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ORIGINAL PAPER

Mindfulness Meditation Weakens Attachment to Self: Evidence from a Self vs Other Binding Task

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Abstract

Objectives Mindfulness meditation is based on Buddhist teachings and meditation practices that promote a reduced identification with thoughts and mental states. Mindfulness meditation is also suggested to promote *self-other* integration, either by decreasing preference for *self*-related processing or by rebalancing *self* and *other*-related processing. However, it is not clear how meditation practice influences attachment to self and more specifically sense of agency. Hence, we investigated how mindfulness meditation (Vipassana or insight meditation) practice influences an implicit measure of sense of agency known as intentional binding effect with *self*- vs *other*-associated stimuli by comparing long-term meditators with non-meditators.

Methods This study had two phases. The first phase consisted of a perceptual matching task using *self*-related and *other*-related shape-label pairings so that participants can learn the shape-label associations. In the second phase, participants performed an intentional binding task with the same *self*-associated and *other*-associated stimuli displayed as target outcome of self-generated action.

Results While meditators did show faster responses to self vs other shape-label processing similar to non-meditators, they did not show stronger binding (reduced temporal estimation between action and outcome shape) for self-associated compared with other-associated outcome.

Conclusions The results indicate that even though meditators preferentially process self-related information, they are less attached to self-associated stimuli as indicated by an implicit measure of sense of agency. These results have implications for theories of action and agency based on contemplative traditions that emphasize less attachment to outcomes of our actions.

Keywords Mindfulness meditation · Self-other referential processing · Temporal binding · Intentional binding · Attachment · Agency

The nature of how "self" and "others" are represented has been largely debated in philosophy, psychology, and cognitive neuroscience. Several studies in social psychology and cognitive neuroscience suggest that *self* and *other* representations are interrelated in both the bodily affective domain and cognitive-conceptual domain. These studies seem to identify a shared network of brain areas considered important for social abilities such as empathy and compassion (Decety and Sommerville 2003; Gallese 2003; Hein and Singer 2008; Meltzoff 2007) and social mechanisms relevant to reducing social bias and acting pro-socially (Aron et al. 2004; Cross et al. 2002; Galinsky et al. 2005; Goldstein and Cialdini 2007). Furthermore, studies on interpersonal multisensory integration, such as the enfacement illusion, demonstrated the flexibility of self-other boundaries, showing that induced changes in body-ownership representation enhance the perceived physical similarity between self and other (e.g., Sforza et al. 2010; Tajadura-Jiménez et al. 2012).

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Recent studies suggest that mind-body meditation techniques such as mindfulness meditation (MM) practices can modulate inter-subjective social behaviors and *self-other* representations, primarily promoting positive interpersonal behaviors (Luberto et al. 2018; Mascaro et al. 2015). For example, MM seems to shape inter-subjective experience by intensifying empathy, compassion, and altruism (e.g., Birnie et al. 2010; Hutcherson et al. 2008; Klimecki et al. 2013; Kristeller and Johnson 2005) while reducing self-referential activity (Berkovich-Ohana et al. 2012; Dor-Ziderman et al. 2016; Farb et al. 2007; see also Desbordes 2019) and promoting *self-other* connectedness (Garrison et al. 2014; Lindahl and Britton 2019; Logie and Frewen 2015; Shi and He 2020; Trautwein et al. 2014, 2016).

MM practice is commonly described as paying attention in an open, non-conceptual, and non-judgmental way, focusing on bodily sensations and mental events with the prospectus of cultivating equanimity and awareness (Bishop et al. 2004; Kabat-Zinn 1990). This practice of observation is supposed to lead to an equanimous and neutral attitude towards the contents of one's own experience and eventually promote a process of subjective detachment from identification with oneself and one's thinking called "decentering" (Fresco et al. 2007; Hölzel et al. 2011). The process of decentering is considered fundamentally involved in subjective changes resulting in improved cognitive functioning and well-being (e.g., Goldin and Gross 2010; Raffone and Srinivasan 2017).

MM especially "Vipassana" or insight meditation from the Buddhist Theravada tradition is often practiced together with *Metta* or "Loving-Kindness meditation" (LKM). LKM explicitly involves cultivating and generating extended feelings of love and kindness towards the *self*, and close- and unfamiliar-*others* (Buddharakkhita 1995; Zeng et al. 2015). A single short session of LKM can increase the social connection between oneself and others, affecting both *self* and *other* referential processing (Hutcherson et al. 2008). Self-bias in neural responses to the *self* vs an *other*'s face was found reduced in long-term LKM meditators compared with controls (i.e., larger P300 amplitudes for self-image vs other-image; Trautwein et al. 2016). Colzato et al. (2012) compared a group of Buddhist monks who practice MM together with LKM to non-meditators in a social version of the Simon task. They found that the monks displayed higher *self-other* integration compared with the non-meditator group. Thus, both the self-*deconstructive* facet of meditation practices, such as in Vipassana meditation emphasizing mindfulness and introspective analysis (self-inquiry), and *constructive* meditation practices with emphasis on interconnection, such as LKM, can affect the self, and the relationship of the self to others (Dahl et al. 2015).

Although above studies showed that MM can impact *self*- and *other*-related representations and promote *self-other* "integration" or "connectedness," the mechanism underlying this modulation is not yet clear. In addition, how attachment to self in terms of agency is influenced by meditation practice is not yet fully understood. A candidate task for investigating the effect of MM (specifically Vipassana meditation) on *self*-associated and *other*-associated stimuli processing could be the intentional binding task (Moore and Obhi 2012).

