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Meditation focused on self-observation of the body impairs metacognitive efficiency

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A R T I C L E I N F O

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A B S T R A C T

In the last decade of research on metacognition, the literature has been focused on understanding its mechanism, function and scope; however, little is known about whether metacognitive capacity can be trained. The specificity of the potential training procedure is in particular still largely unknown. In this study, we evaluate whether metacognition is trainable through generic meditation training, and if so, which component of meditation would be instrumental in this improvement. To this end, we evaluated participants' metacognitive efficiency before and after two types of meditation training protocols: the first focused on mental cues (Mental Monitoring [MM] training), whereas the second focused on body cues (Self-observation of the Body [SoB] training). Results indicated that while metacognitive efficiency was stable in MM training group, it was significantly reduced in the SoB group after training. This suggests that metacognition should not be conceived as a *stable* capacity but rather as a *malleable* skill.

1. Introduction

Metacognition refers to the ability to access and describe one's own mental contents (Flavell, 1979). This ability seems to be essential in our daily life. In effect, correctly assessing our own mental states allows us to distinguish correct from incorrect decisions based on confidence (Koriat, 2012), but also to know the degree of effort that we have deployed in these decisions (Naccache et al., 2005), as well as to be able to track the time elapsed to perform a task (Corallo, Sackur, Dehaene, & Sigman, 2008). All the above converge on the notion that the capacity to monitor our own mind seems to be essential to controlling our behavior (Nelson & Narens, 1990). However, little is known about whether metacognition can or cannot be trained. Recently, Carpenter et al. (2019) succeeded in improving participants' metacognition after eight training sessions an another metacognitive task, with feedback; improvement transferred to another metacognitive task. In this last study, metacognition was trained and tested on two laboratory tasks.

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Previously, Baird, Mrazek, Phillips, and Schooler (2014) found that participants could improve their metacognitive sensitivity after receiving brief and intense meditation training. Baird et al. (2014) study employed an active control group, during which participants attended nutrition courses, while the meditation group performed a type of focused attention meditation, inspired by Buddhist practice (Lutz, Slagter, Dunne, & Davidson, 2008). Note that from this study it seems to be impossible to identify which particular aspect of a meditation training leads to improved metacognition. This is the main aim of the present study.

In general, the study of metacognitive capacity presents multiple evaluation methods (Overgaard & Sandberg, 2012) and conceptualization in different fields of psychology (Dunlosky & Bjork, 2008; Zohar & Barzilai, 2013). This study responds to a specific field of experimental psychology (Fleming & Frith, 2014), in which metacognitive capacity is not evaluated by simply capturing individuals' beliefs with respect to their own mental contents, but rather by evaluating how accurate they are at monitoring the accuracy of their decisions (i.e., *metacognitive efficiency*). According to this, metacognitive efficiency refers to the relationship between subjective reports (e.g., high / low confidence) and objective behavior (incorrect / correct decisions). Metacognition, in this particular experimental context, is defined as the relationship between individual performance (objectively captured in a decision-making task) and individual confidence (subjectively estimated for each of these decisions).

Speculative speaking, metacognition could operate similarly to an attentional process, but directed toward mental contents, even sharing certain cortical circuits (Fernandez-Duque, Baird, & Posner, 2000). In this line, Reyes and Sackur (2014) suggested that when individuals (during metacognition) focus their attention on their own behavior, the monitoring process should be conceptualized as a self-observation of the body (SoB) mechanism. By contrast, when individuals focus their attention on pure mental contents, i.e., a source of information that comes from cognitive processes, metacognition should be conceptualized as a mental monitoring (MM) mechanism. Additionally, the SoB / MM distinction is in line with the distinction between internal *vs*. external attention (Chun, Golomb, & Turk-Browne, 2011). Chun et al. argue that what differentiates internal from external attention is the content of selection. Internal attention refers to the selection and modulation of internally generated information, and external attention refers to the selection and modulation of sensory information (including one's body) in a modality-specific representation. Thus, while internal attention includes cognitive control processes and operates over representations in working memory, external attention is selective for information from the external, perceptual world (Chun et al., 2011). Internal attention has been related to executive functions like cognitive control (Fan & Turk-Browne, 2013; Miller & Cohen, 2001), long-term memory retrieval (Chun & Turk-Browne, 2007) and conflict monitoring (Botvinick, Carter, Braver, Barch, & Cohen, 2001). As opposed to internal attention, external attention can be put to bear on space (Cave & Bichot, 1999; Rayner, 2009), time (Coull & Nobre, 1998) or sensory processes (Ghazanfar & Schroeder, 2006; Veldhuizen, Bender, Constable, & Small, 2007).

