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Electroencephalographic correlates of states of concentrative meditation

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ABSTRACT

Meditative techniques aim for and meditators report states of mental alertness and focus, concurrent with physical and emotional calm. We aimed to determine the electroencephalographic (EEG) correlates of five states of Buddhist concentrative meditation, particularly addressing a correlation with meditative level. We studied 12 meditators and 12 pair-matched meditation-naïve participants using high-resolution scalp-recorded EEG. To maximise reduction of EMG, data were pre-processed using independent component analysis and surface Laplacian transformed data. Two non-meditative and five meditative states were used: resting baseline, mind-wandering, absorptions 1, 2, 3, 4 and 5 (corresponding to four levels of absorption and an absorption with a different object of focus, otherwise equivalent to level 4; these five meditative states produce repeatable, distinctly different experiences for experienced meditators). The experimental protocol required participants to experience the states in the order listed above, followed immediately by the reverse. We then calculated EEG power in standard frequency bands from 1 to 80 Hz. We observed decreases of central scalp beta (13–25 Hz), and central low gamma (25–48 Hz) power in meditators during deeper absorptions. In contrast, we identified increases in frontal midline and temporo-parietal theta power in meditators, again, during deeper absorptions. Alpha activity was increased over all meditative states, not depth-related. This study demonstrates that the subjective experiences of deepening meditation partially correspond to measures of EEG. Our results are in accord with prior studies on non-graded meditative states. These results are also consistent with increased theta correlating with tightness of focus, and reduced beta/gamma with the desynchronization associated with enhanced alertness.

1. Introduction

Trends in consciousness studies increasingly endorse exploring the neural counterparts to subjective experience by emphasizing first-person accounts (Cohen and Dennett, 2011; Varela, 1996) and anchoring them to something that can be detected and confirmed in replicable experiments (Dennett, 2001). Buddhist meditative practices offer a long history of systematic investigation of subjective experience and provide a unique opportunity for neurobiological explorations of conscious states (Lutz et al., 2007). Meditation denotes any, even momentary or weak, *absorption of mind*, when directed on a single object (Nyanatiloka, 1972). Meditators learn to regulate their own mental states in ways that augment focused attention among other skills (Lutz and Thompson, 2003). It is this extensive familiarity with internal phenomena that is thought to afford skilled practitioners of meditation the ability to achieve distinct and reproducible states during meditation (Lutz et al., 2007; Wallace, 2006).

Sustaining attention on a single object is common across a large number of introspective traditions and valued for its beneficial effects on mental well-being (Chiesa and Serretti, 2010; Ospina et al., 2007). Extended periods of single-pointed attention, when intensified, give rise to subjectively deeper states of meditation, called levels of absorption in the Buddhist tradition. The background and references to this practice are provided in Supplementary Material. Teachers provide practitioners with standard instructions and descriptions of each absorption. The absorptions are experienced by different individuals, which experienced practitioners consistently describe by way of their personal physical and psychological correlates. In deeper absorptions, thought activity subjectively becomes progressively diminished as concentration intensifies. The production of reportable discrete and reproducible states is critical to experimentally investigating meditation from a neuroscientific standpoint (Lutz and Thompson, 2003).

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For decades, researchers have investigated the neurophysiological correlates of a wide range of meditative traditions, and reported on both state (acute) and trait (chronic) effects (Cahn and Polich, 2006; Fell et al., 2010). Relationships between brain changes and the training duration of meditation practitioners have been reported in EEG (Carter et al., 2005; Kasamatsu and Hirai, 1966; Lutz et al., 2004; Murata et al., 1994) and fMRI studies (Brefczynski-Lewis et al., 2007; Fox et al., 2014). There is a growing body of evidence to challenge the idea that meditative practices may only be considered effective within the philosophies they serve (Buzsáki, 2006) as, recently, various mental training techniques have produced significant effects in the brains of meditation-naïve participants (Jha et al., 2007; Milz et al., 2014; Moore et al., 2012; Santarnecchi et al., 2015).

EEG correlations of meditative states have been long sought. The changes as summarized by Cahn and Polich (2006), and Fell et al. (2010) are:

