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The Psychology of Neurofeedback: Clinical Intervention Even if Applied Placebo

The Psychology of Neurofeedback:

Clinical Intervention even if Applied Placebo

(Running head: NEUROFEEDBACK: CLINICAL INTERVENTION, APPLIED PLACEBO)

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ABSTRACT

Advocates of neurofeedback make bold claims concerning brain regulation, treatment of disorders, and mental health. Decades of research and thousands of peer-reviewed publications support neurofeedback using electroencephalography (EEG-nf); yet, few experiments isolate the act of receiving feedback from a specific brain signal as a necessary precursor to obtain the purported benefits. Moreover, while psychosocial parameters including participant motivation and expectation, rather than neurobiological substrates, seem to fuel clinical improvement across a wide range of disorders, for-profit clinics continue to sprout across North America and Europe. Here we highlight the tenuous evidence supporting EEG-nf and sketch out the weaknesses of this approach. We challenge classic arguments often articulated by proponents of EEG-nf and underscore how psychologists and mental health professionals stand to benefit from studying the ubiquitous placebo influences that likely drive these treatment outcomes.

Keywords: self-regulation; psychosocial influences; neurofeedback; EEG; placebo

DOES NEUROFEEDBACK REALLY WORK?

Whereas a large corpus of studies suggests that EEG-nf – the original and most widely practiced form of neurofeedback – constitutes an effective clinical intervention, applying this technique remains controversial, expensive, and time-consuming. In EEG-nf participants aim to self-regulate an ongoing feedback signal derived from electrical brain activity related to a specified behavior. As EEG-nf remains the only neurofeedback technique available to patients, we restrict our discussion to this putative treatment and forego discussing research surrounding fMRI-neurofeedback (see Thibault, Lifshitz, & Raz, 2016 for a survey of emerging neurofeedback modalities).

First employed to treat attention deficit hyperactivity disorder (ADHD) and epilepsy, some practitioners now leverage EEG-nf to rehabilitate motor skills, boost creativity, maximize cognitive performance, and treat a range of clinical disorders including depression, alcoholism, autism spectrum disorder, and insomnia. Discussion of the mechanisms subserving these supposed effects, however, remains mostly absent from published accounts (Zuberer, Brandeis, & Drechsler, 2015). Meanwhile, proponents of neurofeedback continue to tacitly attribute its alleged benefits to the cutting-edge process of receiving and modulating real-time neural data while often fallaciously presuming that sub-spectrums of electrical brain oscillations directly control single behaviors.

Intriguingly, EEG-nf appears to benefit participants regardless of the feedback source (Thibault, Lifshitz, Birbaumer, & Raz, 2015); sham neurofeedback – derived from an unrelated signal – treats clinical conditions as does veritable neurofeedback (Arnold et al., 2013; Esmail & Linden, 2014; Lansbergen, van Dongen-Boomsma, Buitelaar, & Slaats-Willemse, 2011;

Lofthouse, Arnold, Hersch, Hurt, & DeBeus, 2012; Logeman, Lansbergen, van Os, Bocker, & Kenemans, 2010; Perreau-Linck, Lessard, Lévesque, & Beauregard, 2010; Sonuga-Barke et al., 2013; Van Dongen-Boomsma, Vollebregt, Slaats-Willemse, & Buitelaar, 2013; Vollebregt, van Dongen-Boomsma, Buitelaar, & Slaats-Willemse, 2014; Vollebregt, van Dongen-Boomsma, Slaats-Willemse, & Buitelaar, 2014). Thus, placebo factors permeate EEG-nf and likely account for the majority of relevant experimental findings and clinical outcomes (Thibault & Raz, 2016b).

This state-of-affairs calls for a complementary research agenda aiming to better understand psychosocial factors and exploit such phenomena in a cost-effective and transparent manner. Here, we briefly overview relevant highlights from this research domain, point out the tenuous findings in support of EEG-nf, the specious logic that often prevails, and the conflicts of interest that abound. After arguing that EEG-nf may help certain symptoms – although through alternative mechanisms than those people commonly consider – we conclude with a few suggestions about how to enhance and maximize these clinical benefits.