Additionally, studies interested in the distinction between external *vs*. internal attention have identified that in the case of internal attention, individuals present greater activity in the ventrolateral prefrontal cortex (VLPFC, Herwig, Kaffenberger, Jäncke, & Brühl, 2010), an area traditionally related to memory, decision-making and control processes (Hebscher, Barkan-Abramski, Goldsmith, Aharon-Peretz, & Gilboa, 2016). Interestingly, the insula has been also related to interoceptive monitoring processes (Garfinkel & Critchley, 2013; Zaki, Weber, & Ochsner, 2012). Studies interested in meditative techniques (Tang, Hölzel, & Posner, 2015) suggest greater activity in the dorsolateral prefrontal cortex (dlPFC) and dorsal anterior cingulate cortex (dACC) after 6 weeks of training (Allen et al., 2012); greater activity in the anterior cingulate cortex (ACC) after 1 month of training (Tang et al., 2010) and 1 year of experience in meditation (Andreu et al., 2017), and even greater activity in the rostrolateral ACC and dorsomedial prefrontal cortex (dmPFC) in meditation experts with 8 years of practice (Holzel et al., 2007). Interestingly, all these studies converge on the presence of increased activity in the medial prefrontal cortex (mPFC) when meditation is based on protocols that require the modulation of internal attention (Hasenkamp, Wilson-Mendenhall, Duncan, & Barsalou, 2012). The above is also consistent with studies in the neuroscience of metacognition, where greater metacognitive scores has been associated with greater activity in the dlPFC and anterior prefrontal cortical subregions (Baird, Smallwood, Gorgolewski, & Margulies, 2013; Fleming & Dolan, 2012; Fleming, Weil, Nagy, Dolan, & Rees, 2010; McCurdy et al., 2013), interacting with the cingulate and insula (Fleming, Huijgen, & Dolan, 2012). Overall, these studies suggest that meditative training based on monitoring mental states would seem to target areas that coincide with the cortical areas traditionally related to self-monitoring of internal mental contents. Therefore, in line with Baird et al., 2014 study, we hypothesized that meditation training could lead to improved metacognition, but we enquired as to which component of meditation would be most important in this improvement.

We selected the Meditation Based Stress Reduction program (MBSR, Kabat-Zinn, 1990) as the basis for our study, because previous studies have repeatedly shown that it is clinically effective (Goldberg et al., 2018; Gu, Strauss, Bond, & Cavanagh, 2015). In effect, experimental studies with the MBSR program (or similar) have reported significant changes in higher executive functions: cognitive flexibility (Moore & Malinowski, 2009), emotion regulation (Tang et al., 2015), working memory (Jha, Stanley, Kiyonaga, Wong, & Gelfand, 2010) and in the attentional processing (van den Hurk, Giommi, Gielen, Speckens, & Barendreqt, 2010). All of the above studies considered the MBSR as an indivisible, unique causal factor. However, the MBSR comprises a host of exercises pertaining to various mental and bodily practices such as sitting meditation, walking meditation, body scan and yoga (Kabat-Zinn, 1990), that tap into widely different cognitive resources. While its cognitive and clinical efficacy may well stem from the synergistic combination of different kinds of practices, it remains to be investigated whether some of these practices are more tightly linked to some cognitive improvements. Thus, our strategy consisted in distinguishing the MBSR exercise that induce participants to focus their attention on their own mental contents (MM training protocol) from those exercise that generate attentional monitoring of non-mental contents (SoB training protocol). Beyond our selection of specific content for each group, we adhered to the standard program of the MBSR. The modifications to the MBSR program are detailed in the supplementary materials.

Before and after the 8 weeks training, each participant was individually tested for his or her metacognitive efficiency in two tasks: a perceptual (Fleming et al., 2010) and a memory task (Fleming, Ryu, Golfinos, & Blackmon, 2014; McCurdy et al., 2013). These cognitive tasks were accompanied by two clinical questionnaires, the Perceived Stress Scales (PSS: Cohen, Kamarck, & Mermelstein, 1983) and the Depression Anxiety and Stress Scales (DASS-21: Antony, Bieling, Cox, Enns, & Swinson, 1998). Since our MM and SoB training protocols contain a selection from the well-documented MBSR meditation program, we also incorporated two questionnaires to obtain a mindfulness score for each participant (Five Facet Mindfulness Questionnaire (FFMQ: Baer, Smith, Hopkins, Krietemeyer, & Toney, 2006) and Mindful Attention Awareness Scale (MAAS: Brown & Ryan, 2003). We expect that in both groups the meditation scores (FFMQ and MAAS) and the clinical indicators (PSS & DASS-21) will improve, as both groups experience a subset of the classical MBSR program, and we predicted that metacognitive efficiency should improve more for participants in the Mental Monitoring (MM) meditation training than for participants in the Body Self-Observation (SoB) meditation training.

2. Material and methods

2.1. Participants

Twenty-seven individuals – without previous experience in meditation – participated in the study. They were randomly assigned to either the Mental Monitoring (MM) meditation training protocol (14 participants, 10 women, *M* age = 30.5, *SD* = 11.6), or the Self-observation of the Body (SoB) meditation training protocol (13 participants, 11 women, *M* age = 30.8, *SD* = 12.9). No differences were observed in the number of training days attended (*t*-test (25), $p > .63$; SoB group [*M* = 7.08, *SD* = 0.86, Attendance = 89%] and the MM group [*M* = 7.21, *SD* = 0.58, Attendance = 90%]). The study at all stages was approved by the Ethics Committee of Universidad Austral de Chile (Valdivia, Chile). Informed consent was obtained before the first session. Participants received no compensation for their participation. None of the participants had any knowledge regarding the protocol and all had normal or corrected-to-normal vision. As an exclusion criterion, a history of psychiatric or neurological disorders was considered.

