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Meditation-induced cognitive-control states regulate response-conflict adaptation: Evidence from trial-to-trial adjustments in the Simon task

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ABSTRACT

Here we consider the possibility that meditation has an immediate impact on information processing. Moreover, we were interested to see whether this impact affects attentional input control, as previous observations suggest, or the handling of response conflict. Healthy adults underwent a brief single session of either *focused attention meditation* (*FAM*), which is assumed to increase top-down control, or *open monitoring meditation* (*OMM*), which is assumed to weaken top-down control, before performing a Simon task—which assesses conflict-resolution efficiency. While the size of the Simon effect (reflecting the efficiency of handling response conflict) was unaffected by type of meditation, the amount of dynamic behavioral adjustments (i.e., trial-to-trial variability of the Simon effect: the Gratton effect) was considerably smaller after OMM than after FAM. Our findings suggest that engaging in meditation instantly creates a cognitive-control state that has a specific impact on conflict-driven control adaptations.

1. Introduction

Previous research has shown that meditation practice (ranging from days and weeks to several years) has substantial effects on how people process their physical and social environment, and how they regulate attention and emotion (see, Lippelt, Hommel, & Colzato, 2014, for a recent review). However, all meditation techniques are not the same: while some techniques demand practitioners to focus their attention on only one object or event at a time, other techniques allow, or even recommend accepting any internal or external experience or sensations that might enter awareness. Hence, different meditation techniques can be taken to bias the practitioner towards either tight or rather loose attentional control. This distinction is thought to be most evident with regard to *Focused Attention meditation* (*FAM*) and *Open Monitoring meditation* (*OMM*) (Lutz, Slagter, Dunne, & Davidson, 2008). FAM induces a narrow attentional focus due to the highly concentrative nature of the meditation, whereas OMM induces a broader attentional focus by allowing and welcoming any experiences that might arise during meditation.

In a seminal study, Tang and colleagues (2007) investigated whether a training technique based on meditational practices called integrative body-mind training (IBMT) could improve performance on an Attentional Network Task (ANT; Fan, McCandliss, Sommer, Raz, & Posner, 2002). The ANT is based on a flanker task and was developed to keep track of three

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different attentional sub skills: orientation, alerting, and conflict resolution. In the ANT task, participants discriminate a single target (e.g., letter or arrow) that is surrounded, or flanked, by distractors that indicate the same or opposite response (Eriksen & Eriksen, 1974). While IBMT had no effect on orienting and alerting scores, it did improve conflict resolution. As discussed by Eriksen and St James (1986), in the flanker task the "attentional spotlight" (i.e., the distribution of attention over space) is likely to be diffuse at stimulus onset, thus allowing interference from the flankers, but gradually narrows down to focus on the target. Along these lines, IBMT intervention might thus have effectively shrank the attentional spotlight to focus more strongly on the target and/or sped up the shrinking process. However, the nature of the flanker task makes it difficult to distinguish between such a rather input-related impact on information processing and effects that are more related to response-selection proper. In standard flanker tasks, incompatible flankers are known to create two kinds of selection problems (e.g., Kornblum, Hasbroucq, & Osman, 1990), one related to the fact that flankers represent alternative target stimuli that input-selection processes need to ignore, and another related to the fact that flankers are associated with an alternative but currently incorrect response—which creates response conflict. Accordingly, the findings of Tang et al. (2007) might indicate that meditation makes input selection more focused, or that it improves the handling of response conflict, or both.

The possibility that meditation affects processes other than genuinely attentional ones has been raised just recently. More specifically, we (Colzato, Oztürk, & Hommel, 2012; Colzato, Sellaro, Samara, Baas, & Hommel, 2015; Lippelt et al., 2014) have suggested that FAM and OMM established particular cognitive-control styles that makes response selection more strict/exclusive or more lenient/inclusive (cf., Lutz et al., 2008), respectively, and that this can happen instantaneously, that is, without much practice. In particular, we assume that FAM increases top-down control and thus strengthens top-down support for relevant information and/or local competition between relevant and irrelevant information (Duncan, Humphreys, & Ward, 1997), while OMM weakens top-down control and thus reduces top-down support and/or local competition. To test these predictions, we had people naïve to meditation engage in brief bouts of either FAM or OMM. We hypothesized that this would be sufficient to use particular (i.e., more serial or more parallel, respectively) cognitive-control states and affect performance on a subsequent response conflict task without any spatial-selection demands: the Simon task (Simon & Small, 1969). This task assesses the ability to deal with and resolve response conflict, that is, the ability to select a correct response in the face of other, competing responses (cf., Hommel, 2011). Participants are required to perform lateralized (left vs. right) responses on the basis of a non-spatial stimulus feature, often color. The position of the stimulus varies randomly in such a way that it can spatially correspond or not correspond with the position of the required response. The standard finding shows better performance if stimuli appear in response-congruent (C) than in response-incongruent (I) locations, demonstrating that action goals are indeed challenged, and yet people can overcome these challenges by overruling misleading stimulus-induced response tendencies (Hommel, 2011; Kornblum et al., 1990). If meditation can directly impact the efficiency of dealing with response conflict, the size of the Simon effect (I–C) should be affected by meditation type. As we assume that OMM induces a more lenient response-selection style, we would expect that the size of the Simon effect is larger after OMM.