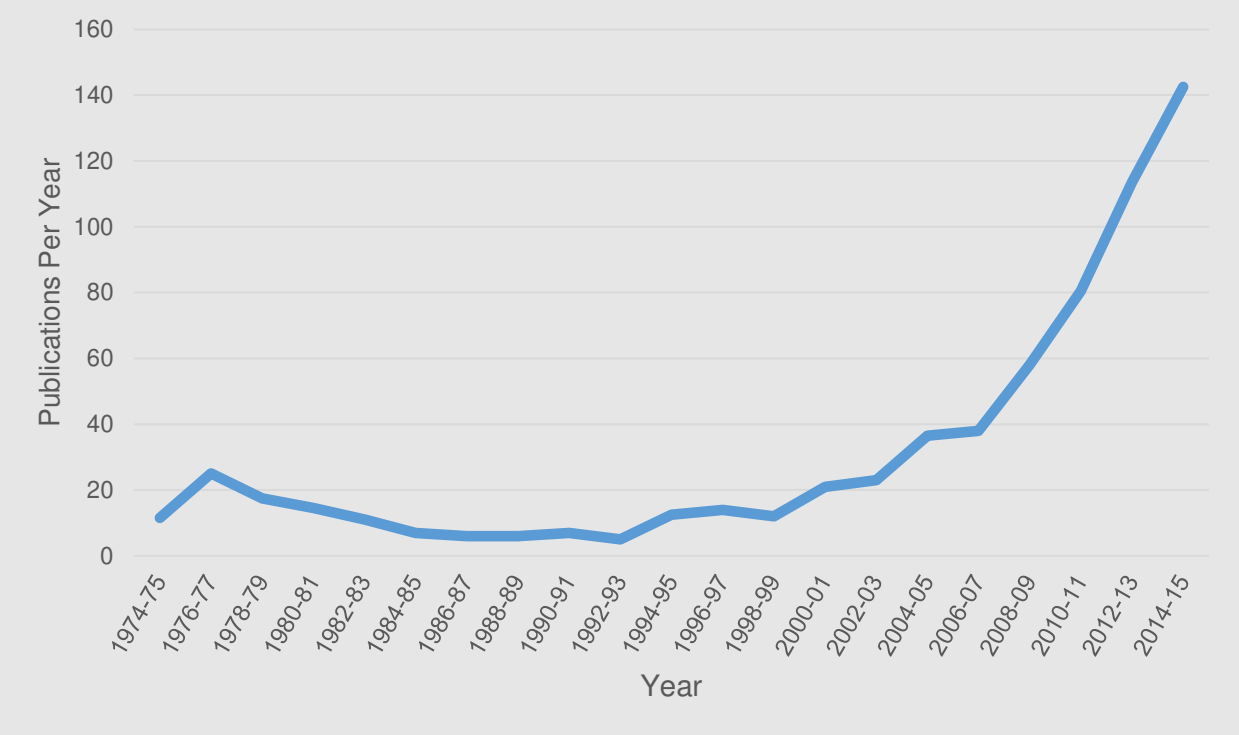

Figure 1. The line representing the number of publications on EEG-nf has been following a steep ascent in recent time, yet fundamental questions linger concerning specificity and mechanisms of action. The plot shows data from the search query "*(EEG OR electroenchephalogra*) AND (neurofeedback OR biofeedback)*" in the field "*Article Title, Abstract, Keywords*" in Scopus®.