2.2. Procedures and stimuli

The general procedure of the experiment was the following: In a first session 4 questionnaires were administered in random order (PSS, DASS-21, MAAS & FFMQ). In a second and third session, individuals performed the cognitive tasks (Perceptual or Memory Task). Order was randomized. Then, the modified MBSR training was implemented (8 sessions, one per week). After training, a new session of questionnaires and two new sessions of cognitive tasks were carried out, with the same randomization as for the pre-training sessions. In total, each subject attended 14 laboratory sessions. The cognitive task sessions were always carried out the day after the questionnaires session.

2.3. Questionnaires

Perceived Stress Scale (PSS: Cohen et al., 1983): A 14-item self-reported questionnaire, which evaluates the level of stress perceived in the last month. The scale has a Likert response format with a range from 0 (never) to 4 points (very often). The total score varies between 0 and 56 points. A higher score indicates a higher level of perceived stress. Both the original version (Cohen et al., 1983) and the Spanish version (Remor, 2006) present high internal reliability (Cronbach's $\alpha = 0.85$ and 0.81 respectively). The reliability coefficients in the present sample for each questionnaire are also reported (see Supplementary Material, SM-I, Table S1).

Depression Anxiety and Stress Scales (DASS-21: Antony et al., 1998): A 21-item self-reported questionnaire, which independently establishes an index of depression (DASS-D), anxiety (DASS-A) and stress (DASS-S). Participants were asked to answer each item according to the presence and intensity of each symptom in the last week. Each of the three scales has seven items with a Likert response format with four alternatives organized on a scale from 0 (never) to 3 (very often) points. The total score of each scale varies between 0 and 21 points. The original version (Antony et al., 1998) present high internal reliability for the scales of depression, anxiety and stress (Cronbach's $\alpha = 0.94$, 0.87 and 0.91, respectively). The Spanish version (Antúnez & Vinet, 2012) present a moderate to high internal reliability for the scales of depression, anxiety and stress (Cronbach's $\alpha = 0.85$, 0.73 and 0.83 respectively).

Mindfulness Attention Awareness Scale (MAAS: Brown & Ryan, 2003): A 15-item self-reported questionnaire, which measures an individual's capacity for awareness of their experience in contrast to having automated behaviors. The participants must respond on a Likert scale ranging from 1 (almost always) to 6 (almost never), with 15 being the minimum score and the maximum being 90. Both the original version (Brown & Ryan, 2003) and the Spanish version (Soler et al., 2012) present high internal reliability (Cronbach's $\alpha = 0.82$ and 0.89, respectively).

Five Facet Mindfulness Questionnaire (FFMQ: Baer et al., 2006): A 39-item self-reported questionnaire, which measures the meditative capacity (mindfulness) in five facets: *Observing, Describing, Acting With Awareness* (AWA), *Non-judging of Inner Experience* and *Non-reactivity to Inner Experience.* The participants must respond on a Likert scale with a range from 1 (never or very rarely) to 5 (very often or always true), with the minimum score being 39 points and the maximum 195 points. In the original version, all five facet scales present a moderate to high internal reliability (Cronbach's $\alpha = 75$ to 0.91). The Spanish version used in this study (Schmidt & Vinet, 2015) present acceptable to good levels of reliability (Cronbach's $\alpha = 0.62$ to 0.86).

2.4. Perceptual task

Stimuli were arrays of six vertical Gabor patches (2.8° in diameter, spatial frequency of 2.2 cycles per visual degree, Fig. 1A) on a

