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SPECIAL ISSUE

Neurofeedback from the Posterior Cingulate Cortex as a Mental Mirror for Meditation

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? *Meditation has several beneficial effects. However, learning how to meditate is not easy, as there are no clearly visible outward signs of performance, making it difficult for teachers to provide feedback. Neurofeedback from the posterior cingulate cortex (PCC), a brain region that is associated with both meditation and mind wandering, may provide a valuable tool to help individuals learn to meditate.*

Introduction

Although meditation has positive psychological, biological and neurobiological effects (Goyal et al., 2014; Hölzel et al., 2011; Schutte & Malouff, 2014), learning how to meditate is not straightforward. Unlike activities like yoga or soccer, where a teacher can see when a practitioner is performing correctly or incorrectly, no immediate feedback to meditation students is possible because there are no easily discernable outward signs of performance. In addition, a teacher's feedback may be biased as it is based on students' verbal descriptions, which are influenced by several factors such as the ability of a student to describe internal states and the interpretation by the teacher. A possible solution to this issue would be to provide real-time neurofeedback, so individuals have a "mental mirror" that informs them on the quality of particular mental aspects of their experience during meditation in real time.

A prime candidate for delivery of this type of neurofeedback would be electroencephalography (EEG), which is relatively cheap and accessible, as well as able to track changes in brain activity quickly (in the range of milliseconds). For almost half a century, brain processes related to meditation have been investigated using this technique (Cahn & Polich, 2006). However, no definitive finding with regard to frequency range or lead placement has yet surfaced. For example, some studies reported a decrease in alpha power during meditation (Jacobs & Lubar, 1989; Pagano & Warrenburg, 1983), some did not find any change in alpha activity (Jacobs, Benson, & Friedman, 1996),

others reported increases in alpha power in primarily frontal regions (Takahashi et al., 2005), while still others reported increases in alpha power in primarily posterior regions (Dunn, Hartigan, & Mikulas, 1999). In addition to these inconsistent results, most EEG studies analyzed the data on the sensory level, which is at best a very coarse marker of where in the brain activity changes during meditation.

We and other researchers have taken a different approach by first determining neural correlates of particular cognitive states related to meditation. By investigating those brain regions where activity changes when people meditate, a theoretical and practical framework can be developed, guiding the design of an EEG neurofeedback paradigm that helps people meditate through objective feedback.

Neural Correlates

Which brain regions change their activity during meditation? The technique currently most frequently used to localize brain activity is functional magnetic resonance imaging (fMRI). With fMRI, the demand for oxygen related to activity in the brain is measured. It is an excellent technique to pinpoint location of brain activity changes. To determine brain regions associated with meditation, we invited 12 experienced meditators and 12 novice meditators to meditate while their brains were scanned using fMRI.

In order to ensure generalizability of findings beyond one specific meditation technique, participants performed three different kinds of meditations within the Theravada tradition: concentration, loving-kindness, and choiceless awareness. Data were collapsed across these three categories. In the first analysis, the fMRI scans were analyzed using functional connectivity analysis, i.e., looking at how activity in different brain regions correlated over time. We found an increased correlation in activity between the posterior cingulate cortex (PCC) and the dorsal anterior cingulate cortex (dACC) in the experienced meditators

compared to the novice meditators (Brewer et al., 2011). These brain regions are main nodes of the so-called default mode network (DMN), which is a network of brain regions that become active when one is wakefully resting and not focused on the outside world.

In the second analysis, we investigated whether certain brain regions become more or less active during meditation compared to wakeful resting. This so-called activation analysis also implicated DMN areas. During meditation, the main nodes of the DMN including the PCC became relatively less active in experienced meditators.

Importantly, these results were corroborated by another study that observed decreases in activity of the same DMN regions in meditators from a different tradition (i.e., Zen meditation) while viewing emotionally evocative pictures (Taylor et al., 2011). An association between the activation of the PCC, meditation, and behavior was observed in another group of Zen meditators by Pagnoni et al. (2012), who demonstrated that PCC deactivation during meditation correlated with improved performance on a sustained attention task. Although these studies all implicated decreases in PCC activity to be associated with meditation, they used fairly small groups of up to 12 participants, which limits their interpretation.

In a study addressing this issue by employing larger groups, meditation-related brain activity was assessed in 20 experienced meditators from the Theravada tradition and 26 novice meditators. Again, participants performed three different kinds of meditation: concentration, loving-kindness and choiceless awareness. Data were collapsed across these three techniques. Compared to resting baseline, experienced meditators showed reduced activity in two main nodes of the DMN, including the PCC, during meditation compared to nonmeditators (Garrison, Zeffiro, Scheinost, Constable, & Brewer, 2015).

In sum, these results indicate that decreases in activity in the PCC are associated with meditation, across different meditation techniques (concentration, loving-kindness and choiceless awareness), and across different meditation traditions (Theravada and Zen). Interestingly, as *decreases* in PCC activity have been found to be associated with meditation, *increases* in activity in this brain region have been suggested to be associated with “getting caught up” in one’s experience, such as getting caught up in mind wandering, a particular viewpoint, or drug craving (Brewer, Garrison, & Whitfield-Gabrieli, 2013). As being caught up can be regarded as the opposite of meditation, the PCC may provide a potentially suitable target for neurofeedback in learning how to meditate, as activity in this brain region

may inform when one is in the meditative state, but also when one is not in the meditative state.