THE SCARCE EVIDENCE IN SUPPORT OF NON-PLACEBO EEG-NF

Neurofeedback is in vogue. Ideas regarding self-regulation of brain processing have received a great deal of attention in the psychological and neurological sciences (Thibault et al., 2015). Moreover, EEG-nf research is thriving (see Figure 1; Thibault et al., 2015; van Boxtel & Gruzelier, 2014). Expanding from a seminal experiment back in 1958, the field of neurofeedback now boasts two international research societies, two devoted journals, dozens of annual conferences, and hundreds of publications each year that largely endorse EEG-nf and often promote it as a viable clinical tool. Some experiments report objective changes in brain activity after neurofeedback (e.g., Beauregard & Lévesque, 2006; Engelbregt et al., 2016; Ghaziri et al.,

2013; Kropotov et al., 2005; Lévesque, Beauregard, & Mensour, 2006; Ros et al., 2013, 2016; Strehl, Leins, et al., 2006) and others highlight a clinical efficacy on par with standard-of-care pharmaceutical treatments (e.g., Flisiak-Antonijczuk, Adamowska, Chładzińska-Kiejna, Kalinowski, & Adamowski, 2015; Fuchs, Birbaumer, Lutzenberger, Gruzelier, & Kaiser, 2003; Kotchoubey et al., 2001; Rossiter & La Vaque, 1995). Meanwhile, few formal accounts document relative shortcomings or take a critical look at EEG-nf.

Box 1. Mechanism underlying learned neural regulation

Animal research suggests that intentional and goal-directed operant conditioning drives neurofeedback learning and requires corticostriatal plasticity (Koralek, Jin, Long, Costa, & Carmena, 2012). Whereas neurofeedback studies in non-human animals implant electrodes directly into the brain and show clear learning effects, experiments with humans rely on scalp electrodes and only occasionally measure whether participants learn to modulate the signal of interest (e.g., Engelbregt et al., 2016; Strehl, Trevorrow, et al., 2006). Instead, these studies often focus on behavioral variables and other neural measures. Thus, not only does the link between learned neural regulation and behavior remain unclear, sparse evidence supports the idea that humans can reliably modulate EEG-nf signals. To develop a more scientific basis for EEG-nf, it would behoove researchers to test correlations among learned brain regulation, behavioral measures, and other neural variables. To further shed light on the neural conditions that foster learned regulation, researchers recently developed a technological innovation that allows experimenters to record brain oscillations while applying transcranial direct current stimulation (tDCS) to disrupt or enhance specific neural activity (Soekadar et al., 2013; Soekadar, Witkowski, Birbaumer, & Cohen, 2015). Tools of this ilk, combined with increasingly rigorous experimental design hold the key to unveiling the functional role of neural oscillations.

Weak evidence supports the efficacy of EEG-nf above and beyond comparable sham treatments; this state-of-affairs prevents the medical community from adding EEG-nf to the clinical standard-of-care armamentarium (Thibault & Raz, 2016b). For example, only one double-blind, sham-controlled EEG-nf experiment has ever documented clinical superiority of

veritable over sham feedback (Ramos-Murguialday et al., 2013). This highly-cited stroke rehabilitation experiment, however, provided over a dozen hour-long physiotherapy sessions between initial and final behavioral measures and further shies away from reporting the raw EEG data supporting a relationship between successful neural modulation and motor improvement.

Whereas all other clinical EEG-nf experiments employing double-blind, sham-controlled designs sought to treat ADHD (Thibault et al., 2016), a few oft-cited studies leverage alternative control methods and aim to treat refractory epilepsy (Kotchoubey et al., 2001; Lubar et al., 1981; Sterman & MacDonald, 1978). Two seminal experiments alternate between one- (Lubar et al., 1981) and three-month long (Sterman & MacDonald, 1978) training periods wherein researchers first provide positive feedback for increasing a select subset of EEG activity, and then reverse the reward contingency without the explicit knowledge of patients (i.e., display positive feedback for decreasing the same subset of neural activity). Whereas this within-subjects, inverse-sham design holds strong potential to unveil the specificity of EEG-nf, these experiments shied away from analyzing differences in seizure frequency among any of the baseline measures, veritable training, and inverse-sham neurofeedback. One study reports no statistical analysis (Lubar et al., 1981) and the other (Sterman & MacDonald, 1978) demonstrates only a reduction in seizure frequency after patients complete both veritable and sham training. These reports oversell the specificity of EEG-nf.

