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Mindfulness meditation associated with alterations in bottom-up processing: Psychophysiological evidence for reduced reactivity

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ABSTRACT

Mental training by meditation has been related to changes in high-level cognitive functions that involve top-down processing. The aim of this study was to investigate whether the practice of meditation is also related to alterations in low-level, bottom-up processing. Therefore, intersensory facilitation (IF) effects in a group of mindfulness meditators (MM) were compared to IF effects in an age- and gender-matched control group. Smaller and even absent IF effects were found in the MM group, which suggests that changes in bottom-up processing are associated with MM. Furthermore, reduced interference of a visual warning stimulus with the IF effects was found, which suggests an improved allocation of attentional resources in mindfulness meditators, even across modalities.

1. Introduction

In recent years there has been a significant increase in research on the effects of meditation on brain and behavior (Davidson et al., 2003; Kabat-Zinn, 2003; Moore and Malinowski, 2009; Slagter et al., 2007; van den Hurk et al., 2010). Among other findings, meditation has been associated with improvements in attentional processing (Lutz et al., 2009; van den Hurk et al., 2010) and better resource allocation (Slagter et al., 2007). One of the most consistent findings has been better executive attention as shown by improved performance of meditators in Stroop (like) tasks (Chan and Woollacott, 2007; Moore and Malinowski, 2009; van den Hurk et al., 2010). The improvement in executive attention points to a greater ability of meditators to inhibit incorrect responses and suggests a reduction in reactivity due to improved top-down control. Actually, many, if not all, research findings on meditation related effects have been limited to high-level, top-down processing. To our knowledge, only in a recent study by Vestergaard-Poulsen et al. (2009), have differences between meditators and non-meditators in low-level brain structures been investigated. An increase in gray matter density in the medulla oblongata, a brain region in the lower brain stem, was found in meditators. Thus, the aim of our study was to investigate whether also functional differences in low-level, bottom-up processing are associated with meditation.

One well-known phenomenon that is considered to reflect bottom-up processing is intersensory facilitation (IF) (Kirchner and Colonius, 2005). IF stands for the reduction in reaction time (RT) to a stimulus presented in one modality when it is accompanied, close in time, by the presentation of a stimulus in another modality (Keuss et al., 1990; Kirchner and Colonius, 2005; Schmidt et al., 1984; Stoffels et al., 1985). For example, Keuss et al. (1990) demonstrated that non-informative sounds (auditory accessories) of low to moderate intensity facilitate RT to a visual stimulus. Even more, they showed that visual choice reactions become faster with increasing intensity of the auditory accessory, which is remarkable since the auditory stimulus does not provide any information about the correct response. Interestingly, the latter finding on IF effects by Keuss et al. (1990) bears a close resemblance to the StartReact Effect (SRE), i.e., the fact that high intensity, startle inducing auditory stimuli (high intensity accessory) can speed up simple as well as choice visual RT in comparison with auditory stimuli of moderate intensity (Oude Nijhuis et al., 2007; Valls-Sole et al., 1995). In addition to RT facilitation as observed in IF, the SRE has been associated with increases in speed and acceleration of movement (Siegmund et al., 2001). Contrary to previous research findings, which suggested that the SRE is the result of startle, recent studies provided compelling evidence for the view that the SRE reflects stimulus-intensity facilitatory effects (Carlsen et al., 2007; Lipp et al., 2006). As such, the SRE might be considered as a specific case of IF with auditory accessories of moderate and high intensity, of which the latter have high potential to elicit a startle response.

The research findings of reduced reactivity due to improved high-level, top-down processing led us to the hypothesis that meditation

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might be related to reduced (re)activity in low-level, bottom-up processing. In order to test this first hypothesis, a group with extensive mindfulness meditation (MM) experience was compared to an age- and gender-matched control group on IF effects in a visual choice reaction time task involving head rotations. The level of IF was indexed by the size of the SRE in the following outcome parameters: onset latency of head rotation, onset latency of EMG activity in neck muscles, peak angular velocity of head rotation and peak angular acceleration of head rotation. A reduction in (re)activity in bottom-up processing would be revealed by attenuated IF effects. In other words, for each of the outcome parameters a smaller SRE in the MM group was expected. In addition, since previous literature showed that a visual warning stimulus seems to draw attention away from the auditory modality and, as a corollary, reduces the influence of auditory stimuli (Lipp et al., 2000; Schicatano and Blumenthal, 1998), we wanted to test the second hypothesis that, due to an improved deployment of attentional resources in the group of meditators (Slagter et al., 2007; van den Hurk et al., 2010), the IF effects are less affected by an interfering visual warning stimulus in this group. For this reason, trials with and without a visual warning stimulus were presented and the condition without an interfering visual warning was considered the default condition in which to study the IF effects.

2. Methods

2.1. Ethical approval

The experiment was done in accordance with the standards of the Declaration of Helsinki and was approved by the local ethical committee, i.e., Central Committee on Research on Human Subjects (CCMO) region Arnhem/Nijmegen. All subjects gave written informed consent before start of the experiment. They were paid 15 euros for participation in the experiment and received a refund of their travel expenses.