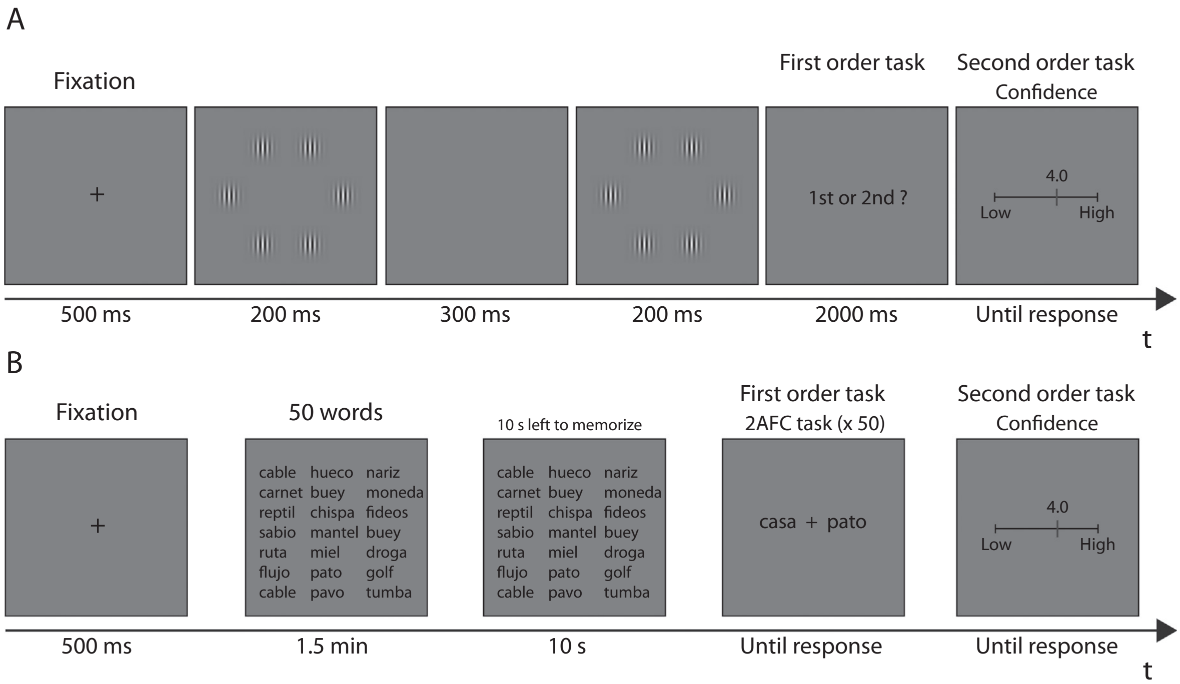

Fig. 1. Figure represents the (A) perceptual and (B) memory tasks implemented in the protocol. In the perceptual task (A), participants viewed the two arrays of stimulus for 200 *ms* each. In one of the arrays, one random Gabor patch had a higher contrast. Participants had to decide at which interval the contrasted Gabor was presented, during a 2000 *ms* response window. Immediately after the participants' response, they were instructed to give an estimate of their confidence about their decision on a visual analog scale for confidence. In the memory task (B), participants were asked to memorize as many of the set of words as possible. Once the presentation of the stimuli had finished, a series of 50 two-alternative forced-choice judgments (2AFC task) were presented. Two words appeared on each side of the fixation cross. Participants were asked to indicate which of the two words had been previously memorized. Once the decision had been made, participants were asked to estimate the confidence in their decision.

uniform grey background (luminance: 44 cd/m^2), presented on an imaginary circle (6.2°) at the center of a CRT screen (size 17″, resolution of 1024 × 768 pixels, refresh rate of 100 Hz, viewing distance ~55 cm). The task consisted in deciding in which of two arrays of Gabor patches, presented in a sequence, one Gabor patch had higher contrast was presented (Fleming et al., 2010). On a trial-by-trial basis, participants were asked to estimate their confidence in their decision. Participants were tested in a darkened room with the monitor as the only source of light. The experimental session comprised 300 trials in 6 blocks with a 60-second pause between each block. The trial structure was the following: after a fixation spot (500 *ms*), participants viewed the two arrays for 200 *ms* each, separated by an interval of 300 *ms*. In one of the arrays, one random Gabor patch had a higher contrast. Participants had to decide at which interval the contrasted Gabor was presented during a 2000 *ms* response window, by pressing the “Q” (first interval) or “W” (second interval) key on a standard QWERTY keyboard. During the experiment, contrast varied on a trial-by-trial basis according to a 1-up 2-down staircase method with the aim of adjusting the individuals’ performance to 71% (Garcia-Pérez, 1998). Immediately after their response, they were instructed to give an estimate of their confidence about their decision on a visual analog scale for confidence, anchored at 1 and 6.

2.5. Memory task

Stimuli consisted of 50 Spanish words grouped in 5 columns (Fig. 1B) presented for 1.5 min on a gray background (luminance: 44.1 cd/m^2; the characteristics of the monitor are the same as those mentioned for the perceptual task). Then, in the test phase, participants were instructed to decide which of two words had been previously presented. Only one of these two words was randomly selected from the study array, the other word was a lure selected from the same set of words. After each trial, we ask the participants to estimate the degree of confidence in their decision (McCurdy et al., 2013). The Spanish words were generated from the LEXESP database (Sebastián-Gallés, Martí, Carreiras, & Cuetos, 2000). With respect to the characteristics of the words, we used the same criteria as Fleming et al. (2014): each word was 4 to 8 letters long, one to three syllables, and with a range of familiarity, concreteness and imageability between 400 and 700 points. The experimental session comprised 4 blocks (4 study arrays, followed by 4 series of 50 trials), with a pause of 60 s between each block. After a fixation spot (500 *ms*), participants viewed 5 columns of 10 words each. The task consisted of asking participants to memorize as many of the set of words as possible. Once the presentation of the stimuli had finished, a series of 50 two-alternative forced-choice judgments (2AFC task) were presented. Two words appeared on each side of the fixation cross, one of the words being taken from the previously presented list and the other being new. The position of the correct word on the screen was counterbalanced across trials. Participants were asked to indicate which of the two words had been previously memorized: the word on the left ("Q") *vs*. the word on the right ("W"). Once the decision had been made, participants were asked to estimate the confidence in their decision.

