories are gradually recovered (Cabeza & St. Jacques, 2007; Schacter & Addis, 2007; St. Jacques & Cabeza, 2012), and top-down predictions of incoming sensations associated with recollection may be updated intermittently, which may result in smaller prediction errors during memory recall (or memories that are recalled in the absence of available sensations; Barron et al., 2020). Generative retrieval has these features, and ones possibly judged as generative retrieval based on this small prediction error.

Individual differences in internal awareness

Given interoception is involved in direct or involuntary retrieval, we argue that internal awareness can affect also subjective judgments. Internal awareness here refers to interoceptive awareness or mindful awareness. There are various ways to measure interoception (Garfinkel et al., 2015); in this study we will focus on interoceptive sensibility, which is measured by a self-report scale. Interoceptive sensibility contributes to greater internal bodily sensation, and as a result, when a memory that corresponds to current interoceptive experience comes into consciousness, this may lead to greater emotional impact and an increased likelihood that memories will be judged as having been retrieved directly. Conversely, if one's interoception is insensitive, for example when internal bodily sensation is less available or when retrieval is reliant on top-down processing, this may lead to low emotional impact and an increased likelihood to judge memory retrieval as generative. To the best of our knowledge, no empirical studies have examined the relationship between interoception and direct or involuntary retrieval.

Interoceptive sensibility can be involved in involuntary and direct retrieval judgments in two ways. First,

interoceptive sensibility may enhance these bottom-up retrieval processes directly, leading to shorter retrieval latencies and high levels of memory specificity. Second, interoceptive sensibility may determine involuntary and direct retrieval judgments independently of retrieval latency and memory specificity. In this case, the large retrieval impact induced by greater interoceptive sensibility may affect the subjective retrieval process judgments, rendering the explanation from the perspective of interoceptive prediction error plausible.

Interoception and mindfulness are encompassed as internal awareness, which can be improved by mindfulness interventions (Raffone & Srinivasan, 2010), a core component of which is to cultivate interoception (for a review, see Gibson, 2019). In particular, open monitoring practice, which improves the ability to monitor the contents of experience without any reactions or judgments, enables practitioners to be aware of bodily sensations (Lutz et al., 2008; Raffone & Srinivasan, 2010). However, some evidence suggests that interoception and mindfulness are measured as separate but related constructs. The self-administered questionnaire MAIA (Multidimensional Assessment of Interoceptive Awareness; Mehling et al., 2012) measures interoceptive sensibility, and consists of eight factors – one that measures mindful and adaptive aspects, one that measures mindless and maladaptive aspects, and one that does not distinguish between adaptive and maladaptive aspects (Mehling, 2016). Studies examining changes in interoceptive sensibility as an outcome of mindfulness interventions have found effects on some factors of the MAIA, while no change has been found for other factors (Bornemann et al., 2015; de Jong et al., 2016; Fissler et al., 2016). Similarly, mindfulness traits measured by a self-report scale are correlated with some but not all factors in the MAIA (Mehling et al., 2012; Todd et al., 2020). Thus, there are areas of overlap and nonoverlap between interoceptive sensibility and mindfulness, and the two may show different associations with judgments of retrieval process.

The present study

The aims of the present study are to examine whether traits of internal awareness (interoceptive sensibility and mindful awareness) are associated with subjective judgment of the retrieval process. Although subjective and objective measures need to be examined in relation to direct retrieval judgment, as a first step, the present study measures interoceptive sensibility and mindful awareness on self-report scales. If internal awareness is associated with direct retrieval indexes such as faster retrieval latency, this would provide evidence to suggest that it facilitates bottom-up retrieval directly. However, if internal awareness leads to more direct retrieval judgments independently of retrieval latency, this would provide evidence for alternative mechanisms though which internal awareness can affect direct retrieval. In Experiments 1 and 2 we investigate the extent to which internal awareness predicts the subjective component of retrieval judgments and in Experiment 2 we additionally examine the role of the emotional and physical retrieval impact of individual memories on these subjective judgments.

Experiment 1

In Experiment 1, we indexed direct retrieval in three ways (i.e., retrieval latency, cue concreteness, and subjective judgment) to observe direct retrieval judgment. As mentioned above, concrete cues produce more direct retrieval judgments with relatively short retrieval latencies, and memories with short retrieval latencies tend to be judged as having been retrieved directly. We hypothesized that higher levels of interoceptive sensibility and mindful awareness would be associated with more direct retrieval judgments, and that these associations were found even when controlling for the effects of retrieval latency and cue concreteness. Based on the idea that bodily sensation and emotional impact increase the probability of direct retrieval judgments, we employed emotionally valenced cues (positive and negative) that are likely to elicit these feelings.

Materials and methods

Participants

Participants were recruited on Crowd Works (https://crowdworks.jp/), where the registrants undertake tasks online (similar to Amazon Mechanical Turk). As this is a novel study, the prior effect size was estimated to be moderate. We required the sample size (N = 76) to detect a moderate correlation (r = .30) at criteria of $\alpha = 0.05$ and power $(1\text{-}\beta) = 0.80$. 102 participants aged 20–49 years completed the task. Two participants who desired their data to be excluded from analyses and those who made inappropriate descriptions or omissions for over half of the trials in the AMT (Autobiographical Memory Test) (n = 5) were excluded. In total, 95 participants (37.46 ± 6.54 years old, 38 males, 57 females) were included in the analyses.

MAAS

MAAS (Mindful Attention Awareness Scale; Brown & Ryan, 2003) is a 15-item self-report questionnaire measuring mindfulness traits. The Japanese version was developed by Fujino et al. (2015). In this study, each statement was rated on a 6-point scale (1 = almost never, 6 = almost always)

where high scores indicate low mindfulness. Good internal consistency was shown in the present study ($\alpha = .88$).

MAIA

The MAIA (Mehling et al., 2012) is a self-report questionnaire consisting of eight factors and 32 items that measures multidimensional interoceptive sensibility. Participants rated all items on a 6-point scale (0 = not at all, 5 = always). The Japanese version was developed by Shoji et al. (2018), who demonstrated its sufficient reliability and validity. The internal consistency values in this study were as follows: noticing ($\alpha = .70$), not distracting ($\alpha = .78$), not worrying ($\alpha = .41$), attention regulation ($\alpha = .85$), emotional awareness ($\alpha = .84$), self-regulation ($\alpha = .76$), body listening ($\alpha = .88$), and trusting ($\alpha = .83$). These values were acceptable except for the value for not worrying.

AMT

The AMT (Williams & Broadbent, 1986) is a representative task for the retrieval of specific autobiographical memories. The addition of Uzer's extended instruction allowed us to obtain subjective judgments of direct and generative retrieval (Uzer et al., 2012). The task was programmed in lab.js (https://lab.js.org/) and carried out online (the Japanese version of the program is available from https://osf.io/qstn8/).

Firstly, participants were provided with guided instructions on how to complete the task. Participants were instructed to recall a specific memory that occurred at a particular time and place within a day and to press the space bar when they had recalled a specific memory within 30 s. They then practiced using the word cue "friendly," filling in the blanks on the screen with the memories they recalled. Subsequently, they were given instructions about direct and generative retrieval and asked to decide whether a recalled memory had come to mind immediately without any effort and additional information (direct) or whether it had been recalled with effort and/or using additional information (generative). Participants were required to press the "E" key if they experienced a direct retrieval or the "I" key if they experienced a generative retrieval, and then they practiced using "broad" as a cue. Through this guided instruction, participants learnt the sequence of the task: after the presentation of the cue word, when a specific memory came to mind, they pressed the space bar, answered a question regarding the retrieval process, and then entered the memory content.