The intentional binding (IB) is an illusory temporal effect, which refers to perception of the time interval between the *action* and the consequent *outcome* as being shorter than it really is (Haggard et al. 2002). Given its specificity to self-generated action, many researchers consider IB as an implicit measure of sense of agency (for a review, see Moore and Obhi 2012). Recent studies investigated the effect of MM on intentional binding (IB) (Lush et al. 2016; Jo et al. 2014). These studies, mainly driven by the idea that meditators displayed increased awareness of one's inner processes to move, have focused predominantly on the meta-awareness of intentional act. Although Jo et al. (2014) using a classic Libet's Clock paradigm to measure IB did not find a difference between meditators and non-meditators in behavioral data or brain activity, Lush et al. (2016) using the similar paradigm reported stronger intentional binding effect, and thus increase in sense of agency, in meditators compared with non-meditators. This effect was attributed by the authors to greater meta-cognitive access to one's own intentions (see also Jo et al. 2015), resulting from continued practice of sustained attention to intentions and actions in mindfulness practitioners. Even though *self* is an important component of IB, the majority of studies investigated IB primarily in terms of *self's* relation to action (e.g., Haggard and Clark 2003; Haggard et al. 2002; Wolpe et al. 2013) but have rarely investigated self's relation to outcome. We propose that attachment to self can be studied using an implicit measure of sense of agency like intentional binding.

Recently, Makwana and Srinivasan (2019) investigated the role of self-referential processing in IB by using *self*- and *other*-associated stimuli as target outcome of the self-generated action. The authors used a two-phase paradigm; the first phase consisting of a shape-label matching task (as in Sui and Humphreys 2017a). The labels referred to either *self* (i.e., you), close-*other* (i.e., friend), or distant-*others* (i.e., stranger), and were associated with three neutral geometrical shapes. Typically, faster and more accurate responses are observed with self-associated stimuli compared with other-associated stimuli (Sui et al. 2012). In the subsequent task, participants estimated the perceived interval between a self-generated action and the ensuing perceptual outcome (see Moore et al. 2009). Typically, shorter perceived interval indicates stronger intentional binding and greater sense of agency (Haggard et al. 2002; Moore and Obhi 2012). Results showed that participants estimated the delay between action and outcome to be shorter (i.e., stronger IB) for the *self*-associated stimuli (you-associated shape) relative to *other*-associated stimuli (friend- and stranger-associated shape) (see Makwana and Srinivasan 2019). These results were interpreted as the self-association postdictively influencing IB and agency mostly due to the influence of the Self-Attention Network (SAN: Humphreys and Sui 2016). Based on SAN framework, they suggested that self-associated stimuli being salient plausibly recruit more attention, thereby accelerating the processing of self-associated stimuli relative to other-associated stimuli, which in turn leads to increased IB and thus stronger sense of agency (Makwana and Srinivasan 2019).

We used the same paradigm (Makwana and Srinivasan 2019) to compare MM meditators and non-meditators. We hypothesized that with the shape-label matching task, we should replicate the basic self-prioritization effect (Sui et al. 2012) in both the groups. We did not expect any difference between groups as a result of MM training for two reasons. First, because MM is supposed to impact self-referential processing involving mainly changing in a conceptual-cognitive domain (see Northoff et al. 2006; Tagini and Raffone 2010), and thus not at the level of early perceptual processing (see Sui et al. 2012). Indeed, a great deal of studies on the well-known self-bias effect showed that self-relevant information is preferentially processed (for a review, see Sui and Humphreys 2017b). Second, recent studies showed that self-bias remains unaffected also in long-standing meditators (e.g., Trautwein et al. 2016) with report of no difference in behavioral performance such as accuracy and time, contrasting self with other-related visual stimuli (although differences in EEG recording have been presented, i.e., greater P300 amplitudes for *self*-image vs *other*-image) (Trautwein et al. 2014, 2016). Moreover, contemplative traditions emphasize not being attached to one's self and if this is the case, then there should be lesser attachment to self-associated stimuli compared with non-meditators. Thus, we decided to study the effect of *self*-associated stimuli in comparison with *other*-associated stimuli presented as outcome of self-generated action using an IB task. We hypothesized that if meditators have weaker self-other differences and less attachment to self then they would show lesser IB for the *self*-associated compared with *other*-associated stimuli compared with non-meditators.

Methods

Participants

Sixty-three participants (32 meditators and 31 non-meditators) participated in the study. Data from seven meditators and seven non-meditators were excluded based on accuracy in the shape-label task (minimum of 55% accuracy). The meditators (N = 25; mean age = 44.64 years; range 30–70 years; SD = 13.58; 10 females) were included based on years of practice (at least 2 years of experience; mean experience = 7 years). Non-meditators (N = 24; mean age = 41.12 years; range 27–65 years; SD = 11.23; 7 females) were similar in terms of age and gender (mean age unpaired t test: $t(48) = .98$, $p = .33$, mean difference: 3.51, 95% CI [− 3.66, 10.69], Cohen's $d = .28$).

All participants in meditators group were Vipassana (insight) meditators which practiced this technique together with *Metta* (i.e., Loving-Kindness Meditation). The number of participants was decided based on Sui et al. (2012) effect size (η^2) = .41 and Moore et al. (2009) effect size (d) = .8 for power .8, and alpha = .05, using G*Power 3 software (Faul et al. 2007). All participants had normal or corrected-to-normal vision. Informed written consent was obtained from all participants prior to the experimental session. Ethical approval was obtained from the Institutional Ethics Committee.

Procedures

In the shape-label matching task, three geometrical shapes (triangle, square, and circle: each 4.0° × 4.0°) were paired with the three verbal labels (YOU, FRIEND, and STRANGER: 3.5°/4.0° × 0.8°). Each geometrical shape was individually presented above a fixation cross at the center of the screen (0.8° × 0.8°) paired with one verbal label which was displayed below the fixation cross (see Fig. 1). The distance between the fixation cross and the center of each shape and label was 3.5°. In the intentional binding task, the same three geometrical shapes (triangle, square, and circle: each 4.0° × 4.0°) were used. All stimuli were shown in white (255, 255, 255) on a gray background (128, 128, 128). The two tasks ran on a computer connected to a 17-inch monitor (1024 × 768 at 60 Hz) using PsychoPy2 software (Version 1.85.4) (Peirce 2007).