Interestingly, the Simon effect is not entirely stable in size over time. More specifically, the effect of response congruency in the present trial (I–C) is less pronounced after an incongruent trial (iI–iC) than it is after a congruent trial (cI–cC; Gratton, Coles, & Donchin, 1992). This so-called "conflict-adaptation effect" (aka Gratton effect, the term that we prefer as being more theoretically neutral) has been taken to reflect the increase of cognitive control triggered by the experience of conflict (Botvinick, Braver, Barch, Carter, & Cohen, 2001). Accordingly, the Gratton effect can be taken to serve as a measure of control fluctuation and resulting adaptation and seems to rely on a regulatory feedback involving the anterior cingulate cortex (ACC) and the medial prefrontal cortex (PFC) (Botvinick, 2007; Botvinick, Cohen, & Carter, 2004; Botvinick, Nystrom, Fissell, Carter, & Cohen, 1999), the same brain areas found to be associated with enhanced cerebral blood flow with 5 days (30 min per day) IBMT (Tang, Tang, Lu, Feng, & Posner, 2015). Along the same lines, another study in which meditation-naïve participants were randomly assigned to either an 11 h IBMT course or a relaxation training, has reported that the IBMT group showed higher network efficiency and degree of connectivity of the ACC than a group that underwent relaxation training, (Xue, Tang, & Posner, 2011). Moreover, several other studies have also shown improvements in ACC functioning after meditation (Baerentsen, Hartvig, Stødkilde-Jørgensen, & Mammen, 2001; Lazar et al., 2000; Tang et al., 2009; Tang et al., 2010). In other words, both meditation and conflict management are driven by ACC and medial PFC. If so, it is possible that meditation does not, or not only impact the immediate handling of response conflict, as reflected in the Simon effect, but rather the trial-to-trial control adjustments that are reflected in the Gratton effect. If so, one would expect that such adjustments benefit from types of meditation that support focusing, which means that a more pronounced Gratton effect should be obtained after FAM.

The present study served to test these two hypotheses, together with a third hypothesis that meditation can impact the respective control processes instantaneously, that is, without extended practice or expertise. Accordingly, we presented participants with brief, single sessions of either OMM or FAM (Baas, Nevicka, & Ten Velden, 2014) and tested whether this would affect the size of the Simon effect (with smaller effects indicating tighter control) and the size of the Gratton effect (with larger effects indicating tighter control).

2. Method

2.1. Participants

Thirty-six healthy adults (1 male; mean age = 21.06, SD = 3.5) from Leiden University participated in the experiment. Participants were selected individually using the Mini International Neuropsychiatric Interview (M.I.N.I.; Sheehan et al., 1998). The M.I.N.I. is a well-established brief diagnostic tool in clinical and stress research that screens for several psychiatric disorders and drug use (Colzato & Hommel, 2008; Colzato, Kool, & Hommel, 2008; Sheehan et al., 1998). Participants were randomly and equally distributed in two experimental groups. Eighteen participants were exposed to an *open monitoring meditation* (OMM) session and 18 to a *focused attention meditation* (FAM) session. Written informed consent was obtained from all subjects; the protocol and the remuneration arrangements of 5 euro were approved by the local ethical committee (Leiden University, Institute for Psychological Research).

2.2. Simon task

The task consisted of a 20 min session in which participants were instructed to discriminate the color (green vs. blue) of a target circle by pressing one of two lateralized keys on a computer keyboard: the left key in response to the green circle and the right key in response to the blue circle. Target circles were equiprobably presented to the left or to the right of a central fixation point. Participants had to ignore the location of the stimulus and to react as quickly and as accurate as possible to its color. Trials began with the presentation of the fixation point. Afterwards the target stimulus was presented until the response was given but no longer than 1500 ms. Intervals between subsequent stimuli varied randomly but equiprobably, from 1750 to 2250 ms in steps of 100 ms. The task consisted of four blocks of 60 randomly ordered trials, the first of which was a practice block. In half of the trials, stimulus and response positions corresponded, whereas, in the other half, stimulus and response positions did not correspond.

