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Mindfulness and Metacognitive Monitoring Accuracy in Young Meditation Practitioners Compared to Non-Practitioners

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Abstract

Objectives Theoretical models propose metacognition to be one of the underlying cognitive mechanisms of mindfulness. However, only few studies have examined metacognition objectively with laboratory tasks in relation to mindfulness. Here, we investigated whether the metacognitive process of monitoring and its accuracy are associated with mindfulness-based meditation practice.

Method In total, $n = 124$ participants (including $n = 61$ young mindfulness meditation practitioners with at least 3 years of meditation practice engaging in ≥ 3 sessions per week, and $n = 63$ non-practitioners) completed an adapted metacognitive visuo-spatial working memory task and provided monitoring judgments after each trial (confidence judgments [CJ] regarding their recall performance). Monitoring accuracy was operationalized as the relationship between CJ and objective performance. All participants completed the Mindful Attention Awareness Scale (MAAS) and practitioners the Meditation Depth Questionnaire (MEDEQ) as well as open questions regarding their meditation practice.

Results Overall monitoring accuracy was significant ($\bar{r} = 0.52, p < 0.001$), indicating that participants were sensitive to variations in their memory performance. However, no group differences between practitioners and non-practitioners were found, except for the MAAS ($t = -3.14, p = 0.002$), reflecting that practitioners reported higher levels of mindfulness. Within the group of practitioners, no features of meditation practice, nor MEDEQ or MAAS scores were significantly correlated with monitoring accuracy.

Conclusions We discuss the object of monitoring, and the level of consciousness assessed in the present metacognition task as possible reasons for null findings as well as various conceptualizations of meta-awareness within contemplative traditions and its overlap with different facets of metacognition as avenues for future research.

Preregistration The study was preregistered and the preregistration can be accessed at <https://osf.io/k8hcv/>. Regula Neuenschwander and Donna Bryce share first authorship.

Keywords Mindfulness · Meditation · Metacognition · Monitoring · Monitoring accuracy · Meta-awareness

Metacognition is a fundamental part of our ability to know ourselves. It includes both the ability to be aware of one's mind (bottom-up monitoring of cognitive processes)

and to regulate it (top-down control of object-level processes; Nelson & Narens, 1994). Recently, metacognition scholars have proposed that mindfulness-based meditation can be seen as a practice that promotes cultural learning of metacognition (Heyes et al., 2020). Mindfulness involves a close, repetitive observation and reflexive contemplation of one's own experience (Bodhi, 2011). In other words, mindful states emerge when an individual pays attention “on purpose, in the present moment, and non-judgmentally to the unfolding experience” (p. 145, Kabat-Zinn, 2003). Heightened attention and an open orientation to one's own mental processes (Brown & Ryan, 2003) both require that the person monitors and controls their ongoing cognitive activity, which are the two core

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functional mechanisms of procedural metacognition (Nelson & Narens, 1994).

In the past decades, research in basic and applied psychology has amassed a large body of evidence on the importance of metacognition, for instance, in learning and academic achievement (Dent & Koenka, 2016; Ohtani & Hisasaka, 2018), and in the treatment of various forms of psychopathology (Bernstein et al., 2015). A relatively younger body of research suggests that mindfulness-based meditation practice improves mental health outcomes and promotes adaptive behavioral change (Goldberg et al., 2018; Schuman-Olivier et al., 2020). One potential pathway by which mindfulness-based meditation may improve mental health outcomes and promote adaptive behavioral change is through changes in cognitive functioning (Kuan, 2012; Vago et al., 2019). While metacognition has been proposed as one of the main cognitive constructs underlying mindfulness (e.g., Jankowski & Holas, 2014; Shapiro et al., 2006), few studies assess metacognition objectively with established laboratory tasks and their findings are inconsistent (Baird et al., 2014; Böckler & Singer, 2022; Schmidt et al., 2019). The overarching question addressed here was the extent to which the metacognitive process of monitoring is associated with mindfulness-based meditation practice. Specifically, young mindfulness meditation practitioners were expected to show better metacognitive monitoring accuracy in a visuo-spatial working memory task compared to a control group consisting of non-practitioners.

Metacognition theorists commonly refer to two forms of metacognition (Efklides, 2008; Flavell, 1979). *Declarative metacognition* (also, *metacognitive knowledge*) refers to information stored in long-term memory and includes one's knowledge and understanding of cognitive processes, of one's own and other's cognitive abilities, and of strategies and tasks. *Procedural metacognition* (also, *metacognitive skills*) are cognitive processes that allow us to self-observe our learning or cognitive processes (*metacognitive monitoring*) and make appropriate adjustments (*metacognitive control*) during a learning or cognitive task. The influential model of Nelson and Narens (1994) refers to metacognitive monitoring taking place when information flows from the object-level (the level of the cognitive activity) to the meta-level (which contains a mental representation of the cognitive activity).

Metacognitive monitoring is itself a multifaceted concept, comprising a range of experiences and activities. Early research into metacognition examined fleeting experiences like feelings of knowing and tip of the tongue phenomena, which can be attributed to monitoring processes occurring somewhat automatically or unconsciously (Schwartz, 1994). Focusing more on conscious reports, in experimental cognitive psychology, metacognitive monitoring has been studied by collecting monitoring

judgments from participants before or directly after they provide an answer or response in a cognitive task. This can include prospective feelings of knowing, prospective judgments of learning, and retrospective confidence judgments. These can be considered a “read out” of the contents of the meta-level and are also believed to be influenced by various cues (Koriat, 2012). One major advantage of collecting monitoring judgments is that the accuracy of the information gained through monitoring can be evaluated by considering the agreement between monitoring judgments and objective performance. Measures of relative accuracy indicate a person's sensitivity to variations in their performance across trials or items and are assessed via correlations (Mengelkamp & Bannert, 2010). Thus, subjective reports (i.e., *confidence judgments*) along with objective task performance allow an objective assessment of the accuracy of an individual's metacognitive monitoring skills in a particular context.

A plethora of studies have used monitoring judgments to investigate the factors influencing how judgments are made and their accuracy. Most relevant to the current study, Koriat (1997) has demonstrated that more practice providing monitoring judgments on a set of items is associated with improved relative monitoring accuracy, but with impaired absolute monitoring accuracy (over-/underestimation). He interpreted this finding as indicating that participants shift from relying on information-based cues to experience-based cues with practice. Experienced-based cues have internal, subjective sources. One consequential hypothesis is then, that the more often one engages in intentionally monitoring their mental state, the more attuned they will become to their own experiential internal cues which tend to also be more valid. For this reason, in the current study, individuals who regularly practice mindfulness were expected to also provide more accurate monitoring judgments regarding their own cognitive processes.