- Global reduced amplitude delta activity during meditation (Dunn et al., 1999; Hinterberger et al., 2014). Early studies reported sleep-like stages during Transcendental Meditation (TM) (Pagano et al., 1976; Younger et al., 1975), however, the differentiation of meditative states from sleep is now clear (Cahn and Polich, 2006; Fell et al., 2010);
- Increased theta activity during concentrative meditation, often frontally, and following increases in alpha (Aftanas and Golocheikine, 2001; Ahani et al., 2014; Corby et al., 1978; Murata et al., 1994), frontal theta bursts (Banquet, 1973; Fenwick et al., 1977; Kasamatsu and Hirai, 1966; Tanaka et al., 2014; West, 1980), theta differentiating novice and expert meditators (Aftanas and Golocheikine, 2002; Aftanas and Golocheikine, 2003), theta during states of bliss (Aftanas and Golocheikine, 2001) and theta negatively correlating with measures of sympathetic activity (Kubota et al., 2001);
- Increased alpha amplitude, predominantly in occipital regions (Ahani et al., 2014; Anand et al., 1961; Banquet, 1973; Corby et al., 1978; Delmonte, 1984; Kasamatsu and Hirai, 1966; Murata et al., 1994), and slowing of the alpha frequency, often spreading anteriorly (Banquet, 1973; Davidson et al., 1976; Kasamatsu and Hirai, 1966; Lehrer et al., 1980; Murata et al., 1994);
- Decreased beta and gamma during the practice of meditation (Aftanas and Golocheikine, 2005; Hinterberger et al., 2014; Saggar et al., 2012), correlated with meditation experience (Cahn et al., 2010). However, several studies have found increased gamma during meditation (Berkovich-Ohana et al., 2012; Lutz et al., 2004; Thomas et al., 2014).

Despite the numbers of studies of meditation and the advancing understanding of cognitive processes involved (Saggar et al., 2012), few studies provide detailed phenomenological reports in relation to neurophysiological data (Cahn and Polich, 2006; Chiesa and Serretti, 2010). In addition, although researchers have examined state and trait changes in various meditative techniques, there have been no studies on the deepening states of meditative absorption as referred to in traditional texts. Here, we systematically examine the different states of meditative absorption described in the Buddhist tradition, particularly addressing a possible correlation with level of subjective meditative depth.

2. Material and methods

The study was approved by the Clinical Research Ethics Committee of Flinders University and Flinders Medical Centre. All participants signed written informed consent.

2.1. Participants

Twelve meditators (7 female, 5 male, age $\bar{x} = 48.1$ years, range 29–64 years) with 4–34 years meditation experience ($\bar{x} = 18.75$ years) from the Lifeflow Meditation Centre were pair-matched to meditation-naïve controls for age (±6 years), gender, handedness, and education level.

2.2. Meditation technique

The *BreathMindfulness Discourse* (Ānāpānasati Sutta, Pāli) in Theravāda Buddhism provides preparatory instructions as well as detailed core instructions for practicing mindfulness of breath. This form of concentrative meditation, or Focused Attention (FA), involves the voluntary direction and placement of attention on a single stimulus or invariant set of stimuli. The practice can be considered as moving one's awareness from thoughts to sensations, commonly the sensation of breathing. The practices developed by the Lifeflow Meditation Centre and investigated in this paper are largely extracted from these texts. The source material for the practices is provided in Supplementary Material, 1. Source of Buddhist material, 2. The meditative absorptions, and 3. The meditation instructions.

2.3. States of meditation

Table 1 describes the meditation instructions and subjective experiences for each of the meditative states introduced above. When a particular meditative state has been maintained successfully, the subjective experiences of it differ between individuals, and further there is no satisfactory way of ascertaining the duration of successful maintenance of a meditative state: the act of repeatedly enquiring of a practitioner during a meditation is disruptive of the task. Our methods relied on the compliance of experienced meditators, checked by having participants fill out a post-study report to confirm achievement of the requested meditation states. If meditative states were inadequately attained, such a result would influence our results un-favourably, a compromise we accepted.

2.4. Experimental design

Both meditators and controls underwent the same experimental design (Fig. 1). The design was planned with the hypothesis that there would be progressive EEG changes as participants entered and then emerged from the subjectively deeper states, a plan that likely would provide a balance of time effects if any should be present. The plan also provided us with four 'basal' states: entering and emerging Baseline and Mind Wandering. We chose this approach over a strategy in which meditators accessed subjective states in a pre-determined random order, since jumping to a subjectively deep state from a subjectively light state is challenging. The challenges would be greater in the unfamiliar environment of a Faraday cage, with participants wearing EEG caps and blood pressure recordings being made. We judged it as too difficult for meditation practitioners to comply with instructions for randomized states, and decided to use step-wise tasks.

Both groups were guided through each experimental state with identical instructions, pre-recorded in a voice participants were unfamiliar with. Meditators were known to be able to follow instructions due to their training and experience. Controls were asked in advance to follow instructions to the best of their ability. We had to make a choice between instructing controls sufficiently for them to be familiar with meditation, so potentially permitting the controls to meditate, and not giving any assistance, leaving the controls potentially perplexed. Our decision was to reassure controls that they should simply make the best of the instructions, viz, even though the instructions were for meditation, they could ignore the few unusual words and still follow the instruction.

Meditations were performed with the eyes closed. Instructions, listed in Table 1, were presented binaurally via pneumatic headphones with foam earplugs. Blood pressure was taken in the first six states only. The experiment described here was part of a larger study involving three other components. Always first, to avoid carry-on meditation effects, was an audiovisual continuous performance task (tasks-meditation-tasks, approx. 29 min). The mediation task, reported here, was then randomized with a perception experiment (approx. 11 min) and