In the main task, participants were presented with five concrete positive cues (gift, baby, wedding, smile, and party; in Japanese: プレゼント, 赤ちゃん, 結婚式, 笑顔, パーティー), five concrete negative cues (funeral, fight, dentist, final exam, and blood; in Japanese: 葬式, 喧嘩, 歯医者, 期末試験, 血), five abstract positive cues (honest, safe, peaceful, brave, and cooperative; in Japanese: 素直な, 安全な, 平和な, 勇敢な, 協力的な), and five abstract negative cues (timid, dissatisfied, clumsy, apathy, and painful; in Japanese: 弱気な, 不満な, 不器用な, 無気力な, つらい) and completed the same task sequence for each cue provided. The only difference in this online version of the task from the standard laboratory experiment (Uzer et al., 2012) is that even if participants pressed the space bar to record their response latency, the screen that presented a cue word did not proceed until 30 s had elapsed. According to the ordinary procedure (e.g., Matsumoto et al., 2020), two independent raters classified recalled memories into the following five categories: (a) Specific memory: a past event that occurred at a particular time and place within 1 day, (b) Categoric memory: memories that summarized similar events, (c) Extended memory: a past event lasting longer than 1 day, (d) Semantic association: semantic memories that are not events, (e) Omission: no response or inappropriate response. Good agreement on these classifications was obtained among two independent raters (Cohen's $k = .81$).

Prior to the online implementation, we conducted an initial pilot study to examine whether the retrieval latencies and direct retrieval rate were comparable to those found under laboratory conditions. In the first pilot study, the space bar press (retrieval latency) was clearly faster than that in the laboratory experiment, which could be attributed to time pressure (in Crowd Works, participants must complete tasks within 60 min to acquire rewards). To counter this and precisely measure retrieval latency, we set and explicitly stated that a quick space bar press did not lead to advancing to the next screen. In a second pilot study, we excluded trials showing extremely short retrieval latencies (< 500 ms). This decision was made post hoc, following a review of the data and study instructions. Data from a small number of participants indicated that rapid responses on early trials were the result of an attempt to move on to subsequent trials rather than due to memory retrieval per se. While there is little guidance concerning response thresholds for online cognitive studies, a cut-off of < 500 ms was employed here so as to minimize the inclusion of such trials where rapid responses were identified. Finally, we confirmed that direct retrieval judged by participants required approximately 5 s, generative retrieval required approximately 10 s, and the direct retrieval rate was 65%; these results were comparable to those observed under laboratory conditions (e.g., Uzer & Brown, 2017).

Procedure

This study was carried out under the approval of the ethics committee of psychological studies, Faculty of Arts, Shinshu University. After consenting to the study description, participants took part in the experiment online. They were

asked to create an environment in which they could concentrate alone before the experiment began. After entering their demographic data, participants completed the AMT, followed by the self-report questionnaires.[1] Finally, they were asked if they had experienced any problems during the experiment, if they would like their data to be excluded from analysis, and if they had participated in similar experiments in the past. Participants received 300 yen (approximately $3) as compensation for their participation.

Statistical analysis

Statistical analyses were carried out using R statistics. The raw data, R code, and supplementary file are available from the Open Science Framework (https://osf.io/qstn8/). The data treated in this study have a hierarchical structure with 1,900 trials nested within 95 participants. We considered only trials in which participants recalled specific memories, as previous studies examining differences between voluntary and involuntary memory characteristics that have considered memory specificity (Barzykowski et al., 2019; Barzykowski & Staugaard, 2016) suggested that memory specificity can be confounded by emotional impact (Williams et al., 2007). In the analyses restricted to trials in which specific memories were recalled, 1,138 trials nested within 95 participants were included. Among these trials, 13 trials showing extremely short retrieval latency (< 500 ms) were pairwise deleted from analysis according to the pilot study described above. In almost all analyses, except for the descriptive statistics, the retrieval latency was log-transformed because the distribution was skewed to the left.

To check the manipulation for distinguishing retrieval processes, we used the linear mixed model (LMM) or generalized linear mixed model (GLMM) to determine whether retrieval latency, cue concreteness, subjective judgment, and memory specificity were associated with each other, consistent with previous studies. Specifically, we found that (a) concrete cues elicited more specific memories than abstract cues, (b) concrete cues produced more direct retrieval judgments than abstract cues, (c) concrete cues brought shorter retrieval latencies than abstract cues, and (d) retrieval latencies were faster for direct retrieval judgments than for generative retrieval judgments. These analyses were performed using the *lme4* package in R. Since the purpose here is a simple manipulation check, no random slope was entered to build an accurate model; only a random intercept was set.

Next, multilevel correlations (Kenny & la Voie, 1985) were computed using the *lavaan* package in R to examine the relationship between interoceptive sensibility and mindful awareness and direct retrieval judgments. We also examined whether these individual differences were associated with retrieval latency.

Finally, the GLMM was used to examine whether the influence of individual differences (interoceptive sensibility and/or mindful awareness) on direct retrieval judgments were significant when controlling for retrieval latency, cue concreteness, and emotional valence. For model specification, we initially aimed to include random slope effects, provided that we did not lose too much power (Matuschek et al., 2017) and that the model could converge and did not exhibit a singular error (Brown, 2021). First, we created a model (Model 1) with a random intercept and fixed main effects of cue word concreteness, cue valence, and retrieval latency. Next, we created a model with individual difference variables added to the first model (Model 2) and carried out the likelihood ratio test to compare these two models (i.e., examining the significance of individual difference variables). We then tested a model with random slopes added to the first model (Model 3) and a model with random slopes added to the second model (Model 4). However, both models showed a singular error, and this problem was not solved by setting the optimizers, omitting the derivative calculations, or assuming the random intercept and the random slopes to be uncorrelated. A possible reason for these problems is that the model to be estimated was overly complex relative to the data (Matuschek et al., 2017). This change may inflate the risk of Type I error (Barr et al., 2013; Murayama et al., 2014), but a replication study (Experiment 2) would reduce the risk. We therefore abandoned the attempt to fit random slope effects into the model. The final model was the second model with the exploratory addition of the interaction terms as the fixed effects (Model 5).

Results

Preliminary analysis

As a manipulation check, the relationship among retrieval latency, cue concreteness, subjective judgments, and memory specificity was tested. Concrete cues produced more specific memories than abstract cues and no interaction effect with cue valence was observed (Table 1 upper). Excluding omissions, specific memories were reported in 84.8% of trials for concrete positive cues, 77.5% for concrete negative cues, 62.3% for abstract positive cues, and 49.8% for abstract negative cues. When specific memories were recalled, concrete cues produced more direct retrieval judgments than abstract cues (79.2% vs. 57.1% on average without a hierarchical assumption); in addition, negative cues produced more direct retrieval

[1] We also measured depression in Experiment 1 and depression and anxiety in Experiment 2, but these are not reported here. Data and correlations are available from the OSF.

