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Review article

The embodied mind: A review on functional genomic and neurological correlates of mind-body therapies

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ABSTRACT

A broad range of mind-body therapies (MBTs) are used by the public today, and a growing body of clinical and basic sciences research has resulted in evidence-based integration of many MBTs into clinical practice. Basic sciences research has identified some of the physiological correlates of MBT practices, leading to a better understanding of the processes by which emotional, cognitive and psychosocial factors can influence health outcomes and well-being. In particular, results from functional genomics and neuroimaging describe some of the processes involved in the mind-body connection and how these can influence health outcomes. Functional genomic and neurophysiological correlates of MBTs are reviewed, detailing studies showing changes in sympathetic nervous system activation of gene transcription factors involved in immune function and inflammation, electroencephalographic and neuroimaging studies on MBT practices, and persistent changes in neural function and morphology associated with these practices. While the broad diversity of study designs and MBTs studied presents a patchwork of results requiring further validation through replication and longitudinal studies, clear themes emerge for MBTs as immunomodulatory, with effects on leukocyte transcription and function related to inflammatory and innate immune responses, and neuromodulatory, with effects on brain function and morphology relevant for attention, learning, and emotion regulation. By detailing the potential mechanisms of action by which MBTs may influence health outcomes, the data generated by these studies have contributed significantly towards a better understanding of the biological mechanisms underlying MBTs.

Contents

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1. Introduction—physiological correlates of mind-Body therapies

The scope of mind-body therapies (MBTs) used by the public today is broad, and generally includes meditation, yoga, guided imagery, breathing exercises, progressive relaxation, Tai Chi Chuan, etc. (National Institutes of Health, 2007). Over the past several decades, substantial evidence has emerged that MBTs can enhance health outcomes, act as effective adjuncts to conventional medical treatment (Astin et al., 2003) and be effectively integrated into an evolving mainstream medical paradigm, referred to as "Integrative Medicine" (Giordano et al., 2002). In the most recent decade, a marked increase in clinical data has permitted literature reviews and meta-analyses of clinical trials, resulting in evidence-based integration of MBTs into clinical practice for the treatment of specific pathologies and recommendation of MBTs as preventative strategies for maintaining wellness (Ernst et al., 2007; Jonas et al., 2013).

Emotional, cognitive and psychosocial factors have been shown to significantly affect health outcomes (Cacioppo and Cacioppo, 2014; Cohen et al., 2007; Umberson and Montez, 2010), and the physiological correlates are becoming more clearly elucidated (Swaab et al., 2005). A cross-sectional study showed that high vs. low mindfulness was associated with improvements in markers of cardiovascular health, including smoking, body mass index, fasting glucose and physical activity (Loucks et al., 2015). Other studies using data from large-scale US health surveys have reported that psychosocial factors are correlated with multiple inflammatory markers in the blood (Loucks et al., 2006; Yang et al., 2013), including C-reactive protein, interleukin-6, fibrinogen, E-selectin, and intercellular adhesion molecule-1 (Yang et al., 2014). Notably, these studies used data from large databases of n = 3267 individuals (Loucks et al., 2015), n = 6729 (Yang et al., 2013), n = 647 (Yang et al., 2014) and n = 382 (Loucks et al., 2015), suggesting that psychosocial factors are linked with these inflammatory markers in the population at large.

While a broad range of data from diverse scientific disciplines has led to substantial progress in elucidating some of the general themes for biological substrates of MBT practices (Kuntsevich et al., 2010), here we provide a summary of studies reporting functional genomic and neurophysiological correlates of MBTs. Functional genomics and neurophysiology have provided key data on changes in gene expression and central nervous system function associated with MBT practices. These data provide clear indications for several biological substrates that may underlie MBTs, and contribute important foundations for a developing theory of MBTs and its applications to clinical pathology and preventative health. One challenge for interpreting these results is the large variety of MBT practices employed in different studies, which may be unfamiliar to some readers. For reference, the reader is referred to reviews on the scope of MBTs (National Institutes of Health, 2007) and the varieties of meditation practices (Travis and Shear, 2010).

Of central importance to interpreting results from functional genomics, developments in *psychosocial genomics* have demonstrated the relevance of psychosocial factors in gene expression (Cole 2014; Slavich and Irwin 2014), and identified some underlying processes, such as sympathetic nervous system activation of gene transcription factors (Cole, 2010; Cole et al., 2015; Slavich and Irwin, 2014). This growing body of data showing functional genomic correlates of stress and subjective emotional states has contributed to elucidating the mechanisms underlying many MBTs. Below, these functional genomic links with MBT practices are reviewed, and some of the mechanisms by which these techniques function (illustrated in Fig. 1), with particular emphasis on their role in alleviating the effects of psychological stress.

The data demonstrating neurophysiological correlates of MBTs is also surveyed, including the brain's response to different styles of practice and observations of persistent changes in neural function and morphology associated with these practices. In recent years, advances in neuroimaging and methods of neurophysiology have led to a clearer understanding of neuroanatomy and functions associated with higher-level brain functions such as emotional affect, attention, and diverse forms of cognition. Of particular relevance to MBTs, neuroimaging data has shed light on the influence of emotion on cognition, and vice versa, leading to a conception of mind wherein this interrelationship is of primary functional importance (Dolcos et al., 2011). Relatedly, because brain networks involved in attention, learning, cognition and emotional regulation are susceptible to neuromodulation, these may be important mechanisms by which cognitive and stress-reducing interventions influence behavioral development over the lifespan (Li 2013). These findings from the neurosciences, coupled with results from psychosocial genomics, have produced a much clearer conception of some of the specific means by which emotional, cognitive and psychosocial factors can influence central nervous system structure and function (Garland and Howard 2009).

2. Stress and gene expression

2.1. Social stress and inflammation

A large and growing body of research has elucidated some of the mechanisms involved in cellular responses to psychosocial stress and emotional factors. Human and animal studies have shown that noradrenaline-dependent adrenergic stimulation due to psychosocial stress results in activation of the nuclear factor kappa light chain enhancer of activated B cells (NF-κB) protein complex, which controls genes expressed during inflammation (Bierhaus et al., 2003; Slavich and Irwin, 2014; Wolf et al., 2009). Similar results have been observed for social stressors also: DNA microarray analysis of circulating leukocytes (white blood cells involved in immune response) from high-loneliness vs. low-loneliness individuals showed genome-wide differences in gene expression activity, including over-expression of genes responsive to NF-κB transcription factors and reduced expression of transcripts bearing anti-inflammatory response elements for glucocorticoids (steroid hormones involved in innate immunity) (Cole et al., 2007). Several other gene expression control pathways were also affected in this study, including the inflammation-related glucocorticoid receptor, JAK-STAT signaling pathway (transmits extracellular chemical