Our procedure was based on that of Makwana and Srinivasan (2019). Participants performed the two tasks consecutively in a single session of about 1 h and a half. The first task was the shape-label matching task (Sui et al. 2012), in which participants established an association between neutral geometrical shapes (triangle, square, circle) and *self*- and *other*-associated identities (e.g., yourself, friend, stranger). The second task was the time estimation task to measure IB (Moore et al. 2009).

Shape-Label Matching Task

This task was adapted from Sui et al. (2012). Since a pilot study with older participants found the task difficult, we utilized a modification made by Sui and Humphreys (2017a) for older participants in which shape-label pairings were presented for 500 ms instead of 100 ms.

The shape-label matching task (Fig. 1) started with an association phase. Participants were told to associate

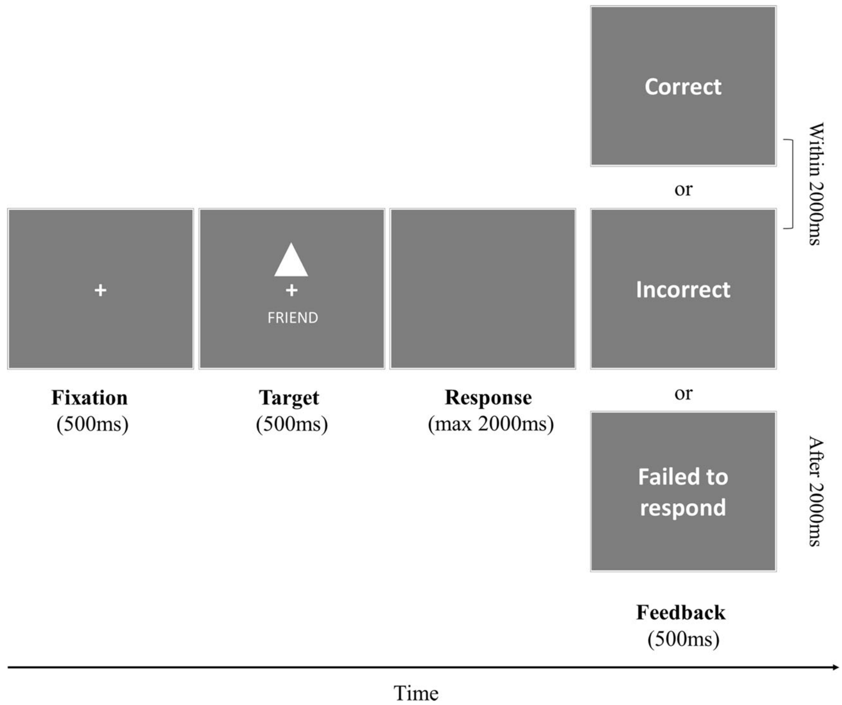

Fig. 1 Trial structure used for the perceptual matching task

themselves, a friend (e.g., best friend), and a stranger (e.g., unfamiliar person) with three geometrical shapes (i.e., triangle, square, and circle). The associations between shapes and labels were counterbalanced across participants. The three identities were indicated by the verbal labels *YOU*, *FRIEND*, and *STRANGER*. Participants were told: "Imagine that YOU are a circle, your FRIEND is a square and a STRANGER is a triangle. Take time to remember this association." When participants memorized the associations, they started with the experimental task. Each trial started with a fixation cross at the center of the screen lasted for 500 ms. Then, the shape-label pairing was presented for 500 ms. After that, participants were asked to judge whether the shape-label pairing was correct or incorrect according to the instructions given in the association phase. Participants were instructed to press as quickly and accurately as possible the left arrow key if the shape-label pair matched with the initial association and the right arrow key if the shape-label pair mismatched. After each response, a feedback appeared on the screen for 500 ms, indicating "Correct" or "Incorrect" according to the participant's response. When the participant did not give a response within 2000 ms from the shape-label pair offset, a feedback message "Failed to respond" appeared on the screen (see Fig. 1 for a schematic representation of the procedure). There were a total of 360 trials (120 trials each for YOU, FRIEND, and STRANGER pairing) in three counterbalanced blocks of 120 trials. Half of the trials had correct (matched) pairing and the other half had incorrect (mismatch) pairing.

Time Estimation Task

This task was adapted from Moore et al. (2009). Before performing the main task, participants started with a training session consisting of 11 trials. Each training trial started with a central fixation cross. Participants pressed the spacebar key to initiate each trial which led to the appearance of a geometrical shape (pentagon), after a variable interval (selected pseudo-randomly among 11 levels having 0 to 1000 ms delays in steps of 100 ms). This target appeared at the center of the screen and lasted 250 ms. Then, participants were asked to report their estimate of the perceived interval between the key press and the onset of the target outcome. Participants were instructed to use the mouse and provide their estimate by approximately selecting the timing on a rating scale displayed on the screen, ranging from 0 to 1000 ms with a resolution of 100 ms. Feedback of actual delay was presented after each response. The purpose of these training trials was to familiarize participants with the task and learn to provide estimates in milliseconds. In addition, this was done to make them to believe that the experiment involves any possible delay between 0 and 1000 ms.

After the training phase, participants performed the experimental task. Here, differently from the training phase, participants' key press led to the appearance of one of the three geometrical shapes used in the shape-label matching task (i.e., triangle, square, or circle) as target outcome. The shape was presented for 250 ms. Then, participants reported their estimate interval between the key press and the onset of the outcome by selecting with the mouse the timing on a rating scale ranging from 0 to 1000 ms with a resolution of 1 ms. Participants could change the response until they were confident about its correctness and then submit it by clicking a button on the screen. After reporting the timing, participants were asked whether the shapes were associated with *YOU*, *FRIEND*, or *STRANGER*. No feedback was provided on the experimental block. Each participant performed 90 trials equally distributed between associations (*YOU*, *FRIEND*, *STRANGER*) and delays (100 ms, 400 ms, 70 ms) (see Fig. 2 for a schematic representation of the procedure). Participants performed 90 trials equally distributed between outcome associations (*YOU*, *FRIEND*, *STRANGER*) and delays (100 ms, 400 ms, 700 ms).