Table 1 Generalized linear mixed model for specific memory response and subjective judgment of retrieval process and linear mixed model for retrieval latency

	Coefficient	SE	OR	95% Lower	95% Upper	*t*	*p*
DV = Specific memory response (1 or 0)							
Intercept	0.49	0.09	1.63	1.37	1.94	5.55	<.001
Cue concreteness	1.39	0.11	4.02	3.26	4.95	13.11	<.001
Cue valence	0.25	0.10	1.28	1.05	1.57	2.39	.017
Cue concreteness * valence	0.25	0.21	1.29	0.86	1.93	1.21	.23
DV = Direct (1) / Generative (0) judgment							
Intercept	0.93	0.11	2.55	2.06	3.15	8.64	<.001
Cue concreteness	1.17	0.15	3.21	2.40	4.30	7.85	<.001
Cue valence	-0.68	0.15	0.51	0.38	0.67	-4.67	<.001
Cue concreteness * valence	0.52	0.29	1.68	0.95	2.97	1.79	.073
DV = Retrieval latency (msec)							
Intercept	8.78	0.07		8.64	8.92	120.50	<.001
Cue concreteness	-0.12	0.04		-0.20	-0.04	-2.99	.003
Cue valence	0.06	0.04		-0.01	0.14	1.65	.090
Retrieval process	-0.45	0.05		-0.54	-0.36	-9.68	<.001

Concrete cue was coded as 0.5 and abstract cue was coded as -0.5. Positive cue was coded as 0.5 and negative cue was coded as -0.5. Direct retrieval was coded as 0.5 and generative retrieval was coded as -0.5 used for independent variable. Retrieval latency was log-transformed for linear model. 95% confidence intervals of Odds Ratio (OR) are shown for GLMM and of coefficient are shown for LMM

Table 2 Descriptive statistics and correlations between mindfulness traits and interoceptive sensibility in Experiment 1

	M	*SD*	1	2	3	4	5	6	7	8	9
1. MAAS	43.65	10.41									
2. MAIA total	74.51	17.48	-.21*								
3. Noticing	9.05	3.43	.14	.44**							
4. Not-Distracting	7.91	2.96	-.43***	.16	-.34***						
5. Not-Worrying	6.46	2.25	-.31**	.25*	-.36***	.31**					
6. AttentionRegulation	17.21	5.18	-.25*	.77***	.30**	.14	.09				
7. EmotionalAwareness	12.03	4.54	.01	.80***	.45***	-.05	.05	.48***			
8. Self-Regulation	9.29	3.46	-.15	.85***	.21*	.05	.26*	.65***	.57***		
9. Body-Listening	5.59	2.98	.03	.74***	.41***	-.13	.02	.37***	.63***	.67***	
10. Trusting	6.96	2.96	-.18	.73***	.19	-.01	.26*	.38***	.53***	.67***	.63***

MAAS Mindful Attention Awareness Scale, *MAIA* Multidimensional Assessment of Interoceptive Awareness

*** $p < .001$, ** $p < .01$, * $p < .05$

judgments than positive cues (77.0% vs. 65.1% on average without a hierarchical assumption) (Table 1, middle). When specific memories were recalled, retrieval latency was faster for concrete cues than abstract cues and was faster for negative cues than positive cues (6.36 s for concrete positive cues, 5.84 s for concrete negative cues, 8.30 s for abstract positive cues, and 7.22 s for abstract negative cues; Table 1, lower). Retrieval latency was faster in trials judged as direct retrieval (5.46 s) than in trials judged as generative retrieval (9.86 s) (Table 1, lower). These results demonstrated that each index of retrieval process was associated with each other and warranted the experimental manipulation.

Descriptive statistics and multilevel correlations

Table 2 shows the descriptive statistics and Pearson's correlation matrix between the individual difference variables. Mindfulness traits (MAAS, mindless) were associated with low levels of interoceptive sensibility (MAIA total) but were not associated with some subordinate factors of interoceptive sensibility, noticing, emotional awareness, and body listening.

Table 3 Descriptive statistics and intercorrelations for specific autobiographical recall in Experiment 1

	Overall		Concrete cues		Abstract cues	
	Subjective judgment	Retrieval latency	Subjective judgment	Retrieval latency	Subjective judgment	Retrieval latency
Subjective judgment	**.08*****	-.32***	**.10****	-.26***	**.09***	-.35***
Retrieval latency (RT)	-.15	**.45*****	-.17	**.44*****	-.11	**.48*****
MAAS	-.03	-.17	-.07	-.16	-.01	-.17
MAIA total	.36*	-.19	.44**	-.23*	.25	-.15
Noticing	.15	-.24*	.11	-.24*	.20	-.25*
Not-Distracting	-.07	-.05	.03	-.03	-.15	-.10
Not-Worrying	.10	.12	.09	.08	.09	.17
Attention Regulation	.09	-.05	.13	-.06	.03	-.04
Emotional Awareness	.39**	-.13	.49**	-.12	.21	-.15
Self-Regulation	.28	-.21	.38*	-.27*	.13	-.13
Body-Listening	.46**	-.29*	.50**	-.34**	.36	-.22
Trusting	.44**	-.10	.45**	-.18	.42*	.01

Interclass correlations were shown in bold. Trial level correlations were shown with underbar and the others were individual level correlations. Retrieval latency was log-transformed

MAAS Mindful Attention Awareness Scale, *MAIA* Multidimensional Assessment of Interoceptive Awareness

*** $p < .001$, ** $p < .01$, * $p < .05$

For the hierarchical structural data, multilevel correlations were calculated within the trial level and individual level (Kenny & la Voie, 1985) for specific autobiographical recall (Table 3). The interclass correlations of retrieval latency and subjective judgments were significant, suggesting that retrieval latency and subjective judgments have a certain stability within individuals. In trait level correlations, individuals with a tendency towards direct retrieval judgments show shorter retrieval latencies. The MAIA total, emotional awareness, body listening, and trusting scores were associated with more direct retrieval judgments. These correlations were also found in any recall (Online Supplementary Material (OSM) Table S1) and observed for concrete cues (Table 3) but not for abstract cues excluding the trusting factor (Table 3). The noticing and body listening factors were related to shorter retrieval latency (Table 3). The correlation between noticing and retrieval latency was also found for concrete and abstract cues, and the correlation between body listening and retrieval latency was also shown in concrete cues. Mindfulness traits were not associated with either subjective judgments or retrieval latency.[2] None of the interoceptive sensibility factors were associated with memory specificity (OSM Table S1).

Subjective judgments on retrieval process

Given the lack of association between mindfulness traits (MAAS) and direct retrieval judgments in the multilevel correlations, subsequent analyses focused on interoceptive sensibility. To avoid repetition of statistical tests, we examined only the effects of the MAIA total score and the emotional awareness, body listening, and trusting scores, which were significantly correlated with direct retrieval judgments in the multilevel correlations. The GLMMs were carried out to examine whether the interoceptive sensibility affects subjective judgments on retrieval process.

We examined Model 1 with cue valence, cue concreteness, and response time (RT) as the independent variables and direct retrieval judgments as the dependent variable. Cue concreteness (odds ratio (*OR*) = 3.08 [95% CI: 2.27–4.18], $p < .001$), negatively valenced cues (*OR* = 0.52 [0.39–0.71], $p < .001$) and short RTs (*OR* = 0.41 [0.33–0.52], $p < .001$) significantly predicted direct retrieval judgments. Next, we tested Model 2 by entering interoceptive sensibility variables and performed likelihood ratio tests with Model 1, respectively. Model 2 fit the data significantly better than Model 1 when entering the MAIA score ($\chi^2 = 4.36$, $p = .037$), emotional awareness ($\chi^2 = 6.79$, $p = .009$), body listening ($\chi^2 = 4.72$, $p = .03$), and trusting ($\chi^2 = 8.97$, $p = .003$). These additional predictors were associated with increasing judgments of direct retrieval (Table 4).