Research efforts that compare placebo factors between EEG-nf and standard treatment are few and far between. For example, one experiment found comparable reductions in seizure frequency, alongside similar levels of self-reported placebo variables (e.g., therapist quality and treatment satisfaction) between patients receiving EEG-nf and those under a new medication regimen; both EEG-nf and medication groups outperformed a respiration biofeedback control

condition (Kotchoubey et al., 2001). This experimental design controlled for the involvement of many placebo factors. The researchers, however, maintained a hypothesis in favor of EEG-nf – potentially exerting greater demand characteristics on neurofeedback participants – and the EEG-nf group trained to improve their condition for thirty-five 90-minute sessions, rather than the thirty-five 10-minute sessions employed in respiration biofeedback or the less time-intensive and rather effortless medication condition. Thus, while this study provides substantial evidence for the benefits of EEG-nf, the involvement of placebo influence remains a concern.

Other arguments for the specificity of EEG-nf rest on the assumption that findings from well-controlled biofeedback studies generalize to neurofeedback. This assumption is spurious for several reasons. First, whereas some researchers account for a number of placebo factors (e.g., Flor & Birbaumer, 1993), the introduction of sham biofeedback often demonstrates equivalence between veridical and placebo biofeedback (e.g., Andrasik & Holroyd, 1980, 1983; Hunyor et al., 1997; Mullinix, Norton, Hack, & Fishman, 1978; Nicassio, Boylan, & McCabe, 1982; Plotkin & Rice, 1981; Rains & Penzien, 2005; Rains, 2008). Second, even if research confirms the specificity of biofeedback, the discrepancy between well-established relationships (e.g., muscle tension and chronic pain or heart rate variability and anxiety) and our muddled insights linking brain oscillations with psychological functioning, precludes generalization. Similarly, findings from the bourgeoning field of fMRI-nf, where participants quickly learn to modulate precise hemodynamic brain signals, remain distinct from EEG-nf research (Sulzer et al., 2013). Despite the growing enthusiasm surrounding fMRI-nf, at this time only sparse evidence supports its clinical utility or posits a superior treatment benefit compared to EEG-nf (Birbaumer, Ruiz, & Sitaram, 2013). Thus, arguments purporting the specificity of EEG-nf would occasionally rely on

studies, which by design had no a-priori intention to examine EEG-nf specificity, and scantily support claims for it.

Relevant experiments investigating disorders beyond ADHD and epilepsy used inadequate experimental designs that prevented disentangling specific effects (i.e., benefits driven by presenting and attempting to modulate a brain signal of interest) from nonspecific factors (i.e., all other aspects related to undergoing neurofeedback: for example, placebo response, participant expectation, demand characteristics, and spontaneous remission). While this absence of evidence hardly implies evidence of absence, the onus of proof rests on those who advocate for and make claims regarding the specificity of EEG-nf (Thibault & Raz, 2016a). Taken together, while EEG-nf alters both brain and behavior, the necessity of receiving veritable feedback to derive therapeutic benefits remains largely unconfirmed and rests on rather tenuous foundations (see **Table 1** for rebuttals concerning common arguments in favor of EEG-nf).

Table 1. Specificity in EEG-nf. This table challenges a number of seemingly strong arguments purporting that the benefits of EEG-nf rely on the administration of a contingent and precise brain signal.

Argument	Research insights and counterarguments challenging EEG-nf
Animals respond to EEG-nf but do not respond to placebos	The main paper referenced to support this tenuous argument demonstrated that three cats extensively trained with EEG-nf, compared to three untreated cats, expressed delayed seizure onset in response to the injection of an epileptogenic compound (Sterman, LoPresti, & Fairchild, 1969). This elderly and methodologically-weak study employed neither statistical analysis nor blinding. Whereas, at least one additional experiment supports the idea that animals can benefit from EEG-nf (Sterman, Goodman, & Kovalesky, 1978), this idea has no bearing on whether the relevant effects are placebo-based. Indeed, animals do respond to placebos. In a blinded study, researchers found that 28 of 34 epileptic dogs responded to placebo treatment (Munana, Zhang, & Patterson, 2010). Research further documents a range of placebo