2.3. Procedure

Participants were invited individually to the laboratory. Upon arrival, they were asked to rate their mood on a 9 × 9 Pleasure × Arousal grid (Russell, Weis, & Mendelsohn, 1989) with values ranging from −4 to 4. Thus, the scale provides a score that indicates the location of the participant's affective state within a two-dimensional space defined by hedonic tone and activation. Hereafter, participants put on their headphones and listened to a 17 min OMM or FAM fragment that was based on transcripts of meditation manipulations by Colzato et al. (2012). The audio fragments were developed, validated, and successfully applied in a previous study by Baas and colleagues (2014) investigating the differential effect of mediation techniques on creativity. In the OMM condition, a male voice guided participants in a step-by-step manner to pay attention to the present moment and to simply notice their feelings, thoughts, and bodily sensations entering into their awareness from moment-to-moment without conceptual elaboration or emotional reactivity. In the FAM condition, the same male voice guided participants in a step-by-step manner to focus and sustain their attention on their own breathing, monitor the quality of attention, and bring their attention back to their breathing whenever their mind had wandered. Next, participants rated again their mood and were presented with the Simon task. After the Simon task, participants rated their mood for the third time. After these measurements, the experimental session was ended and all participants were paid and dismissed.

2.4. Data analysis

Mean correct RTs and percentage of errors (PEs) were submitted to separate repeated-measures ANOVAs with congruency in present trial [congruence (C) vs. incongruence (I)] and congruency in previous trial [congruence (c) vs. incongruence (i)] as within-subjects factors, and group (FAM vs. OMM) as between-subjects factor. Standard Gratton effects, for both RTs and PEs, were calculated by subtracting the Simon effect following correct incongruent trials (iI–iC) from the effect following correct congruent trials (cI–cC). The first trial (1.7%) of each block and post-error trials (3.7%) were excluded from all analyses. Mood was analyzed by means of a repeated-measures analysis of variance (ANOVA) with group (FAM vs. OMM) as between-subjects factor and effect of time (first vs. second vs. third measurement) as within-subjects factor. A significance level of $p < .05$ was adopted for all statistical tests.

3. Results

3.1. Simon task

ANOVAs revealed that responses were faster (420 ms vs. 441 ms) and more accurate (2.0% vs. 5.1%) on congruent than on incongruent trials [$F(1,34) = 24.19$, $p < .001$, $\eta_p^2 = .42$ (RT), $F(1,34) = 20.48$, $p < .001$, $\eta_p^2 = .38$ (PE)]—which is the standard Simon effect. A standard Gratton effect was obtained as well, as indicated by a significant interaction between congruency in previous trials and congruency in present trials for both RTs [$F(1,34) = 121.74$, $p < .001$, $\eta_p^2 = .78$], and PEs [$F(1,34) = 54.34$, $p < .001$, $\eta_p^2 = .62$]. As usual, both RT and PE analyses showed regular Simon effects (53 ms and 7.2%) after congruent trials [$F(1,35) = 112.86$, $p < .001$, $\eta_p^2 = .76$ (RT), $F(1,35) = 59.06$, $p < .001$, $\eta_p^2 = .63$ (PE)], which were reversed in sign (−10 ms and −1.0%), but not significantly so, after incongruent trials [$F(1,35) = 3.18$, $p = .08$, $\eta_p^2 = .08$ (RT), $F(1,35) = 1.44$, $p = .24$, $\eta_p^2 = .04$ (PE)]. More interesting for our purposes, the Gratton effect in RT, but not in PE, was modulated by the type of meditation, as revealed by a significant three-way interaction involving the factors group, congruency in present trial, and congruency in previous trial [$F(1,34) = 7.87$, $p < .01$, $\eta_p^2 = .19$ (RT), $F(1,34) = .22$, $p = .65$, $\eta_p^2 = .006$ (PE)]. The RT effect indicated that the size of the Gratton effect was significantly larger after FAM than after OMM (see Table 1). In contrast, the Simon effect was not mediated by the type of meditation, neither in RTs nor in PEs [$F_s < 1$, $p_s \geqslant .50$] (see Table 1). The main effects of group and congruency in previous trial, as well as the interactions involving the two factors were not significant either [$F_s \leqslant 2.4$, $p_s \geqslant .13$].