2.6. Meditation training

The MBSR program of 8 weekly sessions was modified in order to achieve an intervention centered on internal cues (MM training protocol) *vs*. a control intervention centered on external-body cues (SoB training protocol). In both interventions participants assumed a meditation posture and performed specific exercises, such as body scan in the SoB training and focused attention on thoughts in the MM training. Overall, participants were trained to (i) pay attention to internal (resp. external cues); (ii) identify the attentional connection and disconnection to an internal (resp. external) stimulus; (iii) recognize what is stimulating the distraction; and finally (iv) refocus attention on the internal (resp. external) stimulus. The complete list of specific exercises used in each session is in the Supplementary Material (*SM-II*, Table SII).

2.7. Statistical analysis

Three participants were removed from all the analyses due to a technical problem (one in the SoB group and two in the MM group). First, we analyzed whether the distinction between SoB and MM meditative training protocols generated any difference in the responses to the questionnaires (PSS, DASS-21, MAAS & FFMQ), traditionally used to assess the effectiveness of the MBSR program. Importantly, meditation groups did not present any difference on these variables (PSS, DASS-21, MAAS & FFMQ) before the meditative training (Session 1), suggesting an acceptable baseline for our study (SoB *vs*. MM in Session 1: multiple independent *t*-tests for all dependent variables in the study (questionnaires, first and second-order measures: all $ps > 0.10$). Then, we analyzed the first-order results (Response Times (RTs), Accuracy and Type I Sensitivity: *d′*) in the two cognitive tasks (Perceptual & Memory task), before and after the meditative training protocols (for exhaustive descriptive statistics see Supplementary Material, *SM-I*, Tables S2 and S3). According to previous studies (Fleming et al., 2010, 2014), we adopted the following RTs exclusion criteria: in the perceptual task, trials faster than 100 *ms* and slower than 2000 *ms* were excluded [exclusion of 5.2% of trials]; in the memory task, trials faster than 100 *ms* and slower than 10,000 *ms* were excluded [exclusion = 2% of trials]).

Here we investigated whether the distinction between SoB and MM training induces any difference in metacognition efficiency (second-order results). To test our hypothesis, it is necessary to be sure that the metacognitive variability does not come from differences in the first-order performance across sessions. Maniscalco and Lau (2012) proposed an unbiased SDT approach (signal detection theory, Cf., Green & Swets, 1966) to quantify metacognitive accuracy (meta-*d′*). It is then possible to capture the signal that is available for the second-order, metacognitive (type-2) task, and compare it against the type-1 (*d′*) task (i.e., meta-*d′*/*d′*: metacognitive efficiency index). Thus, meta-*d′* refers to the sensory evidence available for metacognition in signal-to-noise ratio units, just as type-1 *d′* is the sensory evidence available for decision-making in signal-to-noise ratio units. Therefore, meta-*d′*/*d′* can be conceptualized as the individual metacognitive efficiency given a certain level of individual task performance (Fleming & Lau, 2014). Meta-*d′*/*d′* was obtained following Maniscalco and Lau's methods (Maniscalco & Lau, 2012), using maximum likelihood estimation. We used Matt Craddock's R port of Maniscalco and Lau's Matlab functions (https://github.com/craddm/ metaSDT), and thank him for making these available to the community. We tested the statistical effects with independent LMMs (Linear Mixed Models) with a restricted maximum likelihood (REML) estimation method, considering fixed (Session [1 *vs*. 2]; Meditative Group [SoB *vs*. MM], Tasks [Perceptual *vs*. Memory], and all possible interactions) and random effects (random participants' intercept and a random slope for Meditative Group factor). Statistical analyses were performed with SPSS-21 and *R* with the *lme4* package. As Covariance Structure in Mixed Model analysis, we always used VC (Variance Components). Results reported did not significantly differ by modifying covariance structures. In addition, SPSS (MIXED procedure) by default implemented the *Satterthwaite* approximation to calculate degrees of freedom.

3. Results

3.1. Questionnaires

Overall, psychological states as measured through the four questionnaires was improved after meditation training protocols. Results showed a significant main effect of Session on the four questionnaires, Table 1 summarizes these results. In addition, through independent ANOVAs we found a significant interaction between Session and Meditation Group on DASS-S ($F(1, 24) = 5.70$, $p < .05$, $\eta_p^2 = 0.12$) and on FFMQ scores ($F(1, 24) = 4.22$, $p = .051$, $\eta_p^2 = 0.05$). No other interactions were found. Regarding the first interaction (DASS-S), both the SoB group ($F(1, 12) = 15.0$, $p < .001$, $\eta_p^2 = 0.23$; $\text{DASS-S}_{\text{Session-1}} = 7.7$ *vs*. $\text{DASS-S}_{\text{Session-2}} = 4.5$) and the MM group ($F(1, 24) = 16.9$, $p < .001$, $\eta_p^2 = 0.46$; $\text{DASS-S}_{\text{Session-1}} = 12.1$ *vs*. $\text{DASS-S}_{\text{Session-2}} = 2.8$) presented a significant decrease in stress scores. Regarding the second interaction, while the SoB group did not significantly differ from session 1 to session 2 on the FFMQ ($p > .73$), the MM group presented a significance increase ($F(1, 12) = 26.5$, $p < .001$, $\eta_p^2 = 0.26$; $\text{FFMQ}_{\text{Session-1}} = 124$ *vs*. $\text{FFMQ}_{\text{Session-2}} = 147$), suggesting that the group that received training protocol based on mental monitoring (MM) strategies, not only had a greater reduction in the perception of stress (DASS-S), but also a greater increase in the perception of their meditative abilities (FFMQ).