	phenomena in non-human animals for a spectrum of objective measures, including antibody production (Ader, Kelly, Moynihan, Grota, & Cohen, 1993; Jæger, Larsen, & Moe, 2006; McMillan, 1999) and bacterial immunity (Ben-Shaanan et al., 2016).
Placebo explanations cannot account for the magnitude of EEG-nf benefits	Placebos influence many systems including neurotransmitter release, immune responses, hormone levels, cardiopulmonary function, and electrical, hemodynamic, and metabolic brain activity (Price, Finniss, & Benedetti, 2008). Placebo pills improve motor performance in Parkinsonian patients within minutes (Pollo et al., 2002) and sham-surgery can benefit patients for years (Moseley et al., 2002). Placebos can lift depression, inhibit pain, and even decrease antibody production in response to allergens (for a review of placebos, see Raz and Harris, 2016). Placebo effects could conceivably drive the benefits of EEG-nf.
EEG-nf treats ADHD equivalent to stimulant medication	These findings reveal little regarding the mechanisms responsible for neurofeedback-mediated improvement. Only a highly comparable control group (i.e., sham neurofeedback) can reveal whether benefits derive from receiving a particular brain signal. Placebos are not all equal – they wield effects of varying degrees (Kaptchuk et al., 2006). Placebo EEG-nf may prompt greater healing effects than placebo medication. Neurofeedback is more expensive, time-consuming, seemingly cutting-edge, and requires dozens of visits with a practitioner. Thus, comparable results between EEG-nf and a pharmaceutical intervention do not necessarily imply that veritable neurofeedback outperforms sham neurofeedback.
EEG-nf alters objective measures in brain activity	EEG-nf can alter both electrical (Engelbregt et al., 2016; Kropotov et al., 2005; Strehl, Leins, et al., 200box 16) and hemodynamic (Beauregard & Lévesque, 2006; Lévesque et al., 2006) brain signals. Ulterior factors, however, including expectation, sitting attentively for multiple sessions, and regularly visiting a practitioner can also drive the observed neurological changes. Attempting to alter a sham neurofeedback signal alone activates various brain regions compared to passively viewing the same sham neurofeedback stream (Ninaus et al., 2013).
Double-blind studies are inappropriate for EEG-nf research	We have encountered all kinds of arguments along these lines, including neurofeedback is a behavioral therapy, patient are heterogeneous and need individualized training, sham treatment is unethical, therapists must manually adjust reward thresholds, patient-therapist interactions preclude blinding, and the blind is too easily broken (see, for example, Arns, Heinrich, & Strehl, 2014; Hammond, 2010; Kotchoubey et al., 2001). However,

	research on behavioral therapies often include placebo controls (e.g., Hofmann & Smits, 2008), cohorts are no more heterogeneous than in other clinical experiments and blinding individualized treatments is feasible, sham treatments represent standard clinical research practice, automatic thresholding remains viable, and blinds are maintainable (Arnold et al., 2013).
Insufficient funding precludes robust experiments with large samples	Researchers have acquired ample funding to produce thousands of EEG-nf publications and run large scale experiments (e.g., Gevensleben et al., 2009 (n=72); Monastra, Monastra, & George, 2002 (n=100); Janssen et al., 2016 (n=112); Kaiser & Othmer, 2000 (meta-analysis n=1089)). And yet, most EEG-nf experiments scantily employ adequate controls as part of their research design.
The FDA approved neurofeedback	In 1976, the United States Food and Drug Administration (FDA) approved EEG-nf for general relaxation training as a Class II medical device (i.e., one that has insufficient information to provide reasonable assurance of the safety and effectiveness of the device: 94th United States Congress, 1976). The FDA supports no further claims.