Mindfulness-based meditative practices across various cultures and traditions aim to cultivate a deeper introspective awareness of cognitive, emotional, and experiential mental states through the systematic examination of first-person experiences (e.g., Lutz et al., 2007). Mindfulness (*sati* in Pali) is at the heart of all classical systems of Buddhist meditation (Bodhi, 2011). With increasing mindfulness and clear comprehension (*sampajañña* in Pali), meditators gain insight into the reality of their bodies, thoughts, and feelings, as well as mental objects (e.g., images, attitudes) and eventually the transient nature, that is the arising and passing, of physical, mental, or emotional phenomena is revealed. Thus, mindfulness is not only a goal but also a process that deepens with continuous practice and transforms the personality. This process has been operationalized with the Meditation Depth Questionnaire (MEDEQ; Piron, 2020), which assesses effortful struggles with the requirements of

the chosen technique to the realization of the fundamental ground of all being, where all dualities dissolve.

To make the complex construct of mindfulness accessible to psychological research, Brown and Ryan (2003) identified two intertwined processes of mindfulness—attention and awareness—which are constant features of normal functioning but can be considered enhanced attention to (as a capacity that prevents distraction) and open or receptive awareness of current experience (as a capacity to detect distraction when it occurs) during mindful states. The Mindful Attention Awareness Scale (MAAS; Brown & Ryan, 2003), has been developed to measure self-reported mindfulness reliably and briefly both in inter- and intraindividual terms.

Together with the growing popular and scientific interest surrounding the construct and practice of mindfulness and related types of meditation, criticism of the scope and definition of these approaches and their scientific evidence base has grown (Goldberg et al., 2022; Van Dam et al., 2018). To address the question of what meditation encompasses, Matko and colleagues (2021) compiled a collection of 309 meditation techniques spanning all major traditions through a literature search and interviews with expert meditators. The comprehensive classification system yielded seven clusters (e.g., mindful observation, body-centered meditation, contemplation, meditation with movement, Matko & Sedlmeier, 2019), which was used in the present study. Adding to the challenge of operationalization, in the study of long-term meditators, the duration and frequency of meditation sessions have been operationalized differently (Van Dam et al., 2018), resulting in a low level of comparability across studies.

The involvement of metacognition in mindfulness is acknowledged in various theoretical models of mindfulness (e.g., Shapiro et al., 2006). Jankowski and Holas' (2014) *metacognitive model of mindfulness* offers a particularly detailed understanding of the (meta)cognitive mechanisms involved in mindfulness (Norman, 2017). Adopting the structure proposed by Nelson and Narens (1994), which distinguishes between an object-level and a meta-level, they propose an additional level. Metacognition during mindfulness thus takes place at a *meta-meta level*. At the meta-level, metacognitive thoughts or experiences relate to raw, first-level experience or qualia—e.g., “I feel my feet touching the floor.” At the meta-meta-level, the object of metacognition is itself observed—e.g., “I am thinking of the qualities of my bodily sensations.” Thus, a person—when mindful—is aware of being aware (i.e., of their metacognition)—or in other words, mindfulness involves a higher order-conscious awareness of being aware. Importantly, being aware of the present moment (e.g., experiencing bodily sensations) does not necessarily imply that a person is aware of such awareness. While the “lower” level of mindfulness can occur without any conscious intention, the “higher” level needs to be

induced deliberately, and it is assumed that people without any meditation experience can rarely achieve it. Importantly, Jankowski and Holas (2014) suggested that the mindful meta-level is always conscious while the other meta-levels of cognition can occur implicitly (i.e., metacognition may also include implicit and unconscious processes).

Empirical evidence supporting the metacognitive model of mindfulness stems from several lines of research. First, a vast literature from expertise and training studies supports effects of mindfulness on higher-order cognitive functions (in particular, executive function, working memory, and attention; Chiesa et al., 2011; Fabio & Towey, 2018; Whitfield et al., 2022). Second, neurobehavioral research that assesses neural activation during states of mindfulness suggests that the functional and structural plasticity induced by some types of meditation practices occur in the same brain regions that are involved in metacognition (e.g., prefrontal cortex, anterior cingulate cortex, and insula; Fox et al., 2014, 2016; Sezer et al., 2022). Third, several empirical findings suggest that intentionally practiced mindfulness leads to decreases in dissociations between the meta- and object-levels. For instance, temporal dissociation such as mind-wandering is negatively correlated with trait and entrained mindfulness (Mrazek et al., 2012; Smallwood & Schooler, 2006). In sum, although empirical evidence is promising, it is often indirect, the effects are often small, mindfulness-based interventions and practices show large heterogeneity, and studies often lack rigorous methodologies.

With regard to specific effects of mindfulness-based interventions on self-reported metacognitive monitoring and other facets of metacognition, prior research is scarce. For instance, Kok and Singer (2017) investigated the effects of a large-scale mindfulness training project named ReSource, which included 3-month long training modules (in total 9 months of mindfulness training) including three distinct types of mindfulness training: present moment attention and interoceptive awareness (breathing meditation and body scan); care, compassion, and gratitude (loving kindness meditation); and metacognition and perspective-taking (thought-observing meditation). They reported that the thought-observing module led to a greater increase in thought awareness than did two other meditation modules. Observing thoughts also decreased distraction by thoughts; however, this change was not statistically different from the change found in the other two modules. The authors argue that some of the overlapping effects may be attributed to continuing practice in (re)directing and sustaining attention to a given object in the present moment, regardless of its focus (i.e., breath, body, thought).

Further, Sanger and Dorjee (2015) found in 16- to 18-year-old students after eight mindfulness sessions delivered in a school setting a significant change in students' metacognitive beliefs (Cartwright-Hatton et al., 2004).

Mindfulness training was associated with reductions in students' hypercritical self-beliefs, whereas students in the control group showed an increase in reliance on worry. The authors argue that these findings suggest that mindfulness may have a *be-friending* effect on how students relate to their own mind.