[2] In concrete cue conditions, mindfulness traits were associated with memory specificity (Supplementary Table S1), consistent with the finding that mindfulness interventions are effective in reducing overgeneral memory (Heeren et al., 2009; Williams et al., 2000). Since mindfulness traits were not associated with retrieval latency, mindfulness traits are likely related to the monitoring process after memory retrieval rather than facilitating the awareness of memories before they come into consciousness. Matsumoto and Mochizuki (2019) argued that error monitoring after retrieval contributes to memory specificity, and low mindfulness traits may lead to reporting nonspecific memories without monitoring the retrieval goal on autopilot. This idea is also compatible with the finding that mindfulness helps to reduce rumination and thought suppression and to increase cognitive reappraisal after involuntary retrieval (Del Palacio-Gonzalez et al., 2017; Isham et al., 2020); thus, mindfulness may contribute strongly to the post-retrieval process.

Table 4 Generalized linear mixed model for subjective judgment of retrieval process among specific recall in Experiment 1

	Coefficient	SE	*OR*	95% Lower	95% Upper	*Z*	*p*
Step 1 Intercept	1.12	0.13	3.06	2.37	3.94	8.63	<.001
Cue valence	-0.65	0.15	0.52	0.39	0.71	-4.18	<.001
Cue concreteness	1.13	0.16	3.08	2.27	4.18	7.20	<.001
Retrieval latency (RT)	-0.89	0.18	0.41	0.33	0.52	-7.74	<.001
Random effects							
σ^2	3.29	ICC		0.20			
τ^{00} ID	0.84	Marginal R^2 / Conditional R^2			0.217 / 0.377		
Step 2 MAIA	0.01	0.01	1.01	1.00	1.03	2.11	.035
		ΔMarginal R^2 / ΔConditional R^2			0.014 / 0.000		
Step 2 Emotional awareness (EA)	0.07	0.03	1.07	1.02	1.13	2.63	.009
		ΔMarginal R^2 / ΔConditional R^2			0.019 / 0.002		
Step 3 Cue concreteness * EA	0.07	0.04	1.07	1.00	1.15	2.01	.045
		ΔMarginal R^2 / ΔConditional R^2			0.010 / 0.008		
Step 2 Body-listening	0.09	0.04	1.10	1.01	1.19	2.22	.027
		ΔMarginal R^2 / ΔConditional R^2			0.016 / -0.001		
Step 2 Trusting	0.12	0.04	1.13	1.05	1.22	3.07	.002
		ΔMarginal R^2 / ΔConditional R^2			0.024 / -0.004		

Concrete cue was coded as 0.5 and abstract cue was coded as -0.5. Positive cue was coded as 0.5 and negative cue was coded as -0.5. Direct retrieval was coded as 1 and generative retrieval was coded as 0. Retrieval latency was log-transformed for linear model. Marginal and conditional R-squared statistics were based on Nakagawa et al. (2017). Step 1 was common for all regressions, and different variables were entered from Step 2 onwards

Since some associations between interoceptive sensibility factors and direct retrieval judgment emerged for concrete cues in the multilevel correlation analysis, we then, in an exploratory analysis, examined Model 5 with fixed effects between the interaction terms of cue concreteness and interoceptive sensibility factors. We found that the interaction effect was significant only when emotional awareness was used (*OR* = 1.07 [1.00–1.15], *p* = .045). Figure 1 shows the interaction between emotional awareness and cue concreteness to estimate the predicted probability of direct retrieval judgments, suggesting that increasing emotional awareness predicted higher proportions of direct retrieval judgments for concrete cues.

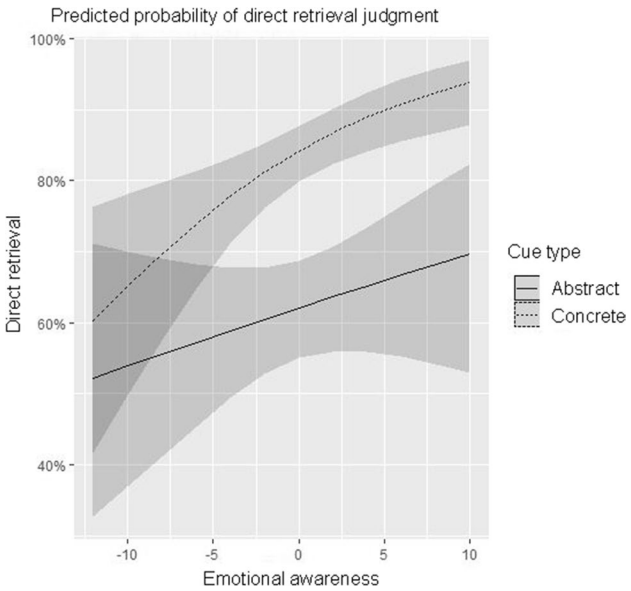

Fig. 1 Predicted probability of direct retrieval judgment and emotional awareness as a function of cue concreteness

Discussion

In Experiment 1, we tested whether interoceptive sensibility and/or mindfulness traits were associated with direct retrieval judgments. Retrieval latency, cue concreteness, and subjective judgment were identified as factors determining direct or generative retrieval, and we examined whether the variance in judgments of retrieval mode are independent of retrieval latency and cue concreteness. We measured interoceptive sensibility and mindfulness traits using a self-administered questionnaire.

In line with previous findings, we replicated that (a) concrete cues lead to greater recall of specific memories than abstract cues (Williams et al., 1999), (b) specific memories elicited by concrete cues were more likely to be judged as being retrieved directly relative to those elicited by abstract cues (Uzer et al., 2012), (c) specific memories elicited by concrete cues have shorter retrieval latencies than those

elicited by abstract cues (Williams et al., 1999), and (d) retrieval latencies of specific memories associated with direct retrieval judgments were faster than for memories associated with generative retrieval judgments regardless of cue (Uzer et al., 2012).

Concrete cues seem to be highly salient unique cues, which have been shown to trigger direct/involuntary retrieval (Berntsen et al., 2013). Generative retrieval involves longer retrieval latency because memories are constructed through top-down processes, whereas direct retrieval requires shorter latency because memories are recalled immediately through bottom-up associative processes. These results demonstrated that retrieval latency, cue concreteness, and direct retrieval judgments can each separate generative retrieval from direct retrieval and that they are interrelated (but not fully correspondent) variables.

The key finding here is that interoceptive sensibility factors (MAIA total score, emotional awareness, body listening, and trusting) predicted direct retrieval judgments, and these associations were independent of other direct retrieval indices such as retrieval latency. Since retrieval latency cannot fully explain direct retrieval judgments (Mace et al., 2021), we cannot completely rule out the possibility that high interoceptive sensibility facilitated bottom-up retrieval itself, but the results of Experiment 1 suggest that high interoceptive sensibility leads to a greater impact of the retrieval, increasing the likelihood that memories are judged as being retrieved directly. Interestingly, these associations were stronger for concrete cues, especially for emotional awareness factors. Concrete cues not only elicit mental imagery but also greater bodily sensations (Holmes & Mathews, 2010), and these sensations lead to a greater impact at retrieval, making judgments of direct retrieval more likely. In contrast, since abstract cues are less likely to elicit mental imagery and interoceptive feelings, the retrieval impact may tend to be lower or top-down memory retrieval may be initiated, leading to judgments of generative retrieval. In particular, when participants are instructed to recall (specific) memories, as in this experiment, it has been shown that less accessible memories (e.g., memories with smaller evoked emotions or lower importance) are more likely to come to consciousness compared with when participants are instructed to report any thought (Barzykowski & Staugaard, 2018), and these memories are more likely to be generated by top-down retrieval. During top-down retrieval, higher-order cognition suppresses lower-order sensory information (Kube et al., 2020a, b), potentially making the conditions of generative retrieval less sensitive to individual differences in interoceptive sensibility. Experimental conditions that allow for any thoughts (Barzykowski & Staugaard, 2018) or all memories (Debeer et al., 2009; Matsumoto & Mochizuki, 2017) may facilitate reporting of high-impact memories based on interoceptions, and the effect of individual differences in interoceptive sensibility may be greater.