Measures

Data from each participant were sorted in three conditions based on whether the label was paired with shape associated with YOU, FRIEND, or STRANGER. Reaction time and accuracy were measured in the shape-label matching task. Interval estimates were measured in the intentional binding task.

Data Analyses

Mixed ANOVAs were performed on all the dependent variables followed by post hoc *t* tests corrected with the Bonferroni method for multiple comparisons. Greenhouse-Geisser's correction was applied because sphericity assumption was violated. We report η_p^2 for ANOVA and Cohen's *d* for *t* tests as measures of effect size.

Results

Shape-Label Matching Task

Table 1and Fig. 3 shows results from the shape-label matching task. A mixed ANOVA with association (3 levels: *YOU*, *FRIEND*, *STRANGER*) as within-subjects factor and group (2 levels: meditators, non-meditators) as between-subject factor was performed with reaction time (RT) as the dependent variable. The effect of association was significant, $F(1.69, 79.43) = 138.81$, $p < .001$, $\eta_p^2 = .75$. Post hoc comparisons revealed that participants were faster for self-associated pairings (shape-word pair involving *YOU*) compared with other-associated, both when compared with pairings involving *FRIEND*, $t(48) = 12.88$, $p < .001$, mean difference: 133, 95% CI [108, 158], $d = 1.84$, and with pairings involving *STRANGER*, $t(48) = 15.59$, $p < .001$, mean difference: 161, 95% CI [135, 186], $d = 2.23$, and for *FRIEND* compared with *STRANGER*, $t(48) = -2.71$, $p = .024$, mean difference: − 28, 95% CI [− 53, − 3], $d = -.38$. The main effect of group was not significant, $F(1,47) = .63$, $p = .43$, $\eta_p^2 = .013$. The interaction between association and group was not significant, $F(1.69, 79.43) = .12$, $p = .61$, $\eta_p^2 = .010$.

Similar analysis was conducted with mean percentage of accuracy (%). Missed response trials were counted as error trials as in Sui et al. (2012). Results showed a significant main effect of association, $F(2, 94) = 44.25$, $p < .001$, $\eta_p^2 = .48$. Post hoc comparisons revealed that mean accuracy was greater for self-associated pairings (shape-word pairs involving *YOU*) compared with other-associated, both when compared with pairings involving *FRIEND*, $t(48) = -7.09$, $p < .001$, mean difference: − 9.31, 95% CI [− 12.51, − 6.11], $d = -1.01$,

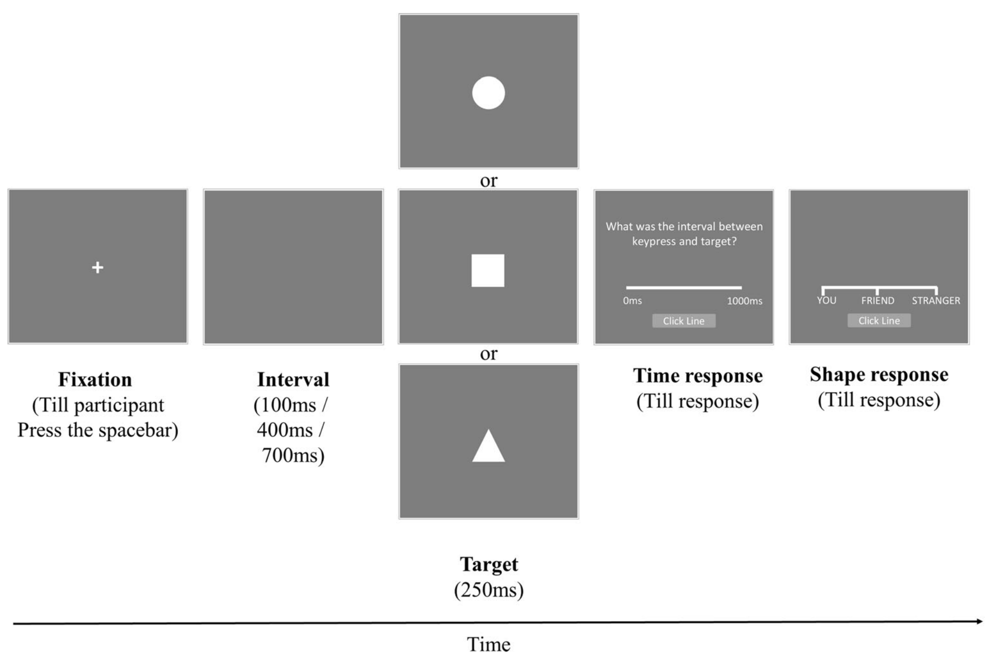

Fig. 2 Trial structure used for intentional binding task

Table 1 Mean reaction time and accuracy for both groups as function of shape association. Standard deviations appear in parentheses. *RT*, reaction time

Shape association	Group	Mean RT (ms)	Accuracy (%)
YOU	Meditators	826 (175)	91.50 (9.2)
	Non-meditators	857 (154)	86.70 (10.2)
	Total	841 (164)	89.10 (9.7)
FRIEND	Meditators	954 (195)	80.96 (15.9)
	Non-meditators	994 (181)	78.61 (12.9)
	Total	974 (188)	79.78 (14.4)
STRANGER	Meditators	977 (206)	79.13 (14.4)
	Non-meditators	1027 (172)	75.69 (14.2)
	Total	1002 (189)	77.41 (14.3)

and *STRANGER*, $t(48) = -8.90$, $p < .001$, mean difference: − 11.68, 95% CI [− 14.88, − 8.48], $d = -1.27$. There was no significant difference between *FRIEND* and *STRANGER*, $t(48) = 1.80$, $p > .05$, mean difference: 2.37, 95% CI [− .82, 5.57], $d = .26$ (see also Sui et al. 2012). There was neither a significant group effect, $F(1,47) = 1.07$, $p = .31$, $\eta_p^2 = .022$, nor a group and association interaction, $F(2, 94) = .43$, $p = .65$, $\eta_p^2 = .009$.

