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Review

The self-regulating brain and neurofeedback: Experimental science and clinical promise

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ABSTRACT

Neurofeedback, one of the primary examples of self-regulation, designates a collection of techniques that train the brain and help to improve its function. Since coming on the scene in the 1960s, electroencephalography-neurofeedback has become a treatment vehicle for a host of mental disorders; however, its clinical effectiveness remains controversial. Modern imaging technologies of the living human brain (e.g., real-time functional magnetic resonance imaging) and increasingly rigorous research protocols that utilize such methodologies begin to shed light on the underlying mechanisms that may facilitate more effective clinical applications. In this paper we focus on recent technological advances in the field of human brain imaging and discuss how these modern methods may influence the field of neurofeedback. Toward this end, we outline the state of the evidence and sketch out future directions to further explore the potential merits of this contentious therapeutic prospect.

1. Introduction

Neurofeedback refers to a self-regulation technique that provides the individual with feedback about specific brain activity in connection with a related behavior. The underlying assumption at the core of this practice posits that through this type of feedback one can entrain, change, and regulate neural activity. This trend appeals to both researchers and practitioners, who wish to understand the neurobiological mechanisms as well as the therapeutic potential this approach may offer. Beyond electroencephalography (EEG), the advent of modern real-time brain imaging technology elucidates the time-course and location of brain activity and seems to open the road to new prospects, including the modulation of seemingly volitionless neural functions (Fig. 1). And yet, imaging-based neurofeedback has hardly transitioned from the cognitive neuroscience lab into the clinical trenches. In this paper we highlight the relative merits and current shortcomings of neurofeedback in the context of contemporary imaging technologies. We discuss how new modalities of brain imaging may provide a future trajectory to consider meaningful research resulting in potential inclusion in the clinical armamentarium.

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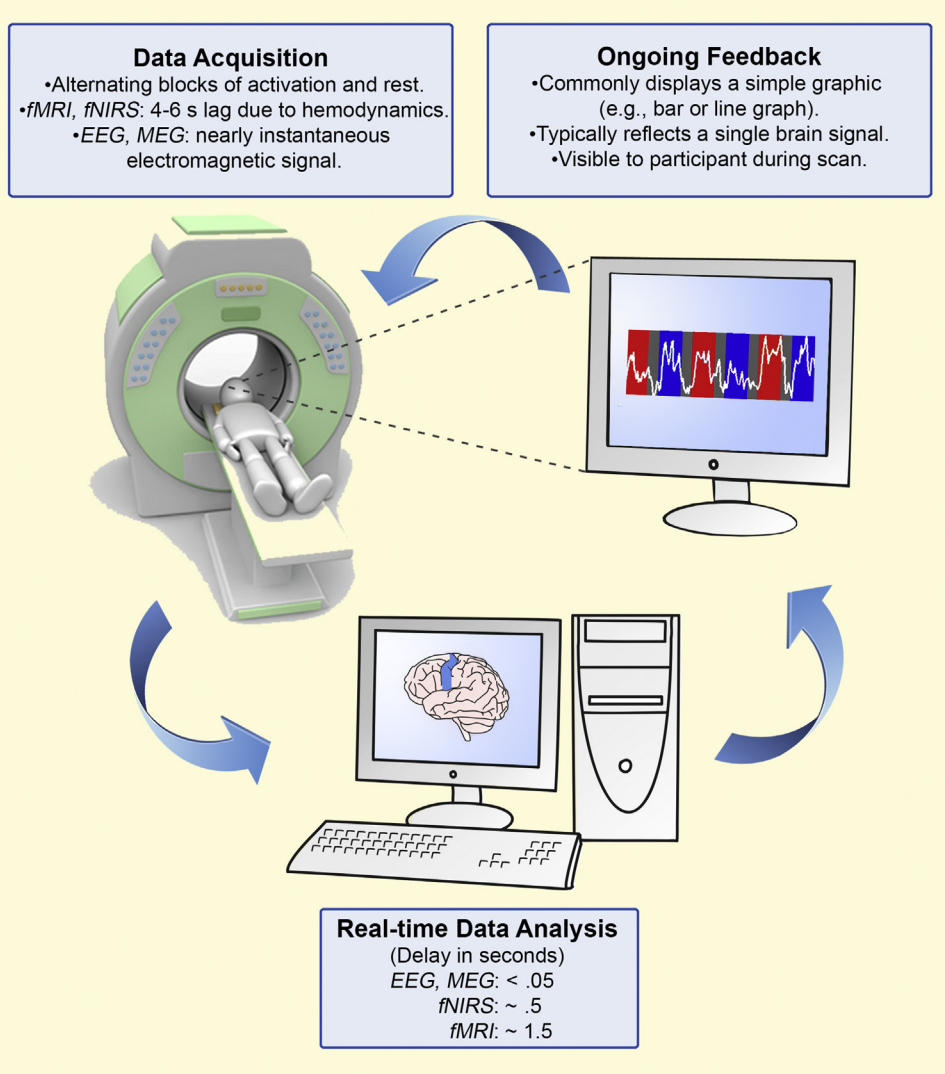

Fig. 1 – A conceptual diagram depicting rtfMRI-nf of the left primary motor cortex.

An evolutionary derivative of biofeedback, in the 1960s neurofeedback emerged to employ neural feedback via EEG (Kamiya, 2011). To this day, specialty clinics and private institutions continue to offer variations on EEG neurofeedback (EEG-nf) for an array of disorders and impairments, although this intervention has been largely dismissed as placebo-driven (see next section). Beyond EEG-nf, the advent of new technologies for imaging the living human brain has vastly expanded the scope of neurofeedback, which today includes more novel methods such as functional magnetic resonance imaging (fMRI), functional near infrared spectroscopy (fNIRS), and magnetoencephalography (MEG) (TIMELINE and Table 1). Thus, current-day neurofeedback draws on diverse imaging methods to help drive volitional control over electromagnetic and hemodynamic alterations in brain activity (Cannon, 2015; Hammond, 2011; Thibault, Lifshitz, Birbaumer, & Raz, 2015). Within each imaging modality, moreover, researchers have developed distinct neurofeedback protocols that target different brain signals and their concomitant physiological processes (Hammond, 2011; Sulzer, Haller, et al., 2013). Whereas proponents of neurofeedback sometimes lump together these diverse protocols, research findings support some imaging techniques more than others. In this paper we explore the potential merits and shortcomings of modern neurofeedback techniques and contextualize their place in the current technological landscape.

2. EEG neurofeedback

More than half-a-century ago neurofeedback came on the scene promoting the main non-invasive technology of the day, EEG, to "image" the living human brain. Although EEG-nf may still hold some appeal as an alternative to conventional medical treatment, mounting evidence refutes the clinical superiority of feedback training over sham treatment (Arnold et al., 2013; Esmail & Linden, 2014; Lansbergen et al., 2011; Lofthouse, Arnold, Hersch, Hurt, & DeBeus, 2012; Logeman, Lansbergen, van Os, Bocker, & Kenemans, 2010; Perreau-