In contrast to these positive mindfulness effects on self-reported metacognition, the findings of studies that employed more objective laboratory measures of metacognitive skills are fewer in number and have delivered less consistent findings. Baird et al. (2014) found improved metacognitive monitoring accuracy (labeled *sensitivity*) in a recognition memory task but not in a perceptual decision task in participants who received an intense 2-week meditation training (focused attention meditation inspired by Buddhist practice) compared to an active control group. Aiming to tease apart effective components of meditation, Schmidt et al. (2019), however, found no improvements in metacognitive sensitivity in a perceptual decision task and memory recognition task (combined) after receiving 8 weeks of thought-observing mindfulness training, and negative effects after a body-focused mindfulness training. Similarly, Böckler and Singer (2022) tested differential training effects in the ReSource project and observed that while none of the training modules significantly altered metacognitive sensitivity in a perceptual decision task, a trend-level finding reflected that all training groups remained stable in their metacognitive sensitivity, whereas the passive control group declined over the course of the study.

When researching working memory and metacognition in the context of mindfulness, it is important to clearly specify how these constructs are operationalized. The assessment of procedural metacognition is always tied to a primary task, and when studying the association between mindfulness practice and metacognitive monitoring, a crucial question to address is, monitoring of which cognitive activity should we investigate? In the current study, a visuo-spatial working memory task was selected as the primary task for various reasons, elaborated here. First, to avoid the undue influence of domain-specific self-concept on monitoring judgments (Händel et al., 2020) and different levels of familiarity and domain-specific expertise across participants, an unfamiliar, non-academic task that did not make demands on language abilities was preferred. Consequently, various cognitive tasks can be considered, and because some prior intervention studies found positive effects on monitoring of memory but not perceptual decision-making (Baird et al., 2014; Böckler & Singer, 2022), memory was prioritized. Within the domain of memory, the fact that working memory has a strong attentional component made it especially relevant to mindfulness-based meditation given the central role of attention in mindfulness (Brown & Ryan, 2003). Consequently, the complex span task was selected as primary task, which

involves shifting between memory maintenance and manipulation of information, and as such taxes the attentional components of working memory models (i.e., the central executive from Baddeley & Hitch, 1974, and the focus of attention from Cowan, 1999). Lastly, it seemed important to avoid a task where performance is assessed via speed, because it has been suggested that mindfulness does not exert its largest effects on tasks assessing speed and accuracy (Gallant, 2016). Rather, because mindfulness instructions typically include taking time to observe present-moment experience in a non-judgmental and decentered way, it may have greater effects on other qualities of attention, such as interoception (Farb et al., 2013) and decentering (Fresco et al., 2007).

Working memory and metacognition have of course been studied previously, mostly in the context of aging. For instance, it has been reported that younger adults give more accurate monitoring judgments about their working memory performance than older adults (Touren et al., 2010), and that those with higher working memory capacity provide more accurate monitoring judgments than those with lower working memory capacity (Komori, 2016). For these reasons, we were optimistic that if mindfulness practice is associated with improvements in the monitoring of working memory, our study would detect them. As mentioned previously, it has also been reported that mindfulness has positive effects on higher-order cognitive functions, including working memory. A recent meta-analysis showed that across subgroup analyses of individual cognitive domains, mindfulness-based programs outperformed comparators for working memory outcomes with a moderate effect size ($g = 0.23$; Whitfield et al., 2022). A proposed explanation for this effect could be the engagement of cognitive processes involved in working memory during mindfulness practice. Mindfulness practice requires one to repeatedly employ “selective and reflective attentional engagement, disengagement, maintenance, and monitoring [...] these processes are also necessary to successfully maintain and manipulate information in working memory” (p. 274, Jha et al., 2019). Given this prior empirical evidence, it was important in the present study to be able to evaluate any group differences on working memory performance, as well as on monitoring judgment accuracy.

From a neurodevelopmental perspective, improvements in metacognition through mindfulness are of special interest, as they have potentially wide-ranging implications, including strengthening the self-regulatory abilities of young people (Kaunhoven & Dorjee, 2017). Given that adolescence and early adulthood are a late catchment period for frontal brain development (Fuster, 2008), and in particular the prefrontal cortex and anterior cingulate cortex that are centrally involved in metacognition (Baird et al., 2013; Fleur et al., 2021; Norman et al., 2019), mindfulness-based practices may exert a pronounced effect within these developmental stages characterized by high plasticity (Weil et al., 2013).

In the present study, practitioners aged 18 to 30 years of age, who have been practicing mindfulness at least three times a week for a minimum of 3 years, were sought. Thus, at the minimum, practitioners in this study have a lifetime practice of approximately 150 h, which would correspond to intermediate practitioners (101–1000 h) by the standard of a recent representative large-scale meditation study (Van Dam et al., 2024). This is a population group that has been rarely studied in meditation expertise research, where a mean age of 40 years or older is common (Goldberg et al., 2021; Lutz et al., 2008; Van Dam et al., 2024).

The overarching question addressed here was the extent to which the metacognitive process of monitoring is associated with mindfulness-based meditation practice. Theoretical and empirical support of the crucial role of metacognition in mindfulness has been solidified and differentiated within the past decade. Mindfulness meditation studies assessing metacognition objectively, however, are sparse and findings are mixed (Baird et al., 2014; Böckler & Singer, 2022; Schmidt et al., 2019). The present study adds to this intervention-based body of evidence by asking whether young mindfulness meditation practitioners show superior metacognitive monitoring accuracy in a visuo-spatial working memory task compared to a control group. Given that theoretical models (e.g., Jankowski & Holas, 2014) propose metacognition to be one of the main underlying cognitive mechanisms of mindfulness, we expected monitoring accuracy to be higher in the group of practitioners compared to non-practitioners (hypothesis 1). Further, we expected that within the group of practitioners, depth of meditation (indexed by the MEDEQ) would be positively correlated with monitoring accuracy and with self-reported mindfulness (indexed by the MAAS; hypothesis 2). We also expected that, within the group of practitioners, monitoring accuracy would be positively correlated with experience in years, duration, and frequency of mindfulness-based practices (hypothesis 3). Monitoring accuracy (correlation between confidence judgments and recall accuracy) was our primary outcome of interest; however, we also considered other indices of metacognitive performance, such as monitoring bias (difference between confidence judgments and recall accuracy), and response time to give the confidence judgments.

