Neuroscience and Biobehavioral Reviews 65 (2016) 208–228

Contents lists available at ScienceDirect

Neuroscience and Biobehavioral Reviews

journal homepage: www.elsevier.com/locate/neubiorev

Review article

Functional neuroanatomy of meditation: A review and meta-analysis of 78 functional neuroimaging investigations

Kieran C.R. Fox[a,*], Matthew L. Dixon[a], Savannah Nijeboer[a], Manesh Girn[a], James L. Floman[b], Michael Lifshitz[c], Melissa Ellamil[d], Peter Sedlmeier[e], Kalina Christoff[a,f]

[a] Department of Psychology, University of British Columbia, 2136 West Mall, Vancouver, B.C., V6T 1Z4, Canada
[b] Department of Educational and Counselling Psychology, and Special Education, University of British Columbia, 2125 Main Mall, Vancouver, B.C., V6T 1Z4, Canada
[c] Integrated Program in Neuroscience, McGill University, 3775 University St., Montreal, QC, H3A 2B4, Canada
[d] Neuroanatomy and Connectivity Research Group, Max Planck Institute for Human Cognitive and Brain Sciences, Stephanstrasse 1a, Leipzig, 04103, Germany
[e] Institut für Psychologie, Technische Universität Chemnitz, 43 Wilhelm-Raabe Street, Chemnitz, Germany
[f] Brain Research Centre, University of British Columbia, 2211 Wesbrook Mall, Vancouver, B.C., V6T 2B5, Canada

ARTICLE INFO

Article history:
Received 7 October 2015
Received in revised form 25 February 2016
Accepted 1 March 2016
Available online 28 March 2016

Keywords:
Meditation
Open monitoring
Focused attention
Functional magnetic resonance imaging
Meta-analysis
Activation likelihood estimation

ABSTRACT

Meditation is a family of mental practices that encompasses a wide array of techniques employing distinctive mental strategies. We systematically reviewed 78 functional neuroimaging (fMRI and PET) studies of meditation, and used activation likelihood estimation to meta-analyze 257 peak foci from 31 experiments involving 527 participants. We found reliably dissociable patterns of brain activation and deactivation for four common styles of meditation (focused attention, mantra recitation, open monitoring, and compassion/loving-kindness), and suggestive differences for three others (visualization, sense-withdrawal, and non-dual awareness practices). Overall, dissociable activation patterns are congruent with the psychological and behavioral aims of each practice. Some brain areas are recruited consistently across multiple techniques—including insula, pre/supplementary motor cortices, dorsal anterior cingulate cortex, and frontopolar cortex—but convergence is the exception rather than the rule. A preliminary effect-size meta-analysis found medium effects for both activations ($d = 0.59$) and deactivations ($d = -0.74$), suggesting potential practical significance. Our meta-analysis supports the neurophysiological dissociability of meditation practices, but also raises many methodological concerns and suggests avenues for future research.

Contents

* Corresponding author.
E-mail address: kfox@psych.ubc.ca (K.C.R. Fox).

http://dx.doi.org/10.1016/j.neubiorev.2016.03.021
0149-7634/

1. Introduction

Meditation has been used as a tool to train the mind for thousands of years (Analayo, 2003; Iyengar, 2005). Broadly speaking, meditation practices involve the monitoring and regulation of attention and emotion (Lutz et al., 2008b; Tang et al., 2015). Meditation can be either directed outward to particular objects and sensory stimuli or turned inward to the workings of the mind and felt experiences of the body. A common principle across all forms of meditation is that through specific and regular practice, the ability to monitor and regulate mental-physical processes can be progressively developed—the way performance on any other cognitive or motor skill can be improved with practice (Ericsson et al., 1993; Slagter et al., 2011; Vago, 2014). Interest in the neural basis of meditative practices has increased enormously over the past decade, and mounting empirical evidence suggests that meditation indeed leads to or is associated with significant changes in cognitive and affective processing (Sedlmeier et al., 2012), as well as alterations in brain structure (Fox et al., 2014) and function (Cahn and Polich, 2006).

Although meditative practices now garner serious interest from the cognitive neuroscience community (Fig. 1), meditation still tends to be viewed as a somewhat uniform practice (e.g., Sperduti et al., 2012). The umbrella-term 'meditation' encompasses a wide variety of distinct practices with specific goals and methods, however. The varying methods and scope of particular forms of meditation include focalizing and sustaining attention (Wallace, 2006), generating and maintaining complex visual imagery (Kozhevnikov et al., 2009), improving emotion regu-