Table 1
Questionnaires applied before and after the meditative training.

Measurement	*Pre Session M (SD)*	*Post Session M (SD)*	*F* (1,24)	η_p^2
PSS	26.2 (7.3)	17.3 (8.6)	35.8 ***	0.26
DASS-21	20.8 (13.1)	8.1 (7.3)	19.0 ***	0.28
DASS (*D*)	4.8 (3.3)	2.5 (4.1)	4.6 *	0.08
DASS (*A*)	6.1 (5.8)	2.0 (1.9)	16.2 ***	0.20
DASS (*S*)	9.8 (6.1)	3.6 (2.8)	24.6 ***	0.31
MAAS	54.5 (12.3)	67.5 (11.0)	54.5 ***	0.23
FFMQ	120.4 (15.8)	132.8 (24.8)	6.6 *	0.10
FFMQ (*non-reactivity*)	20.4 (3.1)	24.9 (4.5)	31.6 ***	0.27
FFMQ (*non-judging*)	22.3 (5.9)	29.3 (8.1)	26.3 ***	0.17
FFMQ (*AWA*)	23.6 (8.1)	28.1 (6.7)	14.4 **	0.09
FFMQ (*describing*)	27.5 (4.3)	31.5 (5.0)	11.6 **	0.16
FFMQ (*observing*)	26.5 (5.1)	31.8 (3.9)	28.9 ***	0.23

Note. Table presents Session main effects on the questionnaires (multiples ANOVAs) applied before and after the meditative training. Session effects on the questionnaires, independently calculated by each meditation training group are presented in the Supplementary Material (*SM-I*, Table S4).
* = p < .05.
** = p < .01.
*** = *p* < .001.

3.2. First-order results

First, results on (Log) RTs indicates a significant reduction in RTs from session 1 to session 2 ($F(1, 66.0) = 14.5$, $p < .001$, $d_{(cohen)} = 0.25$; $RT_{Session\text{-}1} = 1443\,ms$ *vs.* $RT_{Session\text{-}2} = 1236\,ms$) and a main effect of Task ($F(1, 66.0) = 451.9$, $p < .001$, $d = 0.72$; $RT_{Perceptual} = 762\,ms$ *vs.* $RT_{Memory} = 1916\,ms$), without any significant interaction. Second, a similar analysis on Accuracy (ACC) revealed only a significant main effect of Task ($F(1, 66.0) = 12.47$, $p < .01$, $d = 0.31$; $ACC_{Perceptual} = 0.73$ *vs.* $ACC_{Memory} = 0.79$) and an interaction between Session and Task ($F(1, 66.0) = 7.41$, $p < .01$, $d = 0.06$). Importantly, we did not evidence any significant differences in Sessions or Meditation Groups ($p > .06$), nor an interaction between these factors ($p > .99$). The effect reported on the Accuracy and Response Times correspond to an increase in performance in the memory task, where we did not perform any experimental control over performance (Fig. 2A). Finally, a similar analysis on type-1 sensitivity (d'), did not show significant differences regarding the Meditative Group ($p > .63$), nor interaction between Session and Meditative Group ($p > .78$). However, this LMM evidenced a Session main effect ($F(1, 66.0) = 5.50$, $p < .05$, $d = 0.05$; $d''_{Session\text{-}1} = 1.45$ *vs.* $d'_{Session\text{-}2} = 1.59$), Task ($F(1, 66.0) = 4.80$, $p < .05$, $d = 0.18$; $d'_{Perceptual} = 1.36$ *vs.* $d'_{Memory} = 1.68$), and an interaction between Session and Task ($F(1, 66.0) = 4.01$, $p < .05$, $d = 0.04$).

3.3. Second-order task

We predicted that metacognitive efficiency should increase when individuals are trained to monitor their own mental states (MM training protocol). In addition, we also predicted a reduction in metacognitive efficiency in the SoB training protocol, or at least this should be less than that observed in the MM training protocol, given the specific attentional modulations in these meditative interventions. First, for each participant and session, we calculated the metacognitive efficiency (the meta-d'/d') for both the perceptual and memory task independently. We then ran a LMM analysis on metacognitive efficiency, with fixed factors of Tasks (Perceptual *vs.* Memory), Session (1 *vs.* 2), Meditative Group (SoB *vs.* MM), and all possible interactions. We also considered a