Method

Participants

A total of 137 participants from Germany and German-speaking regions of Switzerland took part in the study. Both practitioners (individuals who regularly engage with mindfulness and meditation) and non-practitioners (individuals who do not regularly practice mindfulness and meditation)

were recruited. Practitioners were recruited through emails sent out to Buddhist meditation centers, postings in social media groups that focus on mindfulness and meditation, and mailing lists sent out to Swiss and German universities. Individuals were eligible for the practitioner group if they were between the ages of 18 and 30 years, had at least 3 years of formal practice, and were practicing mindfulness-based meditation at least three times a week. From the practitioner sample, 11 participants had to be excluded ($n = 7$ participants did not fulfil the inclusion criteria *meditation practice* and $n = 4$ did not fulfil the age criteria). After exclusions, the practitioner group consisted of 61 participants ($M_{\text{age}} = 23.56$ years; $SD_{\text{age}} = 3.05$ years; 43 female, 17 male, 1 non-binary). The non-practitioner group was recruited at a German university. Non-practitioners were required to fulfill the age criteria, and they were only eligible if they did not participate in mindfulness or meditation exercises in the last 3 months. From the non-practitioner sample, two participants were excluded because they did not fulfil the age criteria and/or they made too many errors identifying the odd shapes in the Metacognitive Odd One Out task (OOO; see [Data Exclusion](#) below). After these exclusions, the non-practitioner group comprised 63 participants ($M_{\text{age}} = 21.21$; $SD_{\text{age}} = 2.38$ years; 46 females, 17 males).

The final sample ($n = 124$) was larger than the target sample size, which was $n = 102$ with 51 participants in each group. This was determined based on a power analysis calculated in G*Power (Faul et al., 2007) assuming a medium effect size of $d = 0.50$ for the group difference in gamma correlation. In a previous unpublished study using the same task, participants reported if they had engaged in mindfulness practices within the previous 2 months. A group difference in the gamma correlation was observed between those who had engaged in mindfulness practices ($n = 30$) and those who had not ($n = 51$), $t(79) = 1.71$, $p = 0.045$, $d = 0.39$ (one-sided t -test). We expected the effect size in the current study to be larger because we compared much more experienced practitioners with non-practitioners. As such, the power analysis was based on a medium effect size. Descriptive statistics for practitioners and non-practitioners including demographic information (age, gender, education, occupational status) can be found in [Table 1](#).

Practitioners' Characteristics

To get an understanding of the participants' characteristics, multiple choice questions were asked about meditation technique, the affiliated tradition, and the frequency and intensity of their practice. Questions concerning practitioners' meditation techniques and the tradition(s) they followed were based on categories developed by Matko and Sedlmeier (2019). Practitioners were asked to indicate which meditation techniques they practiced (e.g., body-centered

Table 1 Descriptive statistics for practitioners and non-practitioners

	Practitioners <i>n</i> = 61	Non-practitioners <i>n</i> = 63	Group difference
Gender			
Female	43 (70.50%)	46 (73%)	
Male	17 (27.90%)	17 (27%)	
Diverse	1 (1.60%)	0	
Age (years)	<i>M</i> = 23.56 (<i>SD</i> = 3.05)	<i>M</i> = 21.21 (<i>SD</i> = 2.38)	<i>p</i> < 0.001
Education			<i>p</i> < 0.001
Matura/Abitur	38 (62.30%)	60 (95.20%)	
Bachelor	16 (26.20%)	3 (4.80%)	
Master	7 (11.50%)	0	
Occupational status			
Studying	48 (78.69%)	63 (100%)	
Apprenticeship	2 (3.29%)	0	
Working	9 (14.75%)	0	
Other	2 (3.29%)	0	
Self-reported mindfulness (MAAS)	<i>M</i> = 4.12 (<i>SD</i> = 0.73)	<i>M</i> = 3.73 (<i>SD</i> = 0.67)	<i>p</i> < 0.01

Note. MAAS Mindful Attention Awareness Scale (5-point Likert scale)

meditation, mindful observation, visual concentration) and which traditions they followed (Zen Buddhism, Theravada Buddhism, Tibetan Buddhism, Sivananda Yoga, Kundalini Yoga, Yoga (other), Hinduist traditions, Osho, MBSR, Christian traditions, Sufi, Qigong/Tai Chi, other) by selecting all the answers that applied. Practitioners were also asked to indicate for how long they had been practicing mindfulness or meditation (years of practice), as well as how long one current mindfulness/meditation session lasts (mean duration of one session/sitting in minutes), and how frequently they practiced (frequency of practice as sittings per week). Furthermore, they were asked whether they practiced mindfulness-based meditation in a group or by themselves. Descriptive statistics for practitioners can be found in Table 2.

Procedure

Participants (practitioners and non-practitioners) completed the study online on their own laptop or PC (the use of tablets or smartphones was not permitted). They were instructed to only begin the study when they were in a quiet, undisturbed environment; the testing duration was approximately 30 min. Participants clicked on a link that directed them to the Pavlovia platform (Bridges et al., 2020) where the OOO experiment was hosted. On this website, participants were asked to generate a unique identifier, and they had to confirm that they fulfilled the eligibility criteria. Then, participants received information about data protection regulations. Participants were only able to participate after they confirmed that they read and understood all the information

about the study. First, all participants completed the OOO task. Next, they were redirected to the SoSciSurvey platform (Leiner, 2019) and provided some demographic information about their highest educational level and their occupation. Then, all participants completed the MAAS. Finally, only practitioners were asked to provide information about their mindfulness-based practice and to complete the MEDEQ. Participants received a gift card or study credit for their participation. The study was preregistered (<https://osf.io/k8hcv/>).

Measures

Metacognitive Odd One Out Task

Participant's metacognitive monitoring was measured with a metacognitive version of the Odd One Out task (OOO; adapted from Alloway, 2007; see Bryce et al., 2023, for the metacognitive version). The OOO is a computer-based working memory task where participants were shown three boxes each containing a shape: two shapes are the same and one is different (odd one; see Fig. 1). Participants were asked to identify the odd shape by clicking on it and to remember the location of the box in which the odd shape was presented. After a sequence of identifying eight odd shapes, participants were asked to recall the location of the odd shapes in the order in which they were presented. After each trial, participants gave a confidence judgment on a 7-point visual analogue scale (VAS) ranging from *very unsure* to *very sure* to indicate how confident they were about their memory recall. The task was programmed in PsychoPy 3,

