EDITORIAL

Neurofeedback: a challenge for integrative clinical neurophysiological studies

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In the article of Bismuth, Vialatte and Lefaucheur published in this issue of *Neurophysiologie Clinique/Clinical Neurophysiology*, the authors report the design of a single-center, single-blinded, randomized controlled study on neurofeedback [3]. Despite focusing on chronic neuropathic pain, the publication of this study protocol is a commendable initiative. Indeed, it highlights many of the important features that must be taken into account in order to inform the current debate on neurofeedback, through an integrative clinical neurophysiology standpoint.

Neurofeedback is a longstanding neurophysiological approach based on the fact that brain activity may be modulated by conditioning responses. This principle was first demonstrated through electroencephalographic (EEG) studies in the 1930s and 1940's. These studies investigated the EEG alpha blocking response [13], with the first study of Durup and Fessard at the *Laboratoire de Physiologie des Sensations* (*Collége de France*) [5], followed by the studies of Loomis in his laboratory at *Tuxedo Park* [14] and Jasper at the *Montreal Neurological Institute* (McGill University) [8]. The interest raised by these authors was not only in conditioning brain activity, but also in considering neurofeedback as a psychophysiological approach linking mental activities ("psycho-") and brain activities ("-physiology"). As noted by Durup and Fessard in their seminal work on the conditioning of the EEG alpha blocking response: "*l'attitude mentale du sujet intervient dans le déterminisme de la réaction d'arrêt"*[1] [5].

Subsequent studies in the 1960's confirmed that EEG alpha blocking could indeed be conditioned [12, 19] and that it was also possible to modulate brain activity through EEG and mental activities using neurofeedback, both in animals [26, 30] and humans [29]. This later finding paved the way for many therapeutic clinical applications dedicated to the reduction of mental symptoms and cognitive impairments induced by brain pathologies (for a review see [18]). These findings also form the basis of developments focussing on the reduction of functional limitations through rehabilitative procedures based on Brain-Computer Interface (BCI) technologies (for a review see [4]). Neurofeedback has thus attracted the attention of the clinical neurophysiological community [1, 2], Nonetheless, a debate regarding the mechanisms through which neurofeedback may benefit therapeutic procedures was initiated in the *Lancet Psychiatry* [17, 21, 27, 28, 34, 36] and spread to *Brain* [6, 23-25, 31, 32, 38], the *Journal of Attention Disorders* [20, 37], and *American Psychologist* [16, 33, 35]. In summary, the question is the following: does neurofeedback operate through a specific neurophysiological effect on the modulation of the targeted brain activity [16]? Indeed, many other mechanisms could be at play: patient's perceptions of self-efficacy, social reinforcement, or a general but non-specific cognitive training related to the environment of a neurofeedback session [16].

Such mechanisms most likely play a role in neurofeedback efficacy, insofar as a few recent studies did not find any superior effect of neurofeedback over sham neurofeedback (based on signal unrelated to the targeted brain activity) [25, 28]. Thus, other well-designed studies for neurofeedback are

[1] An English translation would be: *"the subject's mental attitude contributes to the occurrence of the blocking response"*

urgently needed: i) double blind randomized controlled trials (RCT) with consensual standards of reporting, but also ii) clinical neurophysiological relevance of the mechanism through which neurofeedback might have a therapeutic benefit [6, 16].

Concerning RCT, a recent checklist has been published in *Brain* [22]. The "*Consensus on the Reporting and Experimental Design of clinical and cognitive-behavioural Neurofeedback studies*" (CRED-nf) best practices checklist 2019 is intended to "*encourage robust experimental design and clear reporting for clinical and cognitive-behavioural neurofeedback experiments*" as a complement to the Consolidated Standards of Reporting Trials (CONSORT) guidelines. Clinical neurophysiologists can only encourage such an initiative, which could help to disentangle the different mechanisms underlying clinical efficacy of neurofeedback. Interestingly enough, the article of Bismuth, Vialatte and Lefaucheur satisfies almost all the design and reporting criteria from the CRED-nf checklist, which is not so common and thus worth noting. Only one reporting criteria appears to be missing: how the feedback was precisely designed and provided (e.g., information on the reward threshold, reward amount and frequency or the EEG-to-feedback mapping). Including such information would have made the protocol reporting even more commendable.

Nevertheless, concerning clinical neurophysiological relevance, we think that the article of Bismuth, Vialatte and Lefaucheur published in this issue helps to go a step further [3], and could be used in the iteration process of the improvement of the CRED-nf checklist. Indeed, all clinical interventions need a model (or theory) of change relevant to the field. Thus, design of neurofeedback protocols should be conducted in accordance with a model of change to demonstrate the causal connection between the constructs of the model and the observed clinical and neurophysiological changes.

For doing so, the first need for neurofeedback is to target a brain activity that is based on a relevant psychophysiological model. By psychophysiologically relevant, we mean that there should be scientific evidence of a clear relationship between the particular neurophysiological marker targeted by the neurofeedback and the cognitive process being studied. A recent "EEG-Copeia" for neurofeedback, such as the "Pharmacopeia" for psychopharmacology has been proposed [15]. An "EEG-Copeia" has been defined as "an organized list of scientifically validated EEG markers, characterized by a specific association with an identified cognitive process, that define a psychophysiological unit of analysis useful for mental or brain disorder evaluation and treatment" [15]. We think that the article of Bismuth, Vialatte and Lefaucheur is an emblematic example of this psychophysiological approach in the choice of the EEG target to relieve chronic neuropathic pain in patients with painful peripheral neuropathy.

The second need for neurofeedback is to base evaluation of the psychosocial factors and mental strategies (Items 3a, 3b, 3c of the CRED-nf [22]) on an explicit learning model during neurofeedback. A recent review of the different learning models in behavioral, developmental and cognitive psychology of the feedback learning processes has been proposed [7]. Despite the fact that there is no consensus on the best learning model for neurofeedback, neurofeedback protocols should

attempt to investigate the variables that could be relevant from a clinical neurophysiological standpoint within an integrated model. Two recent integrated models have been proposed: the psychoengineering model [7] and a cognitive model inspired by BCI research [10], which could be very useful for the field of neurofeedback research [9, 11]. We think that the choice of metric of psychosocial factors and mental strategies in the article of Bismuth, Vialatte and Lefaucheur is also an emblematic example of evaluation grounded in a learning model that enables us to rigorously consider the interests and challenges but also the perils and pitfalls of neurofeedback. Indeed, since the claim of Durup and Fessard, this encourages development of integrative clinical neurophysiology approaches to face "*l'attitude mentale du sujet / the subject's mental attitude*" in a study protocol.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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