The theoretical underpinnings at the core of EEG-nf seem dubious (Beyerstein, 1990; Kline, Brann, & Loney, 2002). Based on research findings correlating clinical conditions with quantitative differences in electrical brain activity, most neurofeedback protocols aim to increase or decrease a select bandwidth of neural oscillations (Thibault et al., 2015). For example, because high beta activity typically correlates with heightened attention, many protocols aim to reinforce beta activity in the treatment of ADHD. If beta oscillations paralleled only a few specific cognitive processes, such logic may hold some appeal; however, beta activity correlates with a wide range of behaviors. As a case in point, alcoholics express high baseline beta activity (Rangaswamy et al., 2002); however, one could hardly argue that upregulating beta would induce alcoholism. Research findings also demonstrate that beta oscillations correlate with poor

attention in ADHD patients, rather than with heightened attention as observed in children without ADHD (Ogrim, Kropotov, & Hestad, 2012).

These wide-ranging behavioral correlates exist across many common EEG-nf targets. For example, while heightened alpha amplitude correlates with meditation (Lagopoulos et al., 2009), attentional suppression (Foxe & Snyder, 2011), working memory (Jensen, Gelfand, Kounios, & Lisman, 2002), eye closure (Barry, Clarke, Johnstone, Magee, & Rushby, 2007) and anxiety (Klimesch, Sauseng, & Hanslmayr, 2007), EEG-nf participants train to amplify alpha activity to relieve depression (Choi et al., 2010), improve cognitive performance (Hanslmayr, Sauseng, Doppelmayr, Schabus, & Klimesch, 2005), and treat phobias, obsessive compulsive disorder, posttraumatic stress, and anxiety (Moore, 2000). While some EEG bandwidths have strongly supported behavioral correlates (e.g., delta and deep sleep or gamma and sensory processing: Jensen, Kaiser, & Lachaux, 2007) insufficient data exists to argue that inducing these oscillations would drive the associated behavior. Taken together, these insights highlight the lack of coherence between recorded electrophysiological brain oscillations – signals derived from the interaction of multiple disparate brain processes – and single behaviors.

If EEG-nf were a powerful and focal tool to modulate brain function in relation to specific behaviors, we would expect to see adverse reactions in some participants (Raz & Michels, 2007; Thibault et al., 2016), especially as distinct experiments encourage neural regulation in opposite directions (e.g., Ros et al., 2016 versus Zoefel, Huster, & Herrmann, 2011). And yet, after almost six decades of neurofeedback research, reports of negative effects remain anecdotal (Hammond & Kirk, 2008). Taken together, therefore, the theory supporting EEG-nf feeds on a prevalent,

albeit injudicious, propensity to reduce multifaceted behaviors to single brain processes (McCabe & Castel, 2008; Weisberg, Keil, Goodstein, Rawson, & Gray, 2008).

While a few non-standard EEG-nf techniques negotiate the aforementioned foundational shortcomings, they come peppered with other caveats and conflicts of interest. For example, z-score neurofeedback aims to alter brain activity in participants to match an averaged signal derived from a database of healthy individuals. This technique overlooks individual variations in physiology and anatomy (e.g., skull thickness), which substantially distort electrical neural signals. In a bibliography of z-score neurofeedback (Applied Neuroscience Inc, 2014), the first author on 37 of the 39 publications included (i.e., 95%) either runs a private EEG-nf practice or sells neurofeedback equipment. Such conflicts of interest extend to the International Society for Neurofeedback and Research (ISNR) where eight of nine board members practice privately and the ninth sells EEG-nf products; the journal *NeuroRegulation*, featuring both an editor-in-chief and an executive editor who practice EEG-nf privately; and the Biofeedback Certification International Alliance (BCIA), Biofeedback Federation of Europe (BFE), and Association for Applied and Psychophysiology and Biofeedback (AAPB) where many members hold active financial stakes in EEG-nf. Notably, financial conflicts of interest also pervade common clinical research (Bekelman & Gross, 2003; Perlis et al., 2005), the expansive pharmaceutical literature (Antonuccio, Danton, & McClanahan, 2003; Rabipour, Delpero, & Raz, 2011), prevalent brain training programs (Underwood, 2016), and to a lesser, but non-negligible extent, research on psychological therapies (Lieb, Osten-Sacken, Stoffers-Winterling, Reiss, & Barth, 2016). Even in the absence of financial interest, moreover, comparative studies across behavioral treatment, psychotherapy, and pharmacology, tend to skew findings towards the specific choice-of-treatment espoused by the authors (Luborsky et al., 1999; Maj, 2008). Such undesirable biases