2.2. Subjects

Thirteen experienced mindfulness meditators and thirteen healthy controls, matched on age and gender, participated in this study. The matching was done in such a way that for each meditator a control subject with the same gender and the same age ± 3 years was selected. Each group consisted of 8 males and 5 females. The mean age of the meditators was 46 (SD = 14) years, with a range of 28–64 years. The mean age of the controls was 45 (SD = 16) years, with a range of 26–67 years. The meditators had a mean MM experience of 14 (SD = 11) years, with a range of 2–36 years. The controls did not have any meditation experience.

2.3. Experimental setup

During the experiment, subjects sat in a dark room in front of a projection screen with a width of 2.70 m and a height of 2.00 m at a distance of 80 cm (between the tip of the nose and the screen). Prior to the experiment, three axes were defined relative to the subject as *x*-axis (anterior–posterior), *y*-axis (left–right) and *z*-axis (up–down). All measured positions refer to this coordinate system. The position of the cyclopean eye of the subject was aligned with a fixation cross that was presented right in front of the subject at the center of the screen. Subjects were strapped to the chair with two seatbelts running from the shoulders to the hips in order to ensure that only head rotations could be made. Spatial cues (white circles with diameter of 5 cm) were projected either 8° to the left or to the right on the *y*-axis from the centrally projected fixation cross. The target stimuli were white circles (diameter = 12 cm), printed on black, A4-sized paper, positioned 60° to the left and right on the *y*-axis from the subjects' center (see Fig. 1 for a schematic overview of the experimental setup). The fixed locations of the central fixation cross and target stimuli ensured similar head rotations across conditions and subjects.

2.3.1. Choice reaction time task

Subjects were instructed to rotate their head as fast as possible from the central fixation cross to the target stimulus when a spatial cue was presented. A spatial cue presented to either the left or right of the central fixation cross instructed the subjects to rotate their head to the left or right target stimulus, respectively. Spatial cues were presented on an equal (50%–50%) basis for left and right targets. In warning trials the central fixation cross turned from white into a red color, signaling the subjects that the spatial cue would appear within 1 to 3 s. In trials without a warning stimulus (no-warning trials) the central fixation cross did not change color. Warning and no-warning trials were randomly presented on a 50%–50% basis (see Fig. 2 for a schematic overview of warning and no-warning trials). High intensity (HI) acoustic stimuli were presented in one-third of all trials to reduce habituation to this stimulus and moderate intensity (MI) stimuli were presented in the remaining trials. All combinations of left versus right rotation, warning versus no-warning, and HI versus MI acoustic stimuli yielded 8 different types of trials that were presented in a pseudo-random order. Before the start of the actual experiment, five practice trials were presented, including one HI trial. The actual experiment consisted of six blocks of 24 trials giving a total of 144 trials (72 warning and 72 no-warning trials). The whole experiment lasted for about 30 min. In between blocks subjects were given time to pause and could indicate the start of the next block when they felt ready.

2.3.2. Acoustic stimuli

Acoustic stimuli with a duration of 300 ms were used. The onset of the acoustic stimuli was simultaneous with the onset of the spatial cues as in previous studies (Keuss et al., 1990; Oude Nijhuis et al., 2007). HI (MI) acoustic stimuli were presented with an intensity of 107 (67) dB measured at the location of the subjects head with a Bruel & Kjaer measuring amplifier type 2610. Two acoustic stimuli with frequencies of 2000 and 2500 Hz were randomly used in order to prevent habituation effects to the stimulus. The acoustic stimuli were sent out by a SM10 loudspeaker located 1.5 m directly behind the subject, similarly as in Carlsen et al. (2007). In this way, the acoustic stimulus did not provide any spatial information about the target position. See also Oude Nijhuis et al. (2007), who showed that the location of the acoustic stimulus source did not affect the response. Timing of the fixation cross, the visual cues and the auditory stimuli as

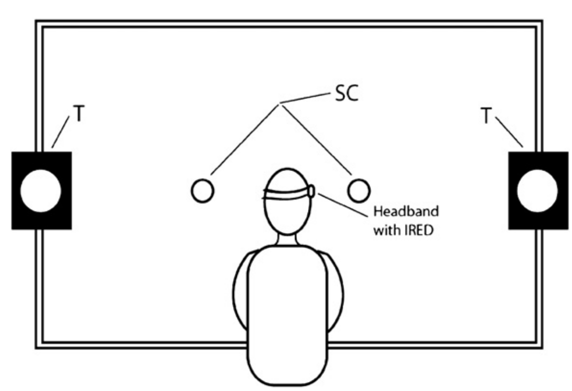

Fig. 1. Experimental setup. Posterior schematic overview of the experimental setup showing a subject sitting in the chair in front of the screen. Spatial cues are indicated by SC. The visual target stimuli are indicated by T. In each trial, a spatial cue was presented either to the left or to the right of the subject, signaling the subject to make a head rotation to either the left or right target stimulus, respectively.