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Effects of non-pharmacological pain treatments on brain states

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HIGHLIGHTS

- This is the first study to examine, in the same sample, the effects of hypnosis, meditation, transcranial direct current stimulation (tDCS), and neurofeedback on pain and brain oscillations, relative to a control procedure.
- Each procedure resulted in oscillation changes that differed from the control procedure and from each other, suggesting different modes of action on brain activity.
- Changes in pain intensity associated with the procedures were not, however, significantly associated with changes in brain oscillations, suggesting that brain activity measures used in this study do not reflect pain intensity.

ABSTRACT

Objective: To (1) evaluate the effects of a single session of four non-pharmacological pain interventions, relative to a sham tDCS procedure, on pain and electroencephalogram- (EEG-) assessed brain oscillations, and (2) determine the extent to which procedure-related changes in pain intensity are associated with changes in brain oscillations.
Methods: 30 individuals with spinal cord injury and chronic pain were given an EEG and administered measures of pain before and after five procedures (hypnosis, meditation, transcranial direct current stimulation [tDCS], neurofeedback, and a control sham tDCS procedure).
Results: Each procedure was associated with a different pattern of changes in brain activity, and all active procedures were significantly different from the control procedure in at least three bandwidths. Very weak and mostly non-significant associations were found between changes in EEG-assessed brain activity and pain.
Conclusions: Different non-pharmacological pain treatments have distinctive effects on brain oscillation patterns. However, changes in EEG-assessed brain oscillations are not significantly associated with changes in pain, and therefore such changes do not appear useful for explaining the benefits of these treatments.
Significance: The results provide new findings regarding the unique effects of four non-pharmacological treatments on pain and brain activity.

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1. Introduction

Despite the important advances in our scientific understanding of pain and its causes, chronic pain remains a significant health problem worldwide with profound negative impacts on individuals and society (Institute of Medicine Committee on Advancing Pain Research Care and Education, 2011; Nakamura et al., 2011; Reid et al., 2011; Schopflocher et al., 2011). Models of pain popular in the 20th century and earlier focused on peripheral activity. However, research in the late 20th and early 21st centuries has established CNS structures as playing a key role in the development and experience of chronic pain (Apkarian et al.,2009; Jensen, 2010). We now know that while nociception (information about damage or potential damage sent to the CNS from the periphery) plays a role in some chronic pain problems, nociception is neither necessary nor sufficient for someone to experience pain. Rather, pain is now recognized to be the result of a complex interaction of activity in multiple cortical–subcortical neural networks and processes (Jensen, 2010). Research has also demonstrated that central neural networks are plastic: ongoing activation of pain-related central networks can lead to changes in these networks, consolidating and thus facilitating pain processing even independent of peripheral neural activation (Gustin et al., 2012). This growing recognition of the importance of CNS among pain researchers and clinicians has contributed to a concomitant interest in interventions – many of them non-pharmacological – that directly or indirectly target cortical or subcortical activity as ways to manage pain (Moseley and Flor, 2012).

Interventions that target CNS activity include hypnosis, electroencephalographic (EEG) biofeedback (also known as neurofeedback), meditation training and practice, and transcranial direct current stimulation (tDCS). However, the extent to which these treatments operate via their effects on CNS activity and whether these CNS effects are similar or different across treatments has not yet been elucidated.

At its most basic, hypnosis can be viewed as having two components: (1) a hypnotic induction (“...initial suggestions for using one’s imagination”; p. 262, Green et al., 2005) followed by (2) “...suggestions for changes in subjective experience, alterations in perception, sensation, thought, or behavior” (p. 262, Green et al., 2005). Although treatment response to suggestions without a formal hypnotic induction is possible, research indicates that responses to suggestions are stronger when a hypnotic induction is part of the procedure (Derbyshire et al., 2004). As might be expected, hypnotic treatments for chronic pain usually include suggestions for experiencing reductions in pain intensity or increases in the ability to ignore pain. In addition, hypnotic pain treatment often also includes suggestions for changes in pain-related thoughts and behaviors (Jensen et al., 2011; Patterson and Jensen, 2003).