Mindfulness traits were not associated with direct retrieval judgments. Mindfulness traits were correlated with some factors on the interoceptive sensibility scale but not with the emotional awareness, body listening, and trusting factors, which were related to direct retrieval judgments. This suggests that mindfulness traits, in contrast to interoceptive sensibility, are not involved in direct retrieval judgments in this experiment.

Experiment 2

In Experiment 1, interoceptive sensibility was associated with direct retrieval judgments primarily for concrete cues, perhaps because participants perceived direct retrieval to have occurred based on the bodily sensations activated by the concrete cue words. If this is the case, may we also expect participants to subjectively experience stronger bodily sensations and more emotional impact when direct retrieval is perceived to have occurred? If direct retrieval judgments are based on the retrieval impact, we should find not only a trait-level correlation with interoceptive sensibility, as shown in Study 1, but also a trial-level correlation with physical and emotional impacts. Physical and emotional impacts are characteristics of involuntary memory (Berntsen & Hall, 2004), but it remains unclear whether these impacts are involved in subjective judgments of direct retrieval. Investigating memory characteristics will provide greater insight into the involvement of interoceptive sensibility in direct retrieval judgments.

The primary aim of Experiment 2 was to replicate the results of Experiment 1, in which interoceptive sensibility was related to the subjective judgment of direct retrieval, but mindfulness traits were not related. We then tested the second hypothesis that physical reaction and emotional impact accompanied with memory retrieval in response to concrete cues produce direct retrieval judgments. Finally, we tested a mediation model in which interoceptive sensibility triggers physical and emotional impacts that in turn lead to direct retrieval judgments. In Experiment 2, we test these hypotheses using only concrete cues because the association of interoceptive sensibility and direct retrieval judgment only emerged for concrete cues in Experiment 1.

Materials and methods

Participants

One hundred thirty-seven participants aged 18–49 years old were recruited from Yahoo! Crowdsourcing (https://

crowdsourcing.yahoo.co.jp/). Prior to recruitment, we set the exclusion criteria as follows: problem reported during the task (n = 1), participants who asked to exclude their data from the analysis (n = 4), participants who participated in a similar study (n = 8), and inappropriate responses or omission from over half of the trials in the AMT (n = 11). In total, the data obtained from 113 participants (42.32 ± 4.99 years old, 84 males, 29 females) were analyzed.

Questionnaires

We used the MAAS and MAIA as in Experiment 1. The internal consistencies were as follows: MAAS (α = .89), noticing (α = .73), not distracting (α = .68), not worrying (α = .23), attention regulation (α = .88), emotional awareness (α = .81), self-regulation (α = .77), body listening (α = .89), and trusting (α = .84).

Memory characteristics questionnaire

To measure the physical and emotional impact induced by memory retrieval, we used a memory characteristics questionnaire adopted from Watson et al. (2012). For a brief adaptation, we selected six questions: *emotional impact* (Did the memory affect your mood?), *physical reaction* (Did you physically react in response to the memory (e.g., smiling, crying, shivering, having a rapid pulse)?), *original valence* (How do you remember your emotions at the time of the event?), *importance* (Does this memory refer to an important event in your life?), *vividness* (How vivid is the memory?), and *rehearsal* (Have you previously thought about this memory?). Participants rated each question using a 7-point scale: emotional impact (1 = strongly negative, 4 = neutral (no impact), 7 = strongly positive), physical reaction (1= not at all, 7 = very), original valence (1 = strongly negative, 4 = neutral, 7 = strongly positive), importance (1 = not important, 7 = very important), vividness (1 = cloudy and imageless, 7 = clear and vivid), and rehearsal (1 = never, 7 = often). Emotional impact and original valence were transformed into absolute values from the theoretical mean (i.e., 4).

AMT

We used five positive concrete cues and five negative concrete cues, which were identical to the concrete cues used in Experiment 1. Other settings of the task were the same as in Experiment 1. Regarding memory specificity, two independent raters classified the responses into the five categories and obtained good agreement (Cohen's k = .77).

Statistical analysis

In Experiment 2, 1,130 trials nested within 113 participants were analyzed. In the analyses restricted to specific memories, 813 trials nested in 113 participants were analyzed. First, we conducted preliminary analyses to examine the relation between subjective judgments and retrieval latency in specific autobiographical recall. Next, a multilevel correlation analysis was carried out to examine the association between level 2 variables (interoceptive sensibility and mindfulness traits) and level 1 variables (subjective judgments, retrieval latency, emotional impact, physical reaction, and original valence). We then carried out the GLMM for subjective judgments of direct retrieval to examine whether interoceptive sensibility leads to direct retrieval judgment independent of retrieval latency and cue valence. Finally, multilevel mediation analysis was performed to test a model in which physical reaction and emotional impact mediate the association between interoceptive sensibility and subjective judgments (i.e., 2-1-1 model). Physical reaction and emotional impact were aggregated into a single factor score drawn from a factor analysis with the maximum likelihood method and entered into the model. We used the *lavaan* package in R with probit regression as the default to formulate the model.

Results

Preliminary analyses

Excluding omissions, specific memories were reported in 81.4% of the trials for positive cues and 71.2% for negative cues. Among the specific memory responses, direct retrieval judgments were made in 74.5% of trials. The GLMM for subjective judgments showed that shorter retrieval latency predicted direct retrieval judgments (OR = 0.42 [95% CI: 0.31–0.57], $p < .001$; overall mean of direct retrieval: 5.29 s; generative retrieval: 8.62 s).

Descriptive statistics and correlations

Table 5 shows the descriptive statistics and Pearson's correlation matrix between the individual difference variables. Multilevel correlations are shown for specific autobiographical recall (Table 6). As predicted, emotional awareness was correlated with direct retrieval judgment for specific autobiographical recall (r = .33, p = .007). This association was also shown for any recall (OSM Table S2). In contrast, the correlations between direct retrieval judgment and the MAIA total score (r = .20, p = .092), body listening (r = .15, p = .20), and trusting (r = .13, p = .28) did not reach significance. Instances of specific recall judged as direct retrieval had stronger physical

Table 5 Descriptive statistics and correlations between mindfulness traits and interoceptive sensibility in Experiment 2

	M	*SD*	1	2	3	4	5	6	7	8	9
1. MAAS	43.19	10.84									
2. MAIA total	71.48	16.08	-.04								
3. Noticing	8.58	3.59	.34***	.37***							
4. Not-Distracting	8.64	2.59	-.36***	.11	-.43***						
5. Not-Worrying	6.62	2.05	-.18	.21*	-.36***	.20*					
6. AttentionRegulation	15.57	5.15	-.01	.71***	.25**	-.01	.10				
7. EmotionalAwareness	11.33	4.11	.11	.75***	.54***	-.23*	-.06	.39***			
8. Self-Regulation	8.58	3.25	-.14	.77***	.03	.11	.28**	.42***	.44***		
9. Body-Listening	5.80	3.04	.05	.81***	.21*	.17	.06	.37***	.58***	.69***	
10. Trusting	6.37	2.97	-.22*	.78***	-.02	19*	.24*	.39***	.51***	.72***	.70***