Table 2 Characterization of practitioners

	<i>M</i> or <i>N</i> (<i>SD</i> or %)	<i>Min</i>	<i>Max</i>
Mindfulness-based practice			
Years of practice	4.92 (1.93)	3	11
Frequency of practice (sittings per week)	5.22 (2.61)	3	15
Duration of practice (minutes)	21.13 (14.17)	3	61
Setting (alone vs. in groups)	55.74% never in groups		
Meditation technique ^a			
Body-centered meditation	47 (77.01%)		
Mindful observation	45 (73.77%)		
Meditation with movement	23 (37.70%)		
Visual concentration	17 (27.87%)		
Affect-centered meditation	16 (26.23%)		
Mantra meditation	13 (21.31%)		
Contemplation	6 (9.84%)		
Other	4 (6.56%)		
Meditation traditions ^{a,b}			
Yoga (various traditions)	37 (60.70%)		
Buddhism (various traditions)	26 (42.56%)		
Qigong/Tai Chi	10 (16.56%)		
Christian traditions	9 (14.75%)		
MBSR	5 (8.23%)		
Other	9 (14.75%)		
Depth of meditative experiences (MEDEQ)	3.03 (0.65)	1.21	4.46

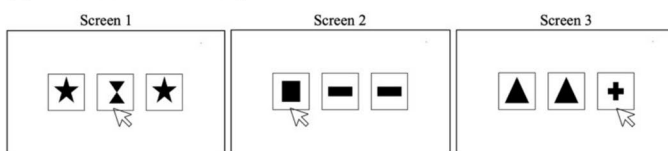
Notes. MEDEQ Meditation Depth Questionnaire (5-point Likert scale). Meditation technique and tradition categorized according to Matko & Sedleier (2019)

^aMultiple choices were possible

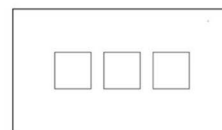
^bNot all traditions are depicted

Example of one metacognitive Odd One Out trial

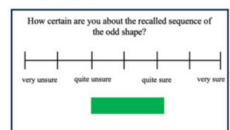
(1) Identification of the odd shapes



(2) Recall of the odd shapes



(3) Providing a confidence judgment



Time →

Fig. 1 Illustration of the metacognitive Odd One Out task. Note: In the Odd One Out task, participants first identified a sequence of eight odd shapes (in the example above, the identification of three out of eight odd shapes is illustrated: participants would click in screen 1 on the box in the middle, in screen 2 on the box on the left, and in screen

3 on the box on the right). Then, in the recall phase, the participants clicked on the boxes in the order in which the odd shapes were presented (middle, left, right). Finally, after each trial, participants gave a confidence judgment about their recall accuracy on a 7-point visual analogue scale

version: 2021.2.0 (Peirce et al., 2019). For each screen, the shapes were randomly selected from a set of 12 geometric shapes, along with the box (out of three) that contained the odd shape. After participants clicked on a box, it turned grey for 500 ms. A red circle appeared on the scale when they clicked on the VAS to indicate their confidence level. To confirm their confidence judgment and to progress through the experiment, participants clicked on a green rectangle on

the lower part of the screen. Thus, participants were able to determine the speed at which they felt comfortable progressing through the experiment.

To ensure all participants understood the task, practice trials were included. First, participants were introduced to the VAS with two questions that varied in their difficulty level (e.g., “how old are you?” and “how much hair do you have on your head?”). After participants provided an answer,

they were asked how certain they were about their answers by using a 7-point VAS ranging from *very unsure* = 0 to *very sure* = 6. This approach has been used previously by Roebbers et al. (2012). Second, participants received a written explanation of the task with pictures. Then, participants were asked to identify and recall the odd shapes in three practice trials with a sequence length of four, six, and eight. Finally, participants completed three practice trials with a sequence length of four, six, and eight and all the components included: (1) identification of the odd shapes, (2) recall of the odd shapes, and (3) providing a confidence judgment regarding their recall accuracy. After the practice trials, participants completed 25 experimental trials with a sequence length of eight.

Recall accuracy was operationalized as the proportion of correctly recalled odd shapes ranging between 0 and 1. Thus, on each experimental trial, participants' percentage of correct recall could be 0%, 12.50%, 25%, 37.50%, 50%, 62.50%, 75%, 87.50%, or 100%. Participants' confidence judgments given on the 7-point VAS ranged from 0 to 6 with a higher value indicating more certainty. In addition, the time that participants needed to give their confidence judgment was recorded in milliseconds. Response time has been proposed to be indicative of how certain a participant is about their monitoring judgment (Kälin & Roebbers, 2020; Roebbers et al., 2019). Participants' recall accuracy and confidence judgments were used to calculate the relative monitoring accuracy (Mengelkamp & Bannert, 2010) for each participant, that is, the Gamma correlation coefficient, $\bar{\gamma}$, between their confidence judgments and percentage of correct recall. A stronger positive correlation indicates participants are more sensitive to trial-by-trial variations in their performance. To calculate a measure of absolute monitoring accuracy, hereafter named *monitoring bias*, we first converted the participants' confidence judgments to a value between 0 and 1. Once the confidence judgments were on the same scale as the recall accuracy scores, for each trial, a bias score was calculated as the recoded confidence judgment minus recall accuracy. In this case, a negative number indicates an underestimation, and a positive number indicates an overestimation of performance (if we accept the assumption that *very unsure* should be mapped to 0 locations correctly recalled and *very sure* should be mapped to all locations correctly recalled). Please note, the measures of monitoring judgment accuracy from binary (correct/incorrect) outcomes derived from signal detection theory (e.g., Maniscalco & Lau, 2012) are not appropriate here, because the present performance measure was the proportion of the sequence correctly recalled.

Mindfulness

Participant's self-reported mindfulness was assessed with the Mindful Attention Awareness Scale (MAAS; Brown &

Ryan, 2003; Michalak et al., 2008).¹ This scale consists of 15 items that describe possible everyday experiences related to mindfulness. The items tap cognitive, social, emotional, interpersonal, and general domains, and all of them describe a lack of mindful behavior (e.g., "I rush through activities without being really attentive to them"). Previous analysis found that all items loaded on one factor. Participants were asked to indicate on a 6-point Likert scale ranging from *almost always* (1) to *almost never* (6) how frequently they had the described experiences. Thus, higher values indicate more mindfulness. The English, original version as well as the German translation indicated good reliability, a Cronbach's $\alpha = 0.83$, and 0.82 respectively. The reliability for the current sample was comparable to the original versions and can be considered good (Cronbach's $\alpha = 0.85$; McDonald's $\omega = 0.85$). The dependent variable of the MAAS scale was the mean value across all 15 items.