Intentional Binding Task

A mixed ANOVA with association (3 levels: YOU, FRIEND, STRANGER) and delay (3 levels: 100 ms, 400 ms, 700 ms) as within-subjects factors and group (2 levels: meditators, non-meditators) as between-subject factor was performed on mean interval estimates as dependent variable. Only temporal estimates from those trials in which the shape was accurately recognized were used for analysis. Overall accuracy for shape recognition was 97.30%. Table 2 and Fig. 4 shows results from the intentional binding task. Results showed significant main effects of association, $F(1.62, 76.51) = 17.12$, $p < .001$, $\eta_p^2 = .27$ and delay, $F(1.21, 52.69) = 152.35$, $p < .001$, $\eta_p^2 = .76$. Post hoc comparisons for the main effect of association revealed that overall interval estimates were significantly lesser for self-associated stimuli (i.e., shapes associated with *YOU* ($M = 385.57$ ms) compared with *STRANGER* ($M = 446.41$ ms), $t(48) = 5.84$, $p < .001$, mean difference: 61.18, 95% CI [35.67, 86.70], $d = .83$. The difference between *FRIEND* ($M = 413.30$ ms) and *STRANGER* was significant, $t(48) = -3.18$, $p = .006$, mean difference: − 33.30, 95% CI [− 58.82, − 7.78], $d = -.45$, and between *YOU* and *FRIEND*, $t(48) = 2.66$, $p = .027$, mean difference: 27.88, 95% CI [2.36, 54.40], $d = .38$. For delay, estimated time increased as the actual delay increased (100 ms compared with 400 ms: $t(48) = -7.96$, $p < .001$, mean difference: − 203.37, 95% CI [− 265.59, − 141.15], $d = -1.14$; 400 ms compared with 700 ms: $t(48) = -9.47$, $p < .001$, mean difference: − 241.65, 95% CI [− 303.88, − 179.43], $d = -1.35$), suggesting that participants were able to perform the task well. Both meditators and non-meditators underestimated the short interval and overestimated the large interval in our study in accordance with "Vierordt's law" (see Lejeune and Wearden 2009). The effect of group was not significant, $F(1, 47) = .05$, $p = .99$, $\eta_p^2 = .000$. None of the two-way interactions was significant (*ps* > 0.05)

Importantly, the ANOVA revealed a significant *association X delay X group* interaction, $F(3.26, 153.30) = 2.64$, $p = .047$, $\eta_p^2 = .053$. Post hoc comparisons revealed that in meditators, there was no significant difference in time estimates between self-associated stimuli (shapes associated with *YOU*) and other-associated stimuli at all the delays: 100 ms delay (*YOU* compared with *FRIEND*, $t(24) = .78$, $p > .99$, mean difference: 14.32, 95% CI [− 52.25, 80.89], $d = .11$, and *STRANGER*, $t(24) = 2.05$, $p > .99$, mean difference: 37.26, 95% CI [− 29.30, 103.84], $d = .29$), 400 ms delay (*YOU* compared with *FRIEND*, $t(24) = 1.50$, $p > .99$, mean difference: 27.34, 95% CI [− 39.22, 93.91], $d = .21$, and *YOU* compared with *STRANGER*, $t(24) = 2.20$, $p > .99$, mean difference: 40.12, 95% CI [− 26.44, 106.70], $d = .31$), and 700 ms delay (*YOU* compared with *FRIEND*, $t(24) = 1.02$, $p > .99$, mean difference: 18.63, 95% CI [− 47.94, 85.20], $d = .15$, and *YOU* compared with *STRANGER*, $t(24) = 2.98$, $p = .49$, mean difference: 54.30, 95% CI [− 12.26, 120.88], $d = .42$). While the differences were not significant (Bonferroni corrected), there was a trend of lesser estimates for YOU compared with STRANGER especially at 700 ms.

In contrast, the pattern for non-meditators was different. The difference between *YOU* and *FRIEND* was not significant for all three delays (*ps* > .05). The difference between *YOU* and *STRANGER* was significant at delays of 100 ms, $t(23) = 4.20$, $p = .006$, mean difference: 78.08, 95% CI [10.13, 146.02], $d = .60$ and 400 ms, $t(23) = 5.83$, $p < .001$, mean difference: 108.38, 95% CI [40.43, 176.32], $d = .83$, showing shorter estimate intervals (i.e., stronger intentional binding) for *YOU* compared with *STRANGER*. In addition, the difference between FRIEND and STRANGER at delay 400 ms was significant, $t(23) = -3.76$, $p = .034$, mean difference: − 69.82, 95% CI [− 137.77, − 1.88], $d = -.53$. None of the differences was significant at 700 ms delay (all *ps* > .05).

To further understand the relationship between the self-association effect and the self vs other IB effect, we performed a correlation with the difference between STRANGER and YOU RTs and the difference between STRANGER and YOU temporal judgment estimates (averaged across the delays) separately for the two groups. The correlation was significant for non-meditators, $r(29) = 0.436$, $p = .033$ indicating that those who showed a larger bias for self in the shape-label task also showed a larger bias for self in the IB task. The correlation was not significant for meditators, $r(30) = 0.186$,