MAAS Mindful Attention Awareness Scale, *MAIA* Multidimensional Assessment of Interoceptive Awareness

*** $p < .001$, ** $p < .01$, * $p < .05$

Table 6 Mutlilevel correlations for specific autobiographical recall in Experiment 2

	Subjective judgment	Retrieval latency	Emotional impact	Physical reaction	Original valence	Importance	Vividness	Rehearsal
Subjective judgment	**.20****	-.23***	.15***	.10***	.16***	.20***	.37***	.24***
Retrieval latency (RT)	-.18	**.50****	.00	-.04	-.04	-.07	-.06	-.08*
Emotional impact	.44**	-.08	**.25****	.35***	.74***	.37***	.38***	.39***
Physical reaction	.36**	-.22*	.49***	**.52****	.35***	.38***	.32***	.47***
Original valence	.35*	.05	.74***	.28*	**.19****	.38***	.38***	.39***
Importance	.53***	-.32*	.49**	.73***	.41**	**.22****	.45***	.68***
Vividness	.43**	-.10	.31*	.40**	.31*	.69***	**.31****	.51***
Rehearsal	.48**	-.20	.38**	.64***	.34*	.87***	.65***	**.31****
MAAS	.13	-.10	.08	-.08	.02	.00	-.12	.01
MAIA total	.20	-.15	-.05	.06	-.18	.09	.20	.27*
Noticing	.24*	-.01	.24*	.10	.27*	.03	.10	.16
Not-Distracting	-.10	-.03	-.10	-.15	-.12	.01	.06	.12
Not-Worrying	.06	.05	-.22	.08	-.33**	.11	.08	.06
Attention Regulation	-.05	.00	-.29*	-.18	-.36**	-.19	-.02	-.05
Emotional Awareness	.33**	-.19	.23*	.19	.06	.20	.24*	.35**
Self-Regulation	.19	-.18	-.12	.07	-.19	.09	.10	.15
Body-Listening	.15	-.21*	.03	.12	-.14	.11	.13	.28*
Trusting	.13	-.12	-.03	.17	-.11	.22	.32**	.30**

Interclass correlations were shown in bold. Trial level correlations were shown with underbar and the others were individual level correlations. Emotional impact and Original valence were transformed into the absolute value (dissociation from the median 4). Retrieval latency was log-transformed

MAAS Mindful Attention Awareness Scale, *MAIA* Multidimensional Assessment of Interoceptive Awareness

*** $p < .001$, ** $p < .01$, * $p < .05$

Table 7 Generalized linear mixed model for subjective judgment of retrieval process among specific recall in Experiment 2

	Coefficient	SE	*OR*	95% Lower	95% Upper	*Z*	*p*
Step 1 Intercept	7.18	1.40				5.13	<.001
Retrieval latency (RT)	-0.82	0.15	0.44	0.33	0.59	-5.36	<.001
Cue valence	-0.19	0.19	0.83	0.57	1.21	-0.97	.33
Emotional awareness	0.11	0.04	1.11	1.03	1.20	2.64	.008
Random effects							
σ^2	3.29	ICC		0.32			
τ^{00} ID	1.58	Marginal R^2 / Conditional R^2				0.217 / 0.377	

Positive cue was coded as 0.5 and negative cue was coded as -0.5. Direct retrieval was coded as 1 and generative retrieval was coded as 0. Retrieval latency was log-transformed for linear model. Mriginal and conditional R-squared statistics were based on Nakagawa et al. (2017)

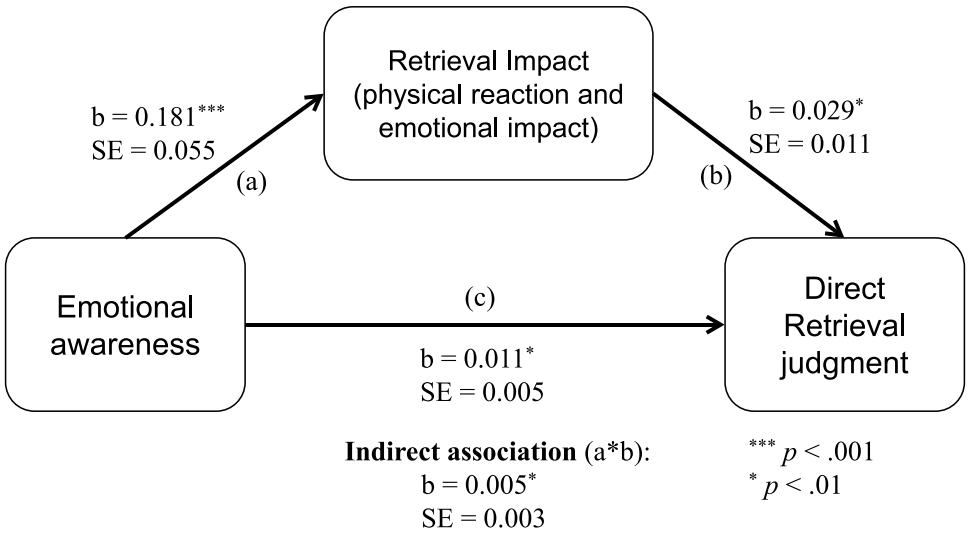

Fig. 2 Multilevel mediation model predicting subjective judgment of direct retrieval

reactions ($r = .10$, $p = .006$) and emotional impact ($r = .15$, $p < .001$). Correlations of emotional awareness with emotional impact were significant ($r = .23$, $p = .046$), but the correlation with physical reaction did not reach significance ($r = .19$, $p = .066$). Emotional awareness was also highly associated with rehearsal ($r = .35$, $p = .002$) and vividness ($r = .24$, $p = .027$), despite having no relation to the emotional valence of the memory at the time of the event ($r = .06$, $p = .63$).

Subjective judgments on retrieval process

Subsequent analyses were focused on emotional awareness, which was consistently associated with direct retrieval judgments in Experiment 1. We performed GLMMs with direct retrieval judgment as the dependent variable. In Model 1, we entered retrieval latency and cue valence, and in Model 2, we additionally entered emotional awareness. Likelihood ratio tests showed that the fitness of Model 2 was significantly better ($\chi^2 = 7.17$, $p = .007$), and the effect of emotional awareness in Model 2 was significant (*OR* = 1.11 [1.03-1.20], $p = .008$; Table 7).

Multilevel mediation analysis

We carried out a multilevel mediation analysis in which the retrieval impact (physical reaction and emotional impact) mediated the association between emotional awareness and subjective judgment of the retrieval process. The results supported a partial mediation model (Fig. 2). At level 2, emotional awareness significantly predicted the retrieval impact ($Z = 2.50$, $p = .012$), and the retrieval impact significantly predicted direct retrieval judgments ($Z = 3.31$, $p < .001$). The indirect association was significant ($Z = 2.00$, $p = .046$), and the direct association (i.e., the association between emotional awareness and direct retrieval judgment) remained significant ($Z = 2.06$, $p = .040$).