Depth of Meditation

Practitioners were asked to complete the Meditation Depth Questionnaire (MEDEQ; Piron, 2001). This questionnaire consists of 30 statements that describe possible meditation experiences. The underlying assumption is that irrespective of the meditation technique, advanced practitioners report similar experiences, which can be arranged along a dimension of meditation depth, ranging from an effortful struggle with the requirements of the chosen technique to the realization of the fundamental ground of all being, where all dualities dissolve (Piron, 2020). The spectrum ranges from (1) hinderances: internal restlessness, drowsiness, sleepiness, motivation, or concentration problems; (2) relaxation: well-being, calm breath, increasing patience, and inner balance; (3) concentration: successful attention direction, mindful observation of internal experiences; (4) essential qualities: transcendence of methods, alertness, body and time experiences; (5) non-duality: calming of cognitive activities, void of conscientiousness. Practitioners were asked to express their agreement with the statements on a 5-point Likert-scale ranging from *not at all* to *very strongly* referring to their mindfulness and meditation practice in the last few weeks as a reference point. The statements described positive meditation experiences such as "My body was pleasantly relaxed" or negative experiences (cf. hinderances), for instance "I experienced boredom." All positively framed items were summed to form sum A, and all negatively framed items were summed to form sum B (Piron, 2025). Because sum B showed unacceptable internal consistency (Cronbach's

¹ While multidimensional mindfulness questionnaires may offer additional advantages, the MAAS was selected given its brevity and the constraints of online testing time.

$\alpha=0.46$; McDonald's ω could not be estimated), only sum A (24 items) was included in the present analyses (Cronbach's $\alpha=0.91$; McDonald's $\omega=0.91$).

Data Analyses

The main aim in this study was to evaluate the presence of group differences in metacognitive monitoring between the two participant groups. To this end, one- or two-sided t -tests were conducted to assess the data with regards to hypothesis 1. To assess the hypotheses about associations among metacognitive monitoring and depth of meditation as well as self-reported mindfulness (hypothesis 2), as well as associations between metacognitive monitoring and experience and intensity of mindfulness-based practices (hypothesis 3), correlational analyses were conducted.

Data were analyzed as planned in the pre-registration document. The data and R script required to run the reported analyses reported below are available on OSF (<https://osf.io/k8hcv/>). Data were analyzed using R (R Core Team, 2021) and Goodman–Kruskal gamma correlations were calculated using the R package *RoCoCo* (Bodenhofer & Klawonn, 2008; Bodenhofer et al., 2013). In addition to the pre-registered analyses, Bayesian t -tests were conducted (using the *BayesFactor* package for R; Morey & Rouder, 2024) and their results are reported alongside the results of the frequentist t -tests. For these analyses, the standard Cauchy distribution of effect sizes centred on zero and a width of $r=0.71$ were specified. Bayes factors BF_{10} greater than 3 are typically considered moderate evidence for the alternative hypothesis (i.e., the alternative hypothesis is more than three times as likely as the null hypothesis given the present data), whereas a BF_{10} less than 0.33 can be considered moderate evidence for the null hypothesis (see Morey et al., 2016; for more details on the quantification of evidence). In the presented results, alpha levels are not corrected for multiple comparisons; instead, readers can evaluate the strength of the evidence via the Bayes factors provided in group comparisons and the 95% confidence intervals provided for correlation coefficients.

Data Exclusion

Because the data were collected online and not under the direct supervision of the research team, data from the OOO task were examined for signs of non-compliance or interruptions. First, participants who were deemed as non-compliant or having not understood the task were identified as those who correctly identified fewer than 40% of the odd shapes in the trio. Data from one participant from the non-practitioner group who had an identification rate close to chance (31%) were excluded for this reason. Single trials

in which the participant took longer than 5 s to provide a confidence judgment were also removed, because we assume these trials may not reflect accurate monitoring judgments if participants were distracted. (Note, this decision was not pre-registered.) This amounted to 3.50% of all trials. After this, a sufficient number of trials per participant remained (ranging from 17 to 25, with a median of 25).

Results

Testing Group Differences in Metacognitive Monitoring and Mindfulness

The first hypothesis stated that meditation practitioners would demonstrate higher metacognitive monitoring accuracy in the OOO task than non-practitioners (see Fig. 2). This was tested via an independent samples t -test (one-sided) comparing the groups on their monitoring accuracy (gamma correlation between confidence judgments and recall accuracy). Both groups showed significant monitoring accuracy (practitioners $\bar{\gamma}=0.52$, $p<0.001$; non-practitioners $\bar{\gamma}=0.53$, $p<0.001$), indicating that they were sensitive to trial-by-trial changes in their performance. There was, however, no group difference in their monitoring accuracy. This, and the results of all other group comparisons, can be found in Table 3. As can be seen, the only significant group difference occurred on the MAAS, reflecting that meditation practitioners reported higher levels of mindfulness in their everyday lives than non-practitioners.

Associations Among Mindfulness and Metacognitive Monitoring in Practitioners

Hypotheses 2 and 3 concerned the associations among metacognitive monitoring and indices of mindfulness and features of meditation practice within the group of practitioners. To address these hypotheses, correlations were calculated among the monitoring accuracy score on the OOO task, self-reported mindfulness (MAAS), and depth of meditation (MEDEQ), as well as measures of the experience and intensity of meditation practices (see Table 4). No indices of mindfulness nor features of meditation practice were significantly correlated with relative monitoring accuracy as measured in the OOO task. With regard to hypothesis 2, practitioners' depth of meditation was not correlated with their self-reported mindfulness ($r=0.22$, $p=0.087$). Interestingly, the intensity of practice (duration and frequency of sessions) was not associated with self-reported mindfulness, whereas those who had practiced meditation for more years also reported achieving a deeper meditative practice.