may also pertain to clinicians who teach or practice a specific technique, especially when monetary transactions loom (e.g., Farah, 2009; Grunbaum, 1986). Such financial investment likely drives publication bias (Turner, Matthews, Linardatos, Tell, & Rosenthal, 2008) and encourages research designs that conflate the benefits of specific mechanism with psychosocial influences, thus inflating the literature with positive findings (Bekelman & Gross, 2003; Perlis et al., 2005).

Box 2. Canvasing the opinions of neurofeedback experts

Visiting an EEG-nf clinic appears on par with the experience of attending a private health center: framed degrees line the walls and the environment mimics that of a medical practice. In a recent visit to a neurofeedback center, we interviewed the lead practitioner who, after two hours of discussion, confided that even he remained unconvinced that presenting a particular brain signal was essential for EEG-nf treatment. Instead, he argued for a comprehensive approach involving multiple concurrent therapies.

Informal discussions with leaders in the field reveal a similar tenor. For example, one of the pioneers of neurofeedback and a leading researcher in the field communicated that it would be naïve to believe that neurofeedback offers an adequate and sufficient treatment for any disorder (Joel Lubar, personal communication, 2016). In line with this opinion, a recent authoritative review states that "it would be foolish to conclude that a foundation of knowledge has been realized enabling textbooks to be written [on EEG-nf]" (Gruzelier, 2014). Furthermore, arguably one of the most rigorous and prolific neurofeedback researchers, Niels Birbaumer, proposed that the cumulative evidence in favor of EEG-nf is preliminary and we stand to benefit from more controlled evidence to confirm that genuine feedback is a necessary component to achieve positive treatment outcomes (personal communication, 2016).

In addition, we recently met with a representative of a non-profit international neurofeedback organization, who emphasized the omnipresence of business interests and scoffed at the idea that the International Society for Neurofeedback and Research consists of academic researchers. Thus, whereas the published literature may paint a semi-rigorous and scholarly image of EEG-nf, under this superficial veneer flourish strong business agendas largely incongruent with the standards of academic investigation and medical research.

PLACEBO SCIENCE AND CLINICAL PRACTICE IN THE CONTEXT OF EEG-NF

EEG-nf works, but it likely relies heavily on placebo phenomena. Whereas the biomedical lore often discounts placebo effects (Raz & Harris, 2016), most accepted treatments that target brain function and behavior – from psychiatry (Weimer, Colloca, & Enck, 2015) to gastroenterology and the brain-gut axis (Elsenbruch & Enck, 2015) – derive substantial benefits from such psychosocial variables (e.g., see antidepressants in Kirsch, 2009; Kirsch et al., 2008). Particularly, some alternative interventions outperform standard-of-care treatments while relying almost entirely on placebo effects (e.g., see acupuncture in Harris, Lifshitz, & Raz, 2015). Placebo effects extend beyond behavioral measures and impact various physiological systems. Through cleverly designed experiments and the use of molecular imaging techniques, researchers demonstrated that placebo analgesics can alter neurotransmitter release (e.g., endogenous opioids: Levine, Gordon, & Fields, 1978; ter Riet, De Craen, De Boer, & Kessels, 1998; Zubieta et al., 2005) and fMRI-indexed brain activity (Kong et al., 2006). Sham neurofeedback, moreover, alters activity originating from a host of cortical regions (Ninaus et al., 2013). If further research confirms the effectiveness of neurofeedback relative to accepted treatments (e.g., Flisiak-Antonijczuk et al., 2015; Fuchs et al., 2003; Kotchoubey et al., 2001; Rossiter & La Vaque, 1995), EEG-nf may well triumph as a therapy.