Discussion

The aim of Experiment 2 was to test the relationship between interoceptive sensibility and direct retrieval judgments revealed in Experiment 1 (Hypothesis 1) and to investigate whether the physical and emotional impacts from memory retrieval predict direct retrieval judgments (Hypothesis 2). Furthermore, we tested a mediation model in which high interoceptive sensibility leads to physical and emotional impacts accompanied with memory retrieval, in turn leading to direct retrieval judgments.

Replicating the results of Experiment 1 and supporting Hypothesis 1, emotional awareness predicted direct retrieval judgments independently of other factors, such as retrieval latency. Furthermore, in support of Hypothesis 2, the physical and emotional impacts accompanied by memory retrieval predicted direct retrieval judgments. This result strengthens the evidence that direct retrieval judgments are based on physical and emotional impacts. Finally, a partial mediation model was also supported. Individuals who are sensitive to interoceptive sensations are more likely to feel physical and emotional impacts, and the magnitude of these impacts leads to the perception of direct retrieval. Although the original valence was not strong, they recalled it repeatedly and vividly. In other words, individuals with a high level of emotional awareness recall an event with a strong impact as a direct retrieval, even if it was originally a typical experience.

Mindfulness traits were not associated with subjective judgments of direct retrieval and emotional awareness, as in Experiment 1. This result suggests that variance of interoceptive sensibility, which was not related to the mindfulness scale, is involved in direct retrieval judgments.

General discussion

While attempts have been made to objectively distinguish between the retrieval process of autobiographical memory and to understand the memory characteristics generated by each retrieval process, the phenomenological issue of how people judge the retrieval process has been largely overlooked until recently (Barzykowski et al., 2021; Sanson et al., 2020). We posited that internal awareness underlies bottom-up retrieval and examined a novel hypothesis that individual differences in internal awareness affect subjective judgments of direct retrieval.

Through two experiments, we demonstrated that emotional awareness, an interoceptive sensibility factor (Mehling et al., 2012), contributes to direct retrieval judgments. As mentioned earlier, there are various ways of measuring interoception, but in the context of this set of experiments we found that emotional awareness, as measured by the self-administered scale, is associated with direct retrieval judgments, supporting the role of interoceptive sensibility on autobiographical recall. The MAIA emotional awareness component assesses the ability to attribute specific physical sensations to physiological manifestations of emotions and reflects more developed interoceptive awareness compared with other MAIA subcomponents (Mehling et al., 2012). Individuals with high levels of emotional awareness may be able to enrich the emotions associated with the higher-order cognitive activity including memory retrieval. The association between emotional awareness and direct retrieval judgments was observed for concrete cues, which are more likely to be associated with past specific events, suggesting that the individual differences in interoceptive sensibility are more critical in associative, direct retrieval processes. Importantly, direct retrieval judgments are predicted by emotional awareness independently of retrieval latency and other related factors.

One interpretation of this finding is that high interoceptive sensibility is not related to more direct retrieval per se, but rather associated with the subjective nature of retrieval judgments. In this case, the question arises as to how participants judged the retrieval process. Another interpretation may be that high interoceptive sensibility increases the likelihood of directly activating bodily sensations related to past memories. However, no correlation between interoceptive sensibility and retrieval latency was observed, possibly because more time was required to attribute the cue-activated sensations to memories (i.e., active inference to interoception; Barrett, 2017; Seth & Friston, 2016) or to elaborate on the details of these memories. Recent research has shown that there are two types of retrieval that can be judged as direct retrieval: *fast retrieval* and *slow retrieval* (Mace et al., 2021). Fast retrieval is pure direct retrieval with short latency and an automatic process, whereas slow retrieval is generative like direct retrieval with relatively long latency and a retrieval-focused process such as cue deliberation and strategy usage. The case of active inference to interoceptions may be considered to be a form of slow retrieval, as it involves a process of strategic interpretation of the interoceptions. Nevertheless, in this case, when participants were asked to judge memory retrieval as either generative or direct, participants judged memory retrieval as having occurred directly. Again, one important question relates to how participants made these subjective judgments.

Based on the hypothesis that subjective judgments of direct retrieval may be guided by the magnitude of the retrieval impact, we found support for a model in which the relationship between interoceptive sensibility and direct retrieval judgments is partially mediated by bodily and emotional impact of the retrieval. Individuals with high levels of emotional awareness tend to experience rich (high-impact) emotions based on bodily sensations during memory retrieval, and are more likely to make direct

retrieval judgments based on these impacts. Previous studies have examined the nature of generatively retrieved, directly retrieved, and involuntarily retrieved memories, and have found that greater involuntariness in memory recall predicts greater emotional impact (Berntsen & Hall, 2004; Del Palacio-Gonzalez et al., 2017; Watson et al., 2012). The current study presents a different framework in which bodily and emotional impact is not regarded as a feature of directly retrieved memories, as in previous studies, but that the impact leads to the judgment of retrieval process.

One plausible hypothesis to explain these results is that interoceptive prediction error leads to retrieval impact and guides the direct retrieval judgments. The predictive processing framework and interoceptive prediction error can explain how emotion is constructed (Barrett, 2017; Critchley & Garfinkel, 2017; Seth & Friston, 2016), and can be applied to all human cognitive activities, including memory (Barron et al., 2020). Since involuntary retrieval is generally an unexpected and surprising experience (Mandler, 2007), people may subjectively feel as if unexpected interoceptions have suddenly occurred. In other words, people experience a large prediction error for the incoming sensations. On the contrary, when retrieval monitoring processes such as retrieval intention and cognitive effort are present during retrieval, these processes may lead to intermittent updating of predictions about the incoming sensations associated with the memory retrieval. In this sense, direct retrieval may have smaller prediction errors than involuntary retrieval because direct retrieval involves retrieval intentions, whereas prediction errors may be larger for direct retrieval than for generative retrieval, which requires more cognitive effort. Latest studies have shown in particular that cognitive effort predicts voluntary versus involuntary retrieval judgments (Barzykowski et al., 2021; Sanson et al., 2020), suggesting that the contrast in cognitive effort between generative and direct retrieval is closely related to the magnitude of prediction error experienced and subjective judgments. When a strong physical reaction occurs, humans may automatically recall memories associated with the reaction, or may engage in a process of actively inferring the perceived prediction error to access memories. At the same time, emotions that explain the interoceptive prediction error are constructed. In this sense, both the magnitude of emotional arousal and involuntariness/directness of retrieval could be integrated by the prediction processing framework. Although recent research has been interested in higher-order predictions, such as Bayesian predictions to increase the probability of detecting threat stimuli, that lead to intrusive memories and images (Kube et al., 2020a), interoceptive or lower-order prediction errors such as those hypothesized here may also be an underlying mechanism of intrusive memories and images. Unfortunately, no direct measurement of prediction error was available in the present study addressing involuntary and direct retrieval based on bodily signals (e.g., heartbeat evoked potentials; Montoya et al., 1993); this represents a future challenge.

Janssen et al. (2021), who conducted one of the few previous studies to examine factors associated with subjective judgments, showed that smaller pupil size was associated with direct retrieval judgments. Based on the theoretical framework proposed in the present study, the results of Janssen et al. (2021) may be reframed as in terms of interoception as indicating that autonomic nervous system responses are involved in direct retrieval judgments. Pupil size, which represents arousal controlled by the autonomic nervous system (Wang et al., 2018), is an index of prediction error (Koenig et al., 2018). The predictive processing theory of emotion to which this study refers is based on prediction error occurring in the autonomic nervous system, and therefore the results of the present study and that of Janssen et al. (2021) may indicate a common interoceptive mechanism for direct retrieval judgments.