Table 3 Results of group comparisons on measures from the OOO task and the MAAS

Variable	Practitioners		Non-practitioners		$t(122)$	p	d	BF_{10}
	M	SD	M	SD				
Monitoring accuracy ($\bar{\gamma}$)	0.52	0.20	0.53	0.20	0.38	0.647	0.07	$0.20 \pm 0.03\%$
Recall accuracy	0.68	0.13	0.69	0.12	0.44	0.664	0.08	$0.21 \pm 0.03\%$
Confidence judgment (CJ)	2.74	0.93	3.00	0.86	1.64	0.104	0.30	$0.64 \pm 0.02\%$
Response time CJ (sec)	1.76	0.37	1.89	0.44	1.77	0.079	0.32	$0.79 \pm 0.02\%$
Monitoring bias	−0.22	0.12	−0.19	0.12	1.56	0.121	0.28	$0.57 \pm 0.02\%$
MAAS	4.12	0.73	3.73	0.67	−3.14	0.002	−0.57	$15.10 \pm 0\%$

Notes. Group comparisons were all two-sided independent samples t -tests aside from the one testing for differences in monitoring accuracy, which was one-sided

Monitoring accuracy = Gamma correlation coefficient between Recall accuracy and CJ. Monitoring bias = recoded CJ – Recall accuracy (negative values indicate an underestimation, positive values an overestimation)

MAAS mean score on the Mindful Attention Awareness Scale



Fig. 2 Mean recall accuracy, confidence judgment, and monitoring accuracy for practitioners and non-practitioners. Note: In the right-most panel, confidence judgment is plotted against recall accuracy. For illustration, single trials were vincentized based on recall accuracy (single trial data entered the data analysis). That is, the first vin-

centile in each panel represents 20% of trials with the lowest recall accuracy for each participant; the second contains the next 20% of trials with lowest recall accuracy, and so on. Error bars represent +1 within-subject SE

Discussion

Metacognition scholars have proposed that mindfulness-based meditation can be viewed as a practice that promotes the cultural learning of metacognition (Heyes et al., 2020). Similarly, mindfulness scholars have theorized that metacognition is one of the main cognitive constructs underlying mindfulness (e.g., Jankowski & Holas, 2014; Shapiro et al., 2006). Testing specific and nuanced metacognitive processes that may change as a result of mindfulness-based practice remains a central task in this field (Vago et al., 2019). In the present study, we tested whether young mindfulness meditation practitioners show better metacognitive monitoring accuracy in a visuo-spatial working memory task compared to a control group consisting of non-practitioners. Contrary

to the hypotheses, no significant group differences were found in any of the metacognitive measures. Within the practitioner group, having practiced meditation for longer was associated with deeper meditative practice, although deeper meditative practice was not associated with higher levels of self-reported mindfulness in everyday life (the latter finding was not consistent with our second hypothesis). With regard to our third hypothesis, that practitioners who more intensively practice meditation will more accurately monitor themselves, no supporting evidence was found.

Present findings indicate that regular mindfulness-based practice in young adults does not appear to be associated with either relative (monitoring accuracy) or absolute (monitoring bias) improvements in metacognitive monitoring of working memory performance in a cognitive experimental

Table 4 Correlations among monitoring accuracy, self-reported mindfulness, depth of meditation, and intensity of meditation practice within the practitioners group

Variable	<i>M</i>	<i>SD</i>	1	2	3	4	5
1. Monitoring accuracy (γ)	0.52	0.20					
2. MAAS	4.12	0.73	0.08 [−0.17, 0.33]				
3. MEDEQ	3.03	0.66	0.10 [−0.15, 0.35]	0.22 [−0.03, 0.45]			
4. Years of practice	4.92	1.93	0.12 [−0.14, 0.36]	0.19 [−0.06, 0.42]	0.30* [0.05, 0.51]		
5. Duration of a session (min)	21.13	14.17	−0.17 [−0.40, 0.09]	0.24 [−0.01, 0.46]	0.10 [−0.16, 0.34]	0.30* [0.05, 0.51]	
6. Frequency (per week)	5.20	2.61	0.03 [−0.23, 0.28]	−0.07 [−0.32, 0.18]	−0.01 [−0.26, 0.24]	0.30* [0.05, 0.51]	0.35** [0.11, 0.55]

Notes. Values in square brackets indicate the 95% confidence interval for each correlation. The confidence interval is a plausible range of population correlations that could have caused the sample correlation (Cumming, 2014)

Monitoring accuracy = Gamma correlation coefficient between Recall accuracy and CJ

MAAS mean score on the Mindful Attention Awareness Scale, *MEDEQ* mean score on the Meditation Depth Questionnaire

* $p < 0.05$; ** $p < 0.01$

context. This conclusion is reinforced by the absence of significant correlations between features of meditation practice, indices of mindfulness, and monitoring accuracy within the practitioner group. Together with previous studies reporting null results (Böckler & Singer, 2022; Schmidt et al., 2019), present findings challenge the notion that mindfulness-based practice is associated with enhanced procedural metacognition as operationalized in experimental cognitive psychology. In contrast, intervention studies reporting improvements in self-reported metacognitive monitoring (Kok & Singer, 2017) and metacognitive beliefs (Sanger & Dorjee, 2015) suggest that changes in declarative metacognition may be prompted by mindfulness-based practice. It must be noted here, however, that accuracy cannot be evaluated in the aforementioned self-report and belief measures. That is, these findings indicate that people believe themselves to behave more metacognitively and to have more insight into themselves in general, but it remains to be addressed whether this is objectively accurate. In the current study, because we collected monitoring judgments in an item- and task-specific manner, we were able to evaluate the accuracy of these judgments and found no difference between the groups. A recent empirical study collected self-reports of metacognitive monitoring abilities and directly assessed monitoring accuracy in the same sample and observed that these measures of metacognition are in fact negatively associated (Double, 2025). It remains a possibility that mindfulness training creates the illusion of insight or self-knowledge, rather than selectively training monitoring processes or refining monitoring judgments.

An alternative explanation for the null findings reported here relates to the level of consciousness required by the present metacognition task. Retrospective confidence judgments rely on deliberate, verbally reportable metacognitive monitoring (Shea & Frith, 2016), whereas mindfulness may train monitoring processes that are more automatic or implicit. Constructs such as feelings of knowing, tip-of-the-tongue phenomena (Schwartz, 1994), or noetic feelings (Proust, 2012) highlight procedural monitoring that operates below the level of conscious awareness. Future studies could examine whether mindfulness affects these less explicit forms of metacognitive monitoring.

The object of monitoring in the present metacognition task was working memory performance, or the strength of the memory trace. It could be that the mindfulness-based practiced by this sample of practitioners does not train their ability to monitor their memory trace but rather the ability to monitor their motor processes or other aspects of attention. Indeed, the domain-generalty of metacognitive monitoring has long been a focus of investigation, with empirical evidence showing mixed results. For instance, Mazancieux and colleagues (2020) investigated correlations among task performance across six tasks and among monitoring accuracy across the same tasks, finding mostly evidence for domain-generalty. Most relevant to the current study is the finding that, although task performance on a visual perception task and a semantic memory task did not correlate, monitoring accuracy across these tasks did show a significant correlation. Notably, however, monitoring accuracy on an episodic memory task and the visual perception task did not correlate. As part of

a review on the domain-generalty of metacognitive monitoring, a meta-analysis conducted by Rouault and colleagues (2018) showed medium-to-strong correlations in monitoring accuracy across different perception-based tasks, but no significant correlations in monitoring accuracy across memory- and perception-based tasks. Their review of neuropsychological and neuroimaging data, however, paints a more nuanced picture suggesting that both shared and distinct monitoring processes may coexist and be flexibly recruited depending on context, judgment type, and individual differences in the tendency to generalize. This perspective was further supported by a more recent review by Mazancieux et al. (2023), who concluded that the evidence supports weak domain-generalty in metacognitive monitoring. Taken together, these findings suggest that a different pattern of results may be obtained if a metacognition task with a different object of monitoring had been employed in the current study.