3.2. Mood

The ANOVA performed on participants' mean mood rating did not reveal any significant effect or interaction between time and group [$F_s \leqslant 2.8$, $p_s \geqslant .07$]. Mood scores were thus comparable across group and time: the mean scores at the three time points were 1.1 (SD = .18), .4 (SD = .9) and .4 (SD = 1.1) for the OMM group, and .5 (SD = 1.4), .5 (SD = .8) and .5 (SD = .9) for the FAM group.

4. Discussion

The findings are straightforward. First, there was no indication that the Simon effect would be affected by meditation. This implies that previous observations of meditation effects in flanker tasks might have more to do with attentional input control (which was not under challenge in the present study) than with the immediate handling of response conflict, at least to the degree that the latter is reflected in the size of the Simon effect. Accordingly, the flanker task may be more sensitive to pick up such local effects than the Simon task, even though we note that the impact of meditation on the flanker task did not always replicate (Larson, Steffen, & Primosch, 2013). Alternatively, given that we did not include a non-meditation condition in our study, we cannot exclude that FAM and OMM influenced the Simon effect in the same way and to the same degree. But even in this case, we could conclude that the Simon effect is not differentially affected by different kinds of meditation.

Second, however, meditation had a significant impact on the Gratton effect. This means that it is the higher-level control policy, rather than local conflict-management routines, that is sensitive to meditation. If we assume that FAM induces a single-channel processing mode that strengthens top-down support for relevant information and/or increases local competition between relevant and irrelevant information (Lippelt et al., 2014), the more pronounced trial-to-trial fluctuation/adaptation indicates that undergoing FAM leads one to engage more in the trial-to-trial fine-tuning of cognitive control. This fits with observations that control fluctuation and resulting adaptation seems to rely on the cingulo-opercular network (Dosenbach, Fair, Cohen, Schlaggar, & Petersen, 2008) and particularly on the ACC (Botvinick, 2007; Botvinick et al., 1999; Botvinick et al., 2004), whose functioning has been found to be improved after meditation in several studies (Baerentsen et al., 2001; Lazar et al., 2000; Tang et al., 2009; Tang et al., 2010; Tang et al., 2015; Xue et al., 2011). Given that mood did not significantly change between the FAM and OMM groups after their respective meditation, we can rule out an account of our results in terms of mood changes. This is particularly important given that the Gratton effect seems to be particularly sensitive to mood (van Steenbergen, Band, & Hommel, 2010). The fact that individual motivation to engage in the fine-tuning of cognitive-control processes increases after FAM may be particular interesting for impulse control disorders which may profit from increasing control strength (i.e., concentration on the goal).

A third implication of our findings is that meditation can act instantaneously. This does not exclude that stronger and/or more long-lasting effects can be obtained with extended practice, but it does show that the control states that meditation seems to help establishing do not require such practice. This raises interesting possibilities of using meditation to optimize cognitive control by biasing cognitive processing towards either more serial or more parallel processing.

Table 1
Mean correct reaction times (RT; in ms), percentage of errors (PE; in %) and Simon and Gratton effects for both of these measures, as a function of meditation group (OMM and FAM). Standard errors are shown in parentheses.

Variables	RT (ms)		PE(%)	
Simon task	OMM	FAM	OMM	FAM
Congruent trial following a congruent trial (cC)	397 (13.9)	408 (13.9)	0.2 (0.2)	0.4 (0.2)
Incongruent trial following a congruent trial (cI)	443 (11.1)	468 (11.1)	7.3 (1.4)	7.8 (1.4)
Congruent trial following an incongruent trial (iC)	424 (15.1)	451 (15.1)	3.8 (0.9)	3.4 (0.9)
Incongruent trial following an incongruent trial (iI)	423 (12.8)	432 (12.8)	2.1 (0.9)	3.2 (0.9)
Simon effect [(cI + iI)/2 – (cC + iC)/2)]	23 (6.1)	20 (6.1)	2.7 (1.0)	3.6 (1.0)
Gratton effect [(cI–cC) – (iI–iC)]	47 (8.0)**	79 (8.0)**	8.7 (1.6)	7.7 (1.6)

** $p < .01$.

Taken altogether, this is the first study to demonstrate that OMM and FAM meditation instantaneously induce specific cognitive-control states that modulate conflict-driven control adaptations (as indexed by the size of the Gratton effect) but not the efficiency of handling response conflict (as reflected by the size of the Simon effect).

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