Neurofeedback

The activation studies described above provided valuable information about changes in brain activity associated with meditation. However, they did not inform us about the temporal association between changes in brain activity and meditation. That is, are deeper subjective experiences of meditation associated with relatively greater decreases of PCC activity? And are spontaneous short episodes of mind wandering during meditation associated with increases in PCC activity? To test this, Garrison et al. (2013) provided real-time neurofeedback from the PCC during a focused attention meditation task. Participants were told that the neurofeedback signal was related to a brain region involved in self-related processing. Furthermore, participants were told that while they meditated with eyes open, the neurofeedback graph would show an upward red signal when they engaged in self-related processes such as mind wandering, and a downward blue signal if fully in meditation. Both novice and experienced meditators reported a significant correspondence between PCC activity and their subjective experiences of meditation and self-related processes. This shows that the neurofeedback signal from the PCC is indicative of the depth of meditation, as well as the presence of mind wandering, supporting the suitability of neurofeedback from the PCC in assisting both novice and experienced meditators.

However, could participants *control* the signal? In the same study, the same participants were asked to volitionally decrease PCC activity. Garrison and colleagues (2013) found that the experienced meditators showed significant PCC deactivation compared to the novice meditators. This shows that the experienced meditators were better in manipulating their PCC activity. However, it could be that the results were influenced by confounding factors such as confirmation bias or other expectancy effects. To exclude this possibility, a series of experiments was performed with a group of experienced meditators that were not involved in the previous studies. In this study, participants followed a blinded discovery protocol: (1) meditation, (2) meditation with mock PCC feedback, (3) meditation with real-time PCC feedback, and (4) volitional manipulation of the graph. This protocol, progressing from the easiest setting of meditation without any feedback to volitional manipulation, allowed participants to discover how the neurofeedback graph corresponded with their subjective experience of meditation. Importantly, participants were not provided with any information regarding the brain region from

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which the neurofeedback signal originated, or what process (i.e., meditation) the neurofeedback signal could represent. The only information provided to the participants was that an upward red signal was related to increased activity in a particular brain region and a downward blue signal in the graph was related to decreased activity in the same brain region. Participants reported a significant correspondence rating between their subjective experience and the neurofeedback graph and were able to volitionally deactivate PCC activity, replicating the earlier results without the bias of being provided experiential anchors.

Neurophenomenology

The neurofeedback study described above linked PCC activity to the subjective experience of meditation and mind wandering. However, the PCC has been associated with numerous cognitive states other than meditation and mind wandering (Andrews-Hanna, Reidler, Sepulcre, Poulin, & Buckner, 2010). As such, the exact processes that the neurofeedback signal represented were still unknown. To investigate this issue, Garrison et al. (2013) analyzed subjective reports of participants in the blinded discovery protocol described above, in which participants described their subjective experiences after each meditation. In a data-driven manner, these reports were coded by content and grouped into different concepts. For example, focus on the body was categorized in the concept “concentration.” These concepts were then categorized as relating to either PCC activation or PCC deactivation. As expected, it was found that undistracted awareness, such as concentration, observing sensory experience and, in particular, an effortless quality of the awareness, corresponded with PCC deactivation. Furthermore, the experience of distracted awareness, such as distraction, interpreting, and “efforting” corresponded with PCC activation. These findings refined our understanding of the PCC correlates of subjective experience (Brewer & Garrison, 2014).

PCC Neurofeedback with EEG Source Localization

The neurofeedback studies described above used fMRI to investigate brain activity related to meditation and mind wandering. However, although fMRI is an excellent technique to pinpoint *where* brain activity changes, it not the best technique to pinpoint *when* brain activity changes, as there is a lag of 4–8 seconds between the peaking of the actual brain activity and the peaking of the fMRI signal. This delay makes it more challenging for participants to interpret the feedback signal. In addition, for fMRI one needs an MRI machine, and these devices are scarce and

expensive. Because of these reasons, fMRI is not the most practical solution to provide neurofeedback. In contrast, EEG allows investigators to track brain activity on a millisecond time-scale, and it is relatively inexpensive and portable, making it a potentially suitable method to deliver neurofeedback to help individuals meditate.

Although EEG does not have the same accuracy to pinpoint where brain activity changes as fMRI, recent innovations have made it possible to use source localization with EEG (van Veen, van Drongelen, Yuchtman, & Suzuki, 1997). Based on the theoretical framework developed with the fMRI findings described above, logical next steps for the field would be to use source-localized EEG neurofeedback from the PCC to guide people to track neural correlates of subjective states associated with meditation and, eventually, provide augmentation strategies for typical teacher-based guidance as individuals learn how to meditate. At our lab, we are now investigating the usefulness of this paradigm. Later this year, we will be starting a large randomized controlled trial to investigate whether source-localized EEG from the PCC as add-on treatment to a regular 8-week mindfulness-based stress reduction (MBSR) course, could help people learn how to meditate. If successful, this will open a new avenue to help people learn mindfulness and receive its associated salutary effects (Goyal et al., 2014; Tang et al., 2007).

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