Important variables for therapists to consider when contemplating neurofeedback include the number needed to treat (NNT), number needed to harm (NNH), potential complications arising from forgoing standard care, the sustainability of positive outcomes, and the probability and severity of side-effects. These variables provide informative trends concerning some standard therapies. For example, consider the field of child psychiatry (Raz, 2006). On the one hand, pediatric antidepressant treatment carries an NNT between 3 and 10 (i.e., for every three to ten children administered antidepressants, only one will improve better than placebo), an NNH

(e.g., in terms of suicidal ideation or suicide attempt) from 112 to 200 (Bridge et al., 2007), and a range of potentially severe side-effects (Jureidini, Doecke, Mansfield, Haby, & Menkes, 2004); pharmacological treatment of ADHD with atomoxetine carries an NNT of 3 for treatment response and 10 for relapse prevention, and an NNH of 9 for abdominal pain, 22 for vomiting, 30 for dyspepsia, and 19 for somnolence (Cheng, Chen, Ko, & Ng, 2007). On the other hand, EEG-nf studies rarely report NNT or NNH, yet side-effects remain mild and uncommon (Hammond & Kirk, 2008), and positive outcomes appear to persist well beyond the treatment period (Gani, Birbaumer, & Strehl, 2008; Gevensleben et al., 2010; Leins et al., 2007; Strehl, Leins, et al., 2006). In a clinical setting, therefore, critically assessing treatment options should reach far beyond significance testing and p-values, and further rely on quantitative and qualitative evaluations of potential complications, treatment sustainability, and the transferability of effects.

Notably, standard neurofeedback treatment often comprises 40 sessions and costs between 4,000 to 10,000 USD (Thibault et al., 2015). If researchers can isolate the underlying placebo mechanisms, practitioners may afford the opportunity to forgo expensive and lengthy training regimes while continuing to offer an effective non-pharmaceutical alternative. For example, if interacting with patients prompts positive outcomes, practitioners could spend more time communicating before commencing neurofeedback. A new wave of research aimed at unveiling psychosocial factors could encourage practitioners to leverage and amplify these therapeutic effects.

Whereas current EEG-nf studies largely neglect investigating treatment mechanisms that rely on participant motivation, belief in the treatment administered, interacting with a practitioner, level of positive feedback, and sense of control of their brain signal, future

experimental designs could aim to isolate and modulate these factors to better identify their relative contributions in neurofeedback-mediated healing (Thibault et al., 2016). Increasingly, EEG-nf experiments administer sham neurofeedback to control for psychosocial variables. These study designs can unveil the importance (or lack thereof) of veritable feedback, but fall short from teasing apart the nonspecific elements that drive healing. Rather than maintaining all psychosocial variables fixed, while altering only veritable and sham feedback, novel research designs could aim to enhance and inhibit individual placebo variables to establish their involvement in EEG-nf and propel a more scientific understanding of neurofeedback (e.g., Rains, 2008).

CONCLUSION

Placebo effects dominate EEG-nf outcomes. Whereas most neurofeedback experts acquiesce to this insight, researchers and practitioners largely shy away from openly disclosing, let alone formally reporting, the involvement and magnitude of these psychosocial factors. In light of the comparable benefits of veritable-versus-sham feedback, conflicts of interest, and a weak theoretical underpinning, advocating for EEG-nf poses a conundrum. On the one hand, many patients erroneously assume they have "nothing to lose" (Raz & Harris, 2016). On the other hand, EEG-nf entails a degree of deception – the putative mechanisms differ from the actual underlying mechanisms. Moreover, cheaper and less time-intensive options may be available.

Neurofeedback remains a viable treatment of choice for patients with sufficient time, money, and motivation to pursue it. Despite and perhaps because the insight that placebos play such a central role in EEG-nf outcomes, researchers and practitioners would stand to benefit

from diverting their efforts away from a tireless search for elusive neurological underpinnings and focus instead on dissecting these overarching influences. If researchers propose to unravel the psychology of neurofeedback, and proponents remain transparent about the underlying mechanisms, we believe practitioners can apply EEG-nf in a manner fitting with standard biomedical ethics.

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DECLARATION OF CONFLICTING INTERESTS

The authors declare that there is no conflict of interest