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A neurocognitive model of meditation based on activation likelihood estimation (ALE) meta-analysis

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ABSTRACT

Meditation comprises a series of practices mainly developed in eastern cultures aiming at controlling emotions and enhancing attentional processes. Several authors proposed to divide meditation techniques in focused attention (FA) and open monitoring (OM) techniques. Previous studies have reported differences in brain networks underlying FA and OM. On the other hand common activations across different meditative practices have been reported. Despite differences between forms of meditation and their underlying cognitive processes, we propose that all meditative techniques could share a central process that would be supported by a core network for meditation since their general common goal is to induce relaxation, regulating attention and developing an attitude of detachment from one's own thoughts. To test this hypothesis, we conducted a quantitative meta-analysis based on activation likelihood estimation (ALE) of 10 neuroimaging studies (91 subjects) on different meditative techniques to evidence the core cortical network subserving meditation. We showed activation of basal ganglia (caudate body), limbic system (enthorinal cortex) and medial prefrontal cortex (MPFC). We discuss the functional role of these structures in meditation and we tentatively propose a neurocognitive model of meditation that could guide future research.

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1. Introduction

Following the classification of Davidson and Goleman (1977), meditative practices can be practically divided into focused-attention (FA) and open monitoring (OM). FA practices are based on the concentration of attention on a particular external, corporal or mental object while ignoring all irrelevant stimuli. At the opposite, OM techniques try to enlarge the attentional focus to all incoming sensations, emotions and thoughts from moment to moment without focusing on any of them (Lutz, Slagter, Dunne, & Davidson, 2008). Meditative schools can be placed on a continuum between these two poles (Andersen, 2000; Wallace, 1999) and most of them use both types of practices complementarily.

Recently Travis and Shear (2010) have classified meditation techniques according to electrophysiological correlates reported across several studies. The authors reported that FA techniques are characterized by a power increase in high frequencies (beta2 and gamma) since power increase in this domain is often associated with focused attention and awareness (Tallon-Baudry, 2009; Vidal, Chaumon, O'Regan, & Tallon-Baudry, 2006; Wyart & Tallon-Baudry, 2008). OM techniques are associated with increased theta activity as this reflects monitoring of inner processes and self referential processing

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(Mu & Han, 2010; Vinogradova, 2001). Finally, they found that some meditative practices are characterized by increased alpha power and coherence reflecting a diminished cognitive control. Accordingly, they proposed to add to FA and OM a third category of meditative practices called automatic self-transcending (AST) mainly comprising transcendental meditation (TM). This state of meditation would be characterized by the absence of a focus of attention, individual control and effort.

The hypothesis that different meditative techniques are subserved by different cognitive processes and in consequence recruit different brain structures has been also explored with neuroimaging techniques. For example, Lou and colleagues (1999) showed that FA on different objects of meditation (bodily sensation, sense of joy, imagery of landscape or symbolic representation of the self) activated slightly different networks. Manna et al. (2010) directly compared FA and OM meditation on the same subjects reporting large differences in the brain regions supporting the two meditative techniques. In particular OM, when compared with FA, activated lateral prefrontal regions. Differences between two different meditative techniques (mantra repetition and breath-based, the former defined as FA and the latter as not FA by the authors), were also recently reported (Wang et al., 2011). The authors showed that the breath-based technique activated to a greater extent limbic structures (hippocampus, parahippocampus and amygdala), insula and lateral frontal areas, while mantra repetition was more associated with activations in the precentral gyrus, parietal cortex and medial frontal gyrus.

Despite differences between forms of meditation and their underlying cognitive processes and brain networks, most of meditative traditions could have a general common goal of regulating attention and developing an attitude of detachment from one's own thoughts, thus a common mechanism representing the core of all meditative practices could be hypothesized. Indeed, with practice, meditation could become a highly automatic and effortless process (Lutz et al., 2008), and as stated by Newberg and Iverson (2003, p. 283): "Phenomenological analysis suggests that the end results of many practices of meditation are similar, although these results might be described using different characteristics depending on the culture and individual. Therefore, it seems reasonable that while the initial neurophysiological activation occurring during any given practice may differ, there should eventually be a convergence". This hypothesis is supported by neuroimaging findings reporting common activations, tested by conjunction analysis, between two kinds of meditation (mantra-based and breath-based) in the left insula and inferior frontal cortex (Wang et al., 2011).

The goal of this paper was to test if there are consistent activations across studies independently of the meditative technique that could represent a core cortical network for meditation. With this aim we conducted a whole brain quantitative meta-analysis based on activation likelihood estimation (ALE) (Laird et al., 2005; Turkeltaub, Eden, Jones, & Zeffiro, 2002) which allows the integration of results across available neuroimaging studies. We made the hypothesis that if different meditative techniques share cognitive mechanisms central for meditation, areas supporting these processes should emerge from our meta-analysis.

2. Materials and methods

2.1. Studies selection

Articles were initially identified by searching on-line databases (PubMed, PsychInfo, and Web of sciences) for English-language manuscripts of neuroimaging studies published till January 2011. The search keywords were "meditation", "brain imaging", "neuroimaging", "fMRI", "PET", "SPECT". In addition, we used the "related articles" function on PubMed to identify additional papers. This search revealed 29 papers.

Between these papers we included in our analysis only studies that responded to the following criteria:

1. Involved healthy adults (28 out of the 29 studies met this criterion).
2. Reported results of whole-brain analyses as coordinates in a standard reference space (Talairach/Tournoux, MNI), papers reporting only ROI analyses or not reporting activations coordinates were excluded (20 out of the 28 studies met this criterion).
3. Reported results for expert meditators. Studies that included a control group of *naïve* meditators were also included if they reported results separately for the two groups, while studies only reporting between groups comparisons were not taken into account (14 out of the 20 studies met this criterion).
4. Assessed brain correlates of meditation by comparing a meditation condition with a rest or control condition. Studies that delivered sensory stimulation (e.g.: visual, auditory or tactile) or assessed perceptual or cognitive correlates during a meditative state were excluded (10 out of the 14 studies met this criterion).

Following our inclusion criteria 10 studies (8 fMRI, 1 PET, and 1 SPECT) were included in the meta-analysis for a total of 91 subjects. An overview of studies and contrasts included is provided in Table 1.

All foci were accepted when reported as significant according to the criteria designated in each individual study (only activated foci were considered, deactivations were not taken into account). Coordinates originally published in MNI space were converted to Talairach space using the Lancaster transformation (Lancaster et al., 2007).

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