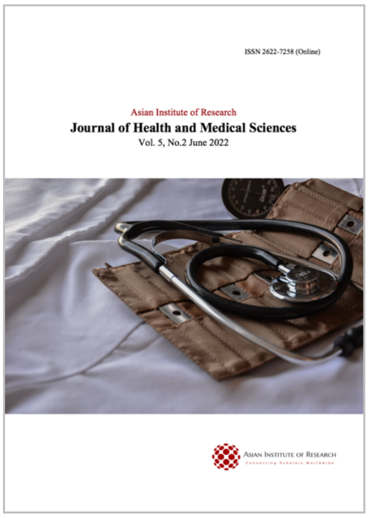

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"Hyperfeedback" as a Tool to Assess and Induce Interpersonal Synchrony: The Role of Applied Social Neurosciences for Research, Training, and Clinical Practice

Maria Elide Vanutelli[1], Claudio Lucchiari[1]

[1] Department of Philosophy "Piero Martinetti", Università degli Studi di Milano, Milan, Italy

Correspondence: Maria Elide Vanutelli. Department of Philosophy, Università degli Studi di Milano, Milan
Via Festa del Perdono, 7, 20