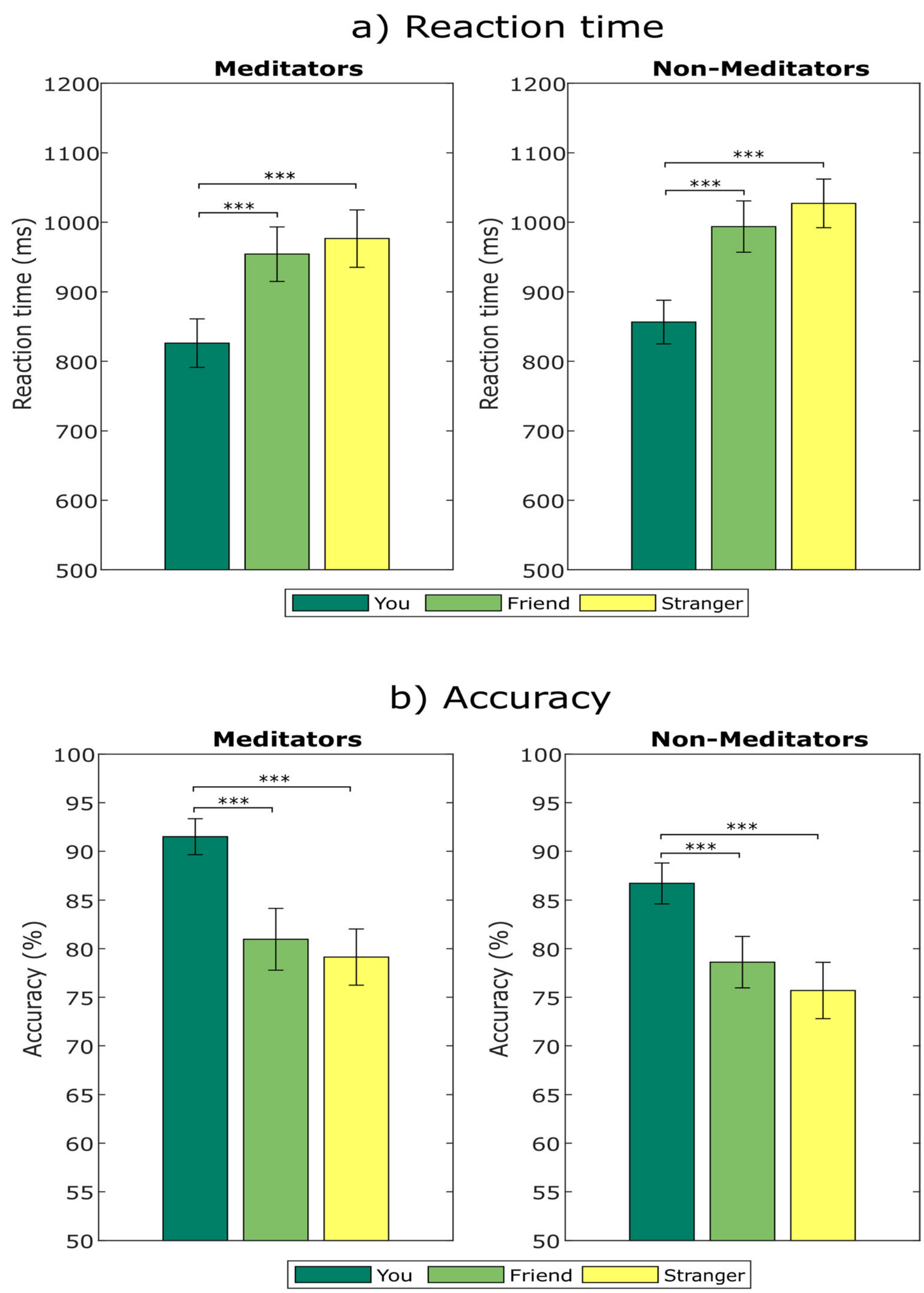

Fig. 3 Bar graph representing the mean reaction time (RT; in milliseconds; panel **a**) and accuracy both for meditators and non-meditators in the shape-label matching task for the *you*, *friend*, and *stranger* conditions. The error bars represent standard error of the mean. ***$p < .001$

p = .372 indicating that the self vs other biases measured by the two tasks may not be related to each other (Fig. 5).

Discussion

This study investigated the effect of mindfulness meditation (MM) on *self* and *other* referential processing in sense of agency as measured through temporal binding. The MM meditators did not show a significant differential IB effect (i.e., estimated time interval between their *action* and the *outcome*) based on self or other associations. However, non-meditators did show a larger intentional binding effect with *self*- compared with *other*-associated stimuli. We argue that MM promotes self-other "integration" or "connectedness" and reduces the difference in estimated interval between "self" and "stranger" seen with non-meditators.

Moreover, we replicated a previous finding that showed a stronger IB effect for self-associated stimuli (see Makwana and Srinivasan 2019) with a sample of middle-aged non-

Table 2 Mean estimated interval (SD in brackets) at each delay for both groups as function of shape association

Shape association	Group	Delay		
		100 ms	400 ms	700 ms
YOU	Meditators	167.13 (111.78)	374.96 (105.03)	639.56 (184.59)
	Non-meditators	175.09 (135.98)	358.23 (93.91)	597.43 (205.38)
	Total	171.11 (123.88)	364 (99.47)	611.68 (194.98)
FRIEND	Meditators	181.45 (123.84)	402.30(123.21)	658.19 (169.58)
	Non-meditators	212.49 (133.62)	396.79 (81.03)	628.48 (169.05)
	Total	196.97 (128.73)	399.54 (102.12)	643.33 (169.31)
STRANGER	Meditators	204.40 (158.73)	415.08 (117.57)	693.86 (148.89)
	Non-meditators	253.17 (192.72)	466.62 (123.37)	646.40 (134.68)
	Total	228.78 (175.72)	440.85 (120.47)	670.13 (141.78)

meditators. Indeed, we found that non-meditators estimated the delay between action and outcome shorter for *self*-associated stimulus compared with *other*-associated stimuli (i.e., stronger IB for *self*-associated stimuli compared with *other*). Our results confirm postdictive mechanisms in intentional binding (see Moore and Haggard 2008; Wegner and Wheatley 1999). Indeed, as discussed by Makwana and Srinivasan (2019), since all outcomes were associated with the same action in IB task, neither predictive or forward models (Blakemore et al. 1999) nor a causal model (Buehner and Humphreys 2009) can explain this modulation in temporal binding with a self- and other-associated stimulus.

We also replicated the self-related processing advantage effect (Sui et al. 2012; Sui and Humphreys 2017a) in the shape-label matching task with both meditators and non-meditators. If the self-bias effect in perceptual processing is due to increased attention (Sui and Humphreys 2017b), then the results indicate that both groups paid more attention to self-associated stimuli resulting in a self-related processing advantage.