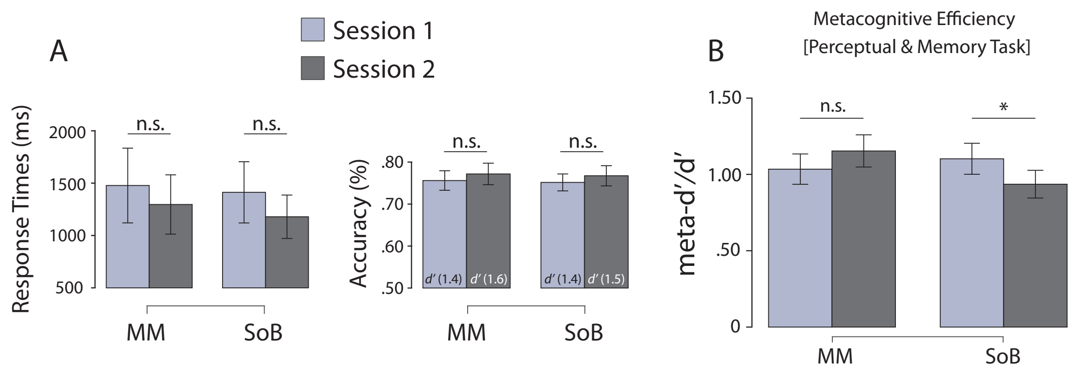

Fig. 2. (A) First order (RTs & ACC [and d']) and (B) Second order results (metacognitive efficiency: meta-d'/d'), as a function of Session and Meditative Group. Error bars represent Cousineau-Morey within-subjects 95% confidence intervals (Cousineau, 2005; Morey, 2008). * = p < .05, n.s. = non-significant.

participant's intercept and a slope of Meditative Group as random effects. Results on the LMM evidenced only a significant interaction between Meditative Group and Session ($F(1, 66.0) = 6.53$, $p < .05$, $d = 0.05$). A deeper LMM analysis on this interaction indicated that while in the MM training group metacognitive efficiency did not significantly differ from session 1 to session 2 ($p > .14$; meta-$d'/d'_{\text{Session-1}} = 1.03$ *vs*. meta-$d'/d'_{\text{Session-2}} = 1.15$), in the SoB training group metacognitive efficiency decreased significantly ($F(1, 35) = 4.85$, $p < .05$, $d = 0.72$; meta-$d'/d'_{\text{Session-1}} = 1.10$ *vs*. meta-$d'/d'_{\text{Session-2}} = 0.93$, Fig. 2B). The same result was evidenced when considering only a random participant intercept ($F(1, 66.0) = 6.52$, $p < .05$, $d = 0.71$). Importantly, the interaction effect did not disappear by controlling first-order variables (RTs, Accuracy and d'), suggesting a reliable decrease in metacognition in the SoB training. The same analysis independently run on the Perceptual and Memory task, while it follows the same trend, presented only marginal effects (Perceptual task: all $ps > 0.071$; Memory task: : all $ps > 0.052$) (see supplementary material, *SM-I*, Table S2).

4. Discussion

In this study our aim was to investigate whether metacognitive efficiency is a fixed capacity or whether it is malleable and subject to practice-based modulations, even coming from outside the laboratory. We predicted that by training individuals to direct their attention to internal cues (mental monitoring, or MM group), they would become more effective at tracking their correct answers from incorrect ones, as assessed by judgments of confidence (an increase in metacognitive efficiency); we expected the opposite for the self-observation of the body (SoB) group, trained on external cues. We captured metacognitive ability through a confidence judgment response, associated to a perceptual and a memory task. We also collected self-reports of the mindfulness ability (MAAS and FFMQ) and clinical states of the participants (DASS-21 and PSS). Results on the questionnaires confirm that our interventions achieve the standard decrease in self-reported depressive, anxiety related and stress symptomatology (DASS-21 & PSS, Table 1), and an increase in self-perceived mindfulness (MAAS & FFMQ, Table 1) expected from Mindfulness Based Stress Reduction training program. As for metacognition, our predictions were only partially confirmed: metacognitive efficiency remained stable in MM group, while it decreased significantly in SoB (Fig. 2B). Importantly, none of the psychological variables derived from questionnaire, or first order performance (RTs, Accuracy, d') explain this modulation of metacognitive efficiency (Fig. 2A).

Our results show that meditation training protocols with selective attentional orienting had a specific impact on metacognition: the SoB training resulted in a negative modulation of the metacognitive efficiency, without significant modulation for the MM training. Critically, from our experimental design we cannot be sure of what mental contents participants trained to orient their attention to in the SoB training protocol. One possibility is that they have increased attention to action execution, and therefore unattended to the course of their mental contents. The fact that attention to action execution would entail poorer metacognitive efficiency, would run counter to predictions from motor theories of metacognition (Faivre, Filevich, Solovey, Kühn, & Blanke, 2017; Fleming et al., 2015), but in any case we can speculate that participants in the SoB training protocol developed their ability to focus their attention *away* from their own thoughts. It is likely that while participants in this group lost some ability to evaluate the correctness of their decisions, they should have improved in perceiving their own body (i.e., interoceptive sensitivity). Thus, we predict that they would improve in a task where they would have to evaluate, e.g., the speed of their own responding (Bryce & Bratzke, 2014). In this line, Fox et al. (2012) showed that introspective accuracy (i.e., metacognition), as measured by subjective assessments of tactile experiences during a body scanning meditation, is more accurate in more experienced practitioners. According to Fox et al. (2012), untrained persons have very poor introspective accuracy, but this skill might be improved by training (i.e., better clarity or high intensity of tactile experiences during a body-scan meditation, Cf., SoB training).