It is also worth considering differences in how meta-awareness is conceptualized across contemplative traditions. Various Buddhist accounts suggest that meta-awareness appears to be essential to shifting one's experiential perspective onto an experience itself (cf. decentering) and experiencing thoughts as mental events, and not as the things that they seem to represent (cf. dereification or metacognitive insight) (Dunne et al., 2019). For some Buddhist styles of mindfulness meditation, meta-awareness is conceptualized as intermittent (occurring at specific times when one explicitly attends to the contents or processes of one's awareness) and propositional (involving internally verbalized, propositionally structured judgments, e.g., "my mind is wandering"; Dunne et al., 2019). In contrast, within nondual styles of practice such as, for instance, Tibetan Mahamudra, theoretical accounts and meditation instructions articulate meta-awareness as non-propositional and non-intermittent or sustained (cf. *mental quiescence*). Specifically, in Mahamudra meditation, practitioners seek to cultivate a form of meta-awareness that continuously monitors awareness even while attention to the anchor (e.g., the breath) is sustained. These differences may influence the extent to which mindfulness-based practices affect metacognitive monitoring as assessed in experimental paradigms and other domains than memory. Future studies could benefit from exploring these distinctions and testing whether practitioners trained in nondual meditation exhibit different metacognitive profiles than those trained in more attentional, focused styles of meditation. In sum, these interpretations of present null results may refine current claims about mindfulness and metacognition.

Limitations and Future Directions

Several limitations of the present study need to be mentioned. First, confidence judgments as employed in the present study were prompted and therefore do not reflect

naturally occurring monitoring processes (Halamish & Undorf, 2020). Future research is needed to explore if spontaneously occurring monitoring processes might be influenced by mindfulness-based practices. Second, a sample of young practitioners who have been largely under-represented in meditation expertise research (e.g., Lutz et al., 2008) was employed. While practitioners' depth of meditation was positively correlated with years of practice, neither the intensity of practice (i.e., duration and frequency of sessions), nor years of practice were associated with self-reported mindfulness. This pattern of associations raises questions regarding the robustness of the practitioners' mindfulness states. Future research is needed to establish the comparability of such samples to participants categorized as advanced or beginner practitioners (Van Dam et al., 2024). Third, the present study employed a quasi-experimental design by comparing pre-existing, self-selected groups of mindfulness practitioners and non-practitioners. This study design allowed achieving high ecological validity by examining long-term commitment to meditation practice. Unfortunately, despite our best efforts to recruit comparable groups, there were, however, significant differences between the groups in age and education level. The practitioners were slightly older and more of them had completed a Bachelor degree, whereas many of the non-practitioners were still studying their Bachelor degree. Therefore, groups are not considered to be very different in intelligence or educational achievement, rather that the practitioners were on average a couple of years further progressed with their education. A further limitation of quasi-experimental designs is of course that unmeasured confounding variables, such as pre-existing differences in cognitive variables, personality traits, or motivation, may have influenced both the decision to engage in mindfulness-based practice and the outcomes measured. Fourth and lastly, the choice of the present mindfulness measure (MAAS questionnaire) may have limited the interpretation of the findings. Future research may employ a more comprehensive measure (e.g., the Five Facet Mindfulness Questionnaire, Baer et al., 2006) to examine group differences in trait mindfulness related to metacognition.

Practices aimed at cultivating metacognition have been extensively studied in educational psychology (Eberhart et al., 2025), and are common in Buddhism, where they have been culturally evolving for more than 2500 years. The question of whether improvements in metacognition induced by mindfulness-based practices can be captured by studying procedural metacognition (i.e., metacognitive monitoring operationalized based on confidence judgments in a visuo-spatial working memory task) was addressed in the present study by comparing young mindfulness practitioners (aged 18–30 years, with at least 3 years of meditation experience) to non-practitioners. The present pre-registered study

advances the field by combining behavioral and self-report measures, focusing on the underrepresented population of young mindfulness meditation practitioners, and reporting theoretically informative null results that refine current claims about mindfulness and metacognition.

Results provide no evidence that regular mindfulness-based practice in young adults is associated with superior metacognitive monitoring accuracy or bias in a cognitive experimental context. The absence of group differences may reflect the mismatch between mindfulness-induced meta-awareness and the type of conscious, deliberate monitoring of memory performance assessed in this study.

Both metacognition and mindfulness are broad and multifaceted constructs (Efklides, 2008; Van Dam et al., 2018) and their relationship likely depends on how these constructs are operationalized and measured (Norman, 2017). It is therefore not surprising that, despite a growing body of empirical work (Baird et al., 2014; Böckler & Singer, 2022; Schmidt et al., 2019), the evidence remains mixed. By adding to the mixed empirical picture, present findings underscore the need for further research to clarify and substantiate theoretical claims about the role of metacognition in mindfulness. Future research should consider broadening operational definitions of metacognition to include both explicit and implicit monitoring to fully understand the relationship between mindfulness and metacognition. Longitudinal designs as well as larger, more diverse samples may also help clarify whether particular forms or intensities of mindfulness-based practice influence metacognitive abilities.

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Author Contributions R.N. and D.B. conceptualized the study and wrote the main manuscript text. J.E. wrote the methods section. All authors were involved in project administration and carried out data collection. D.B. performed the main analyses. All authors reviewed the manuscript.

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Data Availability The pre-registration, the data, and analysis script can be found here: <https://osf.io/k8hcv/>.

Declarations

Ethics Statement The study was reviewed by the ethics board of University of Bern, Switzerland (Nr. 2021–08–00002).

Informed Consent On the Pavlovla platform, where the OOO experiment was hosted, participants received information about data protection regulations. Participants were only able to participate after they confirmed that they read and understood all the information about the study.

Competing interest The authors declare no competing interests.

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