In neurofeedback, subjects are given direct information about their brain states – usually as measured by EEG – and asked to use this information to directly alter brain activity thought to be related to specific behaviors (e.g. pain; Jensen et al., 2007a; Sime, 2004).

Meditation may be the most difficult non-pharmacological intervention to define, given the many procedures and activities that have been described as meditation. However, most of these can be classified into two primary types: (1) “mindfulness” meditation (paying attention to one’s current experience in a nonjudgmental way; Carmody, 2009) and (2) “concentration” meditation (purposeful concentration on a single stimulus, such as one’s breathing or a single word or phrase; Dunn et al., 1999).

tDCS involves the application of weak electrical direct currents (1–2 mA) over the scalp using usually two electrodes – a positive anode electrode and a negative cathode electrode. In pain, the most common electrode montage consists of placing the anode electrode over the primary motor cortex and the cathode electrode over the supra-orbital area (Fregni et al., 2006). tDCS has been shown to provide a sufficient amount of electrical current to reach cortical areas and modify cortical excitability (Brunoni et al., 2012; Wagner et al., 2007).

Evidence supports the clinical efficacy of hypnosis for reducing chronic pain intensity (Jensen and Patterson, 2006; Patterson and Jensen, 2003). Preliminary evidence also supports the potential for neurofeedback (Caro and Winter, 2011; Kayiran et al., 2010), meditation practice (Marchand, 2012; Zeidan et al., 2011), and tDCS (Fenton et al., 2009; Fregni et al., 2006) for reducing chronic pain intensity. Importantly, research findings from a number of sources suggest the possibility that these treatments might be effective, at least in part, because they alter brain states. Moreover, these cortical changes may be reflected in oscillatory cortical electrical wave activity that can be measured by EEG. For example, both acute and chronic pain studies have shown reproducible changes of increased “fast” (beta [13–35 Hz]) brainwave activity thought to be related to active information processing, and reduced “slow” (mostly alpha [8–12 Hz], but also in some studies, theta [4–7.5 Hz]) brain activity associated with subjective relaxation (e.g., Bromm and Lorenz, 1998; Chen et al., 1983). Interestingly, hypnosis and meditation have been shown to increase slow wave activity, especially theta activity (Crawford, 1990; Fell et al., 2010; Williams and Gruzelier, 2001). Further, neurofeedback for pain treatment commonly seeks to reduce fast wave and increase slower wave activity (Jensen et al., 2007a; Sime, 2004). Based on these findings, it would be reasonable to hypothesize that increases in slower wave activity (e.g., theta and alpha) and decreases of faster wave activity (e.g., beta) would be associated with reductions in pain intensity.

Although non-pharmacological interventions theoretically reduce pain by altering brain activity, no studies have performed head-to-head comparisons of the effects of these treatments on brain activity. Nor have any studies examined associations between cortical effects of different treatments and treatment-related changes in pain intensity in the same sample. Increased knowledge about the effects of these treatments on EEG and the associations between changes in EEG activity and changes in pain is important for a number of reasons. First, although each of these treatments appears on the surface to be different, it is possible that they share common underlying mechanisms for reducing pain. For example, it is possible that all of these treatments effectively reduce pain via altering activities associated with reduced fast wave and/or increased slow wave EEG activity. If this were found to be the case, then future research could determine which of these treatments (or which combination(s) of treatments) might work to produce the most profound and longest lasting effects on those EEG bandwidths that are most closely linked to pain relief. On the other hand, if each of these treatments has different effects on brain activity, this would suggest that they operate via different mechanisms. In this case, it is possible that treatments might at times act at odds with each other, and maximizing treatment efficacy may involve matching patients to treatments most effective for their particular condition. Alternatively, different mechanisms of action might be combined synergistically. Such an approach has been shown effective for the combination of noninvasive brain stimulation and antidepressants for the treatment of depression (Brunoni et al., in press).

Given these considerations, the primary purposes of this study were to: (1) determine the effects of a single session of hypnosis, neurofeedback, tDCS, and a concentration meditation procedure on EEG-assessed bandwidth activity, relative to a sham (placebo) tDCS procedure; (2) compare the efficacy of each procedure for reducing pain intensity in a sample of patients with chronic pain