Among direct retrieval judgments, whether memory retrieval occurs automatically or actively (deliberately) from interoceptive feelings may be important when considering the (re) constructive nature of autobiographical memories (Schacter & Addis, 2007). Some argue that stored memory representations are more likely to be retrieved directly if they represent highly accessible memories that are important, emotional, vivid, and highly rehearsed (Barzykowski & Staugaard, 2016), while others argue that memories retrieved both directly and through generative retrieval are reconstructed (Harris & Berntsen, 2019). When memories are retrieved automatically, stored memory representations are likely to come directly to mind, whereas under conditions of active inference following interoception, when one actively searches for memories to attribute the causes of interoception, the reconstruction process is likely to be involved. Tracking these timely retrieval processes using event-related physiological and neural responses will allow us to elucidate the mechanisms of memory reconstruction.

Mindfulness training has been found to increase interoceptive sensibility (Gibson, 2019) but also to reduce the impact of prediction errors (Kirk et al., 2019; Kirk & Montague, 2015), suggesting that mindfulness encompasses an element of noticing physical reactions and not being affected by perceived bodily sensations and emotions. The lack of association between mindfulness traits and direct retrieval judgments in the present study may reflect this trade-off. Although mindfulness traits measured by the MAAS did not predict direct retrieval judgments, multifaceted assessment of mindfulness may reveal some association. For example, observing, a subfactor of the FFMQ (Five Facets Mindfulness Questionnaire; Baer et al., 2006), may have similar effects as emotional awareness (Mehling et al., 2012), as it mainly reflects awareness of

bodily sensations and is not associated with well-being in non-meditators (Baer et al., 2008). Furthermore, as mindfulness training has been shown to cultivate interoception (Gibson, 2019), such interventions could still influence the probability of direct retrieval judgments.

Theoretical implications

Previous studies suggest that highly accessible memories, which are characterized by high emotional intensity, personal importance, rehearsal, and vividness, are more likely to be voluntarily (directly) and involuntarily retrieved, because they are more likely to surpass an awareness threshold and enter consciousness (Barzykowski et al., 2019, 2021; Barzykowski & Staugaard, 2016, 2018). Threshold parameters vary as a function of the intention to recall a memory and by the experimental instructions and current goals guiding memory retrieval (Barzykowski et al., 2021; Barzykowski & Staugaard, 2018). The prediction error account could be integrated with this threshold hypothesis. The degree of memory activation that determines whether the memory crosses the awareness threshold could be related to the magnitude of the prediction error. The threshold hypothesis assumes that the phenomenological qualities of memories determine whether they cross the threshold into conscious awareness; the prediction error framework may provide a neurobiological account of how the interoceptive conditions of memory retrieval may increase the likelihood of memories entering consciousness, as determined by the interoceptive awareness of the individual and the retrieval impact (i.e., prediction error) of the memory itself in the context of current interoceptive information.

Conditions of involuntary memory retrieval may increase the awareness threshold, beyond which only experiences with a large prediction error can enter consciousness. Conversely, the conditions of voluntary retrieval would lower the threshold. Therefore, as shown in previous studies, involuntary retrieval tends to evoke stronger emotional responses, while voluntary retrieval evokes less emotional response (e.g., Watson et al., 2012). Not only the nature of memory itself, but also other factors, such as the individual differences of interoception, affect the retrieval impact. The strength of the prediction error account is that it may provide a way to integrate psychological models of memory retrieval with broader neurobiological models of cognition and emotion.

Clinical implications

While interoceptive sensibility leads to an increased experience of direct retrieval, interoceptive insensibility may impair the ability to make judgments about the retrieval of autobiographical cognitions more broadly and future research may investigate relationships between interoceptive awareness and the experience of memory intrusions, flashback, hallucinations or other forms of spontaneous autobiographical cognition. Difficulties in regulating interoception are evident in anxiety-related disorders (Newman et al., 2013; Paulus et al., 2019). As such, interoceptive interventions may help to reduce intrusive symptoms, which often involve unwanted involuntary memory retrieval (Brewin et al., 2010; Clark, 2005). Interoceptive exposure is often used in behavior therapy, commonly applied to panic disorder, but has recently also been shown to reduce posttraumatic stress symptoms (Wald & Taylor, 2007, 2008). Interoceptive interventions may be more effective in preventing intrusive symptoms across diagnoses than previously thought. In particular, the results of the present study suggest that a greater understanding of the relationship between mindful and interoceptive awareness and their respective relationships to involuntary or direct memory may further advance our understanding and treatment of intrusive memory phenomenon in clinical disorders.

Limitations and future directions

Overcoming the limitations of the present study, described below, constitutes a new research avenue. First, we did not examine the retrieval mechanism in detail. The pathways through which memories are brought to consciousness have a variety of components, including stimuli (cue), physical reaction, mental imagery, interoception, and emotion, and it remains unclear which pathway led to each memory recalled by the participants in this study. Second, we found an association between several subscales of MAIA and direct retrieval judgments in Experiment 1, but did not replicate the results in Experiment 2, except for emotional awareness. It is premature to completely dismiss the contribution of other subscales with these results, and further replication studies are desirable. Third, to accumulate evidence for the contribution of interoception on direct and involuntary retrieval, it is necessary not only to measure interoceptive sensibility with self-administered scales but also to measure interoceptive accuracy, such as with the heartbeat counting task (Schandry, 1981), and to examine the relationship between direct or involuntary retrieval and real-time physiological responses (Montoya et al., 1993). Fourth, we addressed subjective judgments in voluntary, generative, and direct retrieval, but subjective judgments in involuntary and voluntary retrieval remain unclear. Researchers could extend the findings of this study to involuntary retrieval paradigms, where participants do not receive an explicit memory prompt (e.g., in a vigilance task; Schlagman & Kvavilashvili, 2008). Furthermore, latest research raises questions about the definition of direct retrieval and argues for the need to separate direct retrieval into automatic and

generative retrieval-like (Mace et al., 2021). An elaboration of this construct would better clarify the mental basis of subjective judgments of the retrieval process. Finally, as the present study targeted only memories induced by emotional cue words, the mechanisms for direct and involuntary retrieval without emotional involvement remain unclear. While emotional cues are more likely to elicit involuntary retrieval than neutral cues are (Schlagman & Kvavilashvili, 2008), some involuntarily retrieved memories are neutral and thus neither positive nor negative (Kvavilashvili & Schlagman, 2011), and those memories may not be unexpected or surprising (Mandler, 2007). Future studies should examine direct and involuntary retrieval judgments by including neutral words as cues.

Conclusion

This study was a first step in examining the role of interoception on the subjectivity of direct retrieval or involuntary memory. We demonstrated that individual differences in emotional awareness, a subordinate factor of interoceptive sensibility, was associated with subjective judgment of direct retrieval. Furthermore, individuals with more emotional awareness showed greater retrieval impact (physical reaction and emotional impact), and greater impacts predicted direct retrieval judgments. The judgment was unable to be accounted for by other direct retrieval indices such as retrieval latency and cue concreteness. In terms of the predictive processing framework, interoceptive prediction error on surprising and unexpected retrievals that may underlie the retrieval impact led to the subjectivity of direct retrieval. These findings reveal avenues for future research that include the measurement of physiological responses and testing with involuntary retrieval tasks.

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Declarations

Conflicts of interest The authors declare no conflicts of interest.

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