It is important to note that we do not fully replicate the results of the previous study on metacognitive training through meditation (Baird et al., 2014). We did not show a significantly increase in metacognitive efficiency from our meditative training protocols. Some differences could explain this discrepancy: our design was based on the well-known structure of the MBSR program (8 sessions, one per week), whereas Baird et al. (2014) implemented a protocol in a more intensive design (8 sessions, four times per week). Second, the type of training implemented presents some differences with Baird et al. (2014), who used a specific program focused on attentional control (focused attention meditation). We should note in addition, that Baird et al. (2014), do not report any improvement in metacognitive efficiency within the perceptual task, for which they do not report metacognitive efficiency with the meta-d'/d' metric. In contrast with Carpenter et al. (2019), who demonstrate domain general improvement of metacognitive efficiency, we should note that our training protocols were much more distant to the task used to assay metacognition. Indeed, while Carpenter et al. (2019) show transfer from one metacognitive task to another, still both training and test tasks share the general structure that each trial comprises a first and a second order response. Therefore, participants learn to express a judgment on the correctness of their first order response, and this ability generalizes to a new task. In our study, during training, participants did not perform any laboratory task and did not evaluate their own performance. Thus any effect could only come from the modification of the balance of attention toward the internal or the external, irrespective of task context. In spite of the above highlighted discrepancies with (Baird et al., 2014) and (Carpenter et al., 2019), at the most abstract level, our results concur in demonstrating that metacognition is a malleable ability, and not a fixed trait. So far, however, our results suggest that metacognition is more easily degraded than improved.

In future experiments, it should be important to consider that different meditation techniques can have differential effects (e.g., on attentional control). Along this line, we note that Colzato, Sellaro, Samara, Baas, and Hommel (2015), showed that while *open monitoring* meditation improved performance in an attentional blink paradigm (presumably because of laxer top-down attentional control), performance was worse with *focused attention* meditation (presumably because of an opposite tighter top-down control). Thus, the notion that some cognitive performance could deteriorate after meditation training is not novel. Yet, importantly, we fully acknowledge that our division of the organic whole of the MBSR is certainly not optimal in view of maximizing the impact of training.

Indeed, while *focused attention* training protocol (as employed and studied by Baird et al., 2014) meditation and the MBSR have their own internal coherence, with proven real-life and clinical benefits, we created artificial, laboratory and, to some extent arbitrary training protocols, with a view to testing the flexibility of metacognition. In doing so, we certainly lost the synergy between the various components of the MBSR. In addition, we acknowledge the possibility that the artificial training protocols that we created were imbalanced in favor of perception, and thus that the impact they had on attentional orienting were stronger in the perceptual domain. We predict that with a more controlled setting (e.g., specify even more the type of tasks to be used in both the MM and SoB sessions, as well as increase the frequency of the training), it would even be possible to target more specific dimensions of metacognition.

Regarding clinical states, both types of training protocols were effective at reducing perceived stress (DASS-21), although there was a stronger effect in the MM than in the SoB group. Certainly, more and better evidence is needed to evaluate the role of physiological and perceived stress in the modulation of metacognition (Reyes, Silva, Jaramillo, Rehbein, & Sackur, 2015), yet we speculate that individuals who received the MM training protocol could be more apt to implement top-down regulation based on mental cues (Garland, Gaylord, & Fredrickson, 2011). In contrast, individuals trained to monitor their own bodily cues could be more apt to control the physiological and behavioral activity associated with a stressor, i.e., bottom-up regulation (Grecucci, Pappaianni, Siugzdaite, Theuninck, & Job, 2015; Herwig et al., 2010). In both cases, it remains to be studied whether metacognitive efficiency could be related to different emotional regulation strategies via metacognition or via interoception (e.g., Tang & Posner, 2009). Overall, the MM and SoB distinction seems not only interesting for investigating the psychological mechanism underlying metacognitive training protocols, but also for studying psychological disorders associated with certain metacognitive modulation (Rouault, Seow, Gillan, & Fleming, 2018). In conclusion, our results point to a negative impact of training one's external attention on metacognition. External attention training could impair metacognition given that this training was focused to improve attentional resources to the body, and away from one's own mental processes. Thus, in our external attention training individuals could be mobilizing attentional resources to keep the cognitive system alert to possible external perceptual changes (Garfinkel, Seth, Barrett, Suzuki, & Critchley, 2015; Matthias, Schandry, Duschek, & Pollatos, 2009) at the cost of monitoring their own mental processes.

Data availability

Dataset is available at the Open Science Framework at. https://osf.io/trwq3/?view_only=b9b6fff524a2471ca3b0a941d9c87bb3.

CS, GR and JS designed the experiment; CS, MB and AL performed the experiment; GR and JS analyzed the data; CS, GR and JS wrote the manuscript.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.concog.2019.03.001.

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