Given that MM is expected to affect higher order self-facets (Tagini and Raffone 2010), it is not very surprising that MM practice did not influence the more basic self-associated advantage in perceptual processing. In the IB task, the target stimuli were generated by the participants themselves through an action. Makwana and Srinivasan (2019), in light of the Self-Attention Network Model (Humphreys and Sui 2016), indicated that the stronger IB effect for *self*-associated stimuli is due to the degree of attention-mediated self-prioritization. If increased attention to self-related information is the only factor that drives the self-related perceptual processing advantage and larger binding for self-related information, then meditators who showed the self-related processing advantage should also have shown a larger binding effect with self-related stimuli. Correlational analysis shows that only non-mediators show a significant relationship between the self-bias measured using the two tasks. The different patterns of results with the two tasks in meditators imply that perhaps the lesser binding for self-associated stimuli seen with meditators is due to mechanisms other than those proposed in the self-attention network model (Sui and Humphreys 2017b). Unlike non-meditators, the better perceptual processing for self-related information among meditators due to increased attention did not translate to larger binding for self-related information.

The practice of MM and LKM in meditators involving detachment from the self and compassion towards others probably has led to a weaker sense of agency towards self-related information, while maintaining their perceptual processing advantage. Given that many of the actions are performed due to our intentions and desires to satisfy one's self, the larger binding associated with self would perhaps result in stronger attachment (more binding) the fruits of our actions and the meditation practice evidently weakens this attachment as measured through temporal binding (though see Lush et al. 2016, for strengthening effect of meditation on sense of agency, probably due to better meta-cognitive access to one's internal sates and intentions, and hence stronger IB). This is perhaps achieved through a rebalancing of agency-related processes associated with self vs other and may underlie the stronger empathy shown by meditators (Luberto et al. 2018).

A prior study with IB using Libet's clock task had found larger IB for meditators compared with non-meditators (Lush et al. 2016). In terms of overall group effects, we did not find any overall difference between the two groups. This is consistent with the lack of a significant effect with temporal estimates between meditators and non-meditators using the standard task (Jo et al. 2015). One way to reconcile the different findings between our study and the Lush et al. (2016) is that different kinds of stimuli were used in the two studies. While their study measured IB with neutral stimuli, our study manipulated the nature of the outcome stimuli (self- vs other-related) and showed that the binding effect is different for meditators compared with non-meditators. Perhaps the results would be different for different kinds of stimuli that differ in

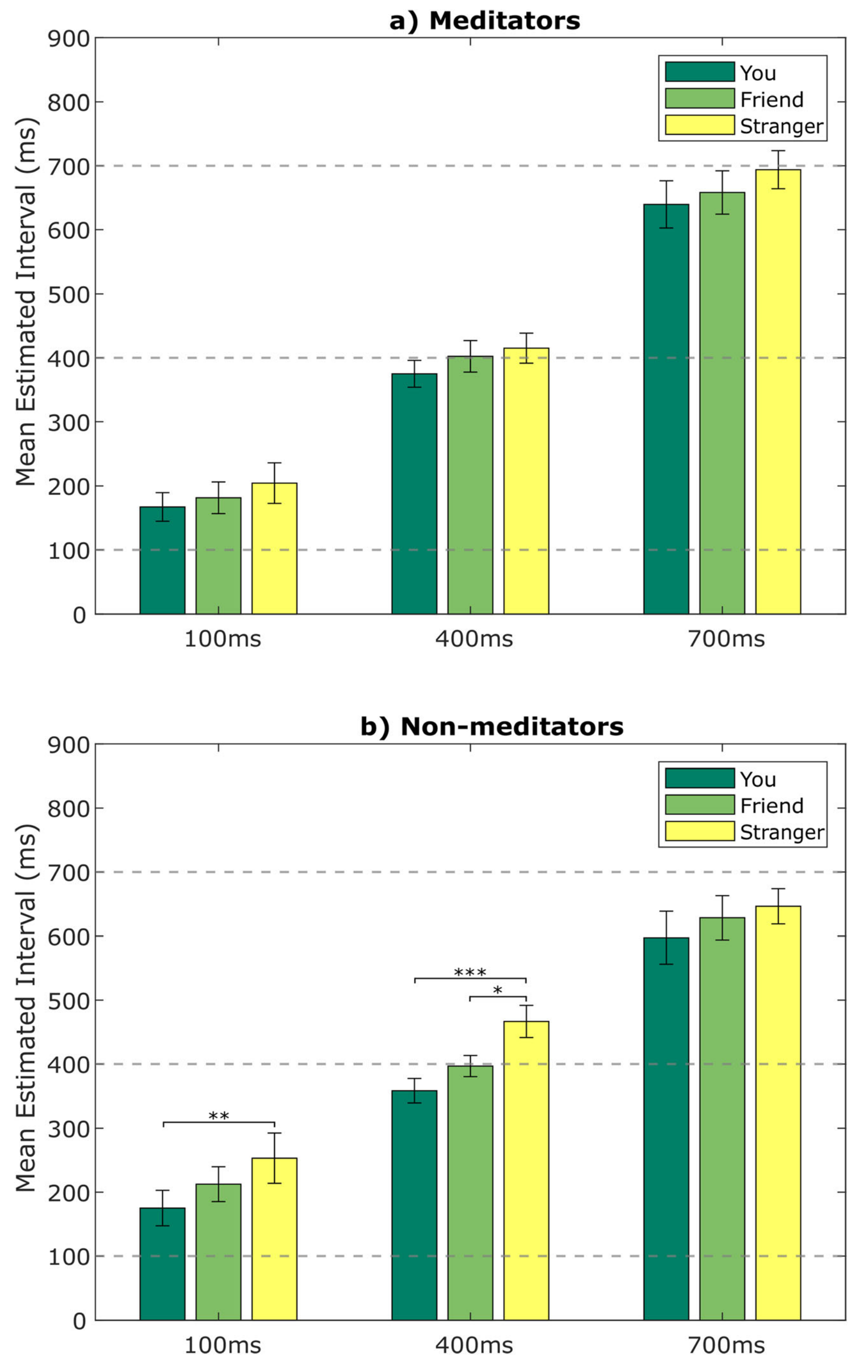

Fig. 4 Bar graph representing the mean interval estimates (in milliseconds) both for meditators and non-meditators (panels **a** and **b**, respectively) against the actual action-outcome delay (100 ms, 400 ms, 700 ms) for the *you*, *friend*, and *stranger* conditions. The error bars represent standard error of the mean. *$p < .05$. **$p < .01$. ***$p < .001$

terms of self-association or motivational saliency using Libet's clock task.

Limitations and Future Research

One limitation of the study is the use of arbitrary abstract stimuli, which are associated with different labels. The lack of prior association with self and other labels enabled us to control for familiarity and experience and show that mediators do not show different temporal estimates for self-associated compared with other-associated stimuli. However, this lacks ecological validity and future studies may use more realistic self- and other-associated stimuli to see whether attachment to self and concepts associated with self is weakened due to mindfulness and meditation practice. In addition, the measurement of attachment in the current study is intentional binding, an implicit measure of sense of agency (Moore and Obhi 2012). The current study demonstrates differences in temporal estimates for different self-associated and other-associated stimuli for non-meditators but is not enough to elucidate the potential mechanisms involved in self-association driven binding. In addition, future studies would need to look explicit measures of sense of agency

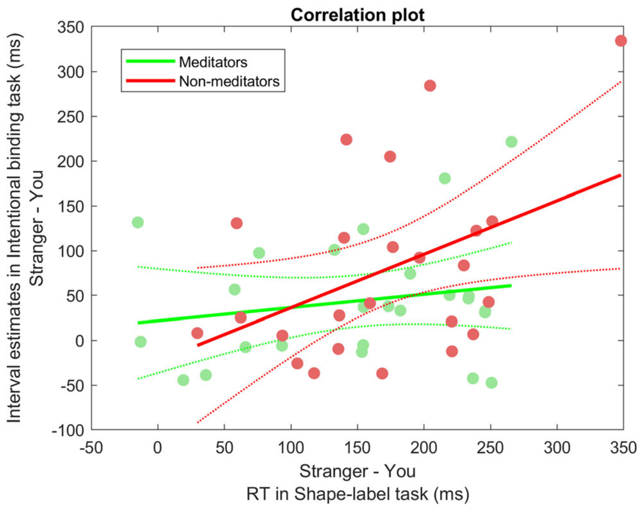

Fig. 5 Scatter plot showing correlation between self-bias effects from the shape-label task and the IB task for meditators and non-meditators

as well as other measures of attachment to build an adequate theory of the effects of meditation on attachment. We would expect that the weakening to attachment to one's self due to meditation practice would be present with other implicit and explicit measures of attachment.

We argue that the stronger IB effect for self-associated stimuli (see Makwana and Srinivasan 2019) in non-meditators could be the result of a stronger activation in ventro-medial prefrontal cortex (vmPFC; the self-related ventral SAN's node) for self-compared with other-associated stimuli (see Mitchell et al. 2006, but also Seger et al. 2004; Vanderwal et al. 2008). This in turn could modulate IB and agency, plausibly through bidirectional interactions with brain areas like temporal parietal junction (TPJ), which has been shown to be involved in several aspects of bodily self-representation including multisensory integration, sense of agency, and self-other differentiation (for a review, see Eddy 2016). Thus, retrospective inference due to sensorimotor integration would lead to stronger IB for self-associated stimuli compared with other-associated stimuli. In this framework, we speculate that our result of the MM may be due to similar activation for both self- and other-associated stimuli in vmPFC, as a result of modulation on conceptual representation of self to include others due to MM, which promotes detachment. This might have led to a similar agency-related processing of self- and other-related stimuli caused by self-generated action and captured by the temporal binding measure. Future neuroimaging studies need to be conducted to support these speculations.

To conclude, the present study demonstrated that MM modulates attachment to self- and other-related representations by using an intentional binding task. Meditators relative to non-meditators showed no difference in terms of IB and agency in processing self- and other-associated stimuli. This effect seems to be driven by a rebalancing of self- and other-related processing which lead to a lack of difference between the two. Our results suggest that the process of "decentering" the self might not solely affect self-related processing but it possibly involves rebalancing the other-related processing as well. Further studies are needed to shed more light on these involved processes. Overall, this study contributes to increase the knowledge about the mechanisms involved in modulation of self-other processing due to MM as well as the relationship between intentional binding, sense of agency, and self-referential processing.

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Author Contributions SGC: conceptualized and designed the study, performed material preparation and data collection, performed data analysis, wrote the first draft, and collaborated in the writing and editing of the final manuscript. MM: proposed, conceptualized, and designed the study, performed data analysis, wrote the first draft, and collaborated in the writing and editing of the final manuscript. LS: performed material preparation and data collection, provided feedback on data analysis, and collaborated in the writing and editing of the final manuscript. MH: performed material preparation and data collection and collaborated in the writing and editing of the final manuscript. LC: performed material preparation and data collection and collaborated in the writing and editing of the final manuscript. AR: proposed the study, contributed to the conception and design of the study, and collaborated in the writing and editing of the final manuscript. NS: contributed to the conception and design of the study, supervised data analysis, wrote the first draft, and collaborated in the writing and editing of the final manuscript.

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Compliance with Ethical Standards

The research involves human participants and the method has been approved by the Institutional Ethics Review Board.

Conflict of Interest The authors declare that they have no conflict of interest.

Ethics Statement All authors state their compliance with the Code of Ethics of the World Medical Association (Declaration of Helsinki). They also agree to the ethical standards of the Faculty of Psychology's Ethical Commission of the Sapienza University of Rome. The study was approved by the Ethics Committee of the Faculty of Psychology at the Sapienza University of Rome.

Informed Consent Written informed consent was obtained from all participants.

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