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Review

The covariation of independent and dependant variables in neurofeedback: A proposal framework to identify cognitive processes and brain activity variables

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ABSTRACT

This methodological article proposes a framework for analysing the relationship between cognitive processes and brain activity using variables measured by neurofeedback (NF) carried out by functional Magnetic Resonance Imagery (fMRI NF). Cognitive processes and brain activity variables can be analysed as either the dependant variable or the independent variable. Firstly, we propose two traditional approaches, defined in the article as the "neuropsychological" approach (NP) and the "psychophysiology" approach (PP), to extract dependent and independent variables in NF protocols. Secondly, we suggest that NF can be inspired by the style of inquiry used in neurophenomenology. fMRI NF allows participants to experiment with his or her own cognitive processes and their effects on brain region of interest (ROI) activations simultaneously. Thus, we suggest that fMRI NF could be improved by implementing "the elicitation interview method", which allows the investigator to gather relevant verbatim from participants' introspection on subjective experiences.

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1. Introduction

The techniques of biofeedback allow a participant to train him or herself to self-regulate a physiological function which is usually neither visible nor consciously controlled (Coben & Evans, 2011). A physiological parameter related to the function in question is measured and processed by a technical interface, thus providing the participant with continuous, real-time information («feedback»). This information, usually in visual or auditory form, enables the participant to control the relevant biological activity («bio»-feedback). Changes made in the desired direction are rewarded and, as a consequence, positively reinforced. Those biofeedback techniques using a single measure of brain activity are referred to as neurofeedback (NF) (Coben & Evans, 2011; Frederick, 2012). In NF protocols, the participant observes his or her own brain activity and develops cognitive strategies to modify this activity in desired directions (Kotchoubey, Kubler, Strehl, Flor, & Birbaumer, 2002). Thus, NF is a technical way to integrate cognitive processes and brain activity (Micoulaud-Franchi, Fond, & Dumas, 2013). Although NF does tackle the critical question of dualism or monism in neuroscience, our aim was not to analyse this question from a philosophical or ontological point of view. Indeed, this question is still the subject of much discussion among neuroscientists and philosophers and, at present, remains moot. Therefore, we prefer to focus our analysis on the question of the covariation of cognitive processes and brain activity by dissecting the variables measured during NF processing. Thus, our approach is based strictly on a methodological point of view. Since the development of NF by means of functional Magnetic Resonance Imagery (fMRI NF), brain activity can be regulated with a much higher spatial resolution than was previously possible by NF by means of scalp-level electroencephalography (EEG NF) (Johnston, Boehm, Healy, Goebel, & Linden, 2010; Ruiz, Buyukturkoglu, Rana, Birbaumer, & Sitaram, 2013). Thus the framework we propose here uses fMRI NF (Weiskopf et al., 2004).

2. Traditional approaches and hypothetical constructs

In NF protocols, we propose a framework to identify dependent (DV, i.e. the variables measured in a given protocol) and independent variables (IV, i.e. the variables controlled in a given protocol that is related to the measured variations of DV). The proposal framework takes into account the "neuropsychological" approach and "psychophysiological" approach, which are two traditional approaches to studying the relation between cognitive processes and brain activity (Cacioppo, Tassinary, & Berntson, 2007; Sitaram et al., 2007; Uttal, 2001).

Neuropsychological approach (NP) has traditionally been used in brain lesion studies analysing the structure and function of the brain as they relate to specific cognitive activities (Uttal, 2001). We suggest that, in NP, cognitive processes are the dependent variables (DV) of brain lesions or stimulations (which are, thus, the independent variables, IV).

Psychophysiological approach (PP) is generally applied in studies of intact human brain to analyse cognitive activities as they relate to brain activities (Cacioppo et al., 2007) and is a standard approach in fMRI (Cacioppo et al., 2007; Schneider, Backes, & Mathiak, 2009; Weiskopf et al., 2003). We propose that PP involves studying the neurophysiological brain outcomes as the dependent variables of the cognitive activity (IV) (see Fig. 1A and B).

In these two approaches (NP and PP) an experimental intermediary is required; the relationship between the DV and the IV is mediated by a set of intermediate or mediating variables. Cognitive processes can only be assayed indirectly using behavioural measures (Uttal, 2001). "How we measure in large part determines what we measure – or, perhaps more precisely, what we think we are measuring" (Uttal, 2001). Thus, cognitive processes are hypothetical constructs that depend on the design of the cognitive tasks. The existence of the process in question is, therefore, confirmed by the task since this task was created for the very purpose of defining it (Uttal, 2001). The experimenter, being removed from the cognitive task, ensures, "externally", that a controlled theoretical model is being applied.

In NP, the behavioural responses (second order dependent variables: DV2NP) following the cognitive tasks (independent variables, IV2NP) are considered resulting from the cognitive anomalies (first order dependent variables: DV1NP) caused by lesions or brain stimulations (independent variables, IV1NP) (Fig. 1A).

In PP, the fMRI BOLD activity (which reflects brain activity indirectly) constitutes a second order dependent variable (DV2PP) of cognitive processes/activity (Fig. 1B). The particular cognitive process that one wishes to study is obtained by prescribing a specific cognitive task and using appropriate behavioural measures that ensure that the cognitive process of interest is isolated. As shown in Fig. 1B, the experimenter is charged with ensuring that the relation between the cognitive task, IV1PP (the stimulus), and the cognitive process, DV1PP (a first order dependent variable) is achieved. The DV1PP, in turn, becomes the independent variable, IV2PP, related to the brain activity dependant variable (DV2PP).

Because the relationship between the participant's cognitive processes and his or her brain activity is, effectively, reduced to a hypothetical construct that assists in the design of protocols, such procedures require an "externally" controlled theoretical model. We say that the theoretical model is "externally" controlled because the experimenter, who is "external" to the task, imposes the cognitive task. So we have the following situation. On the one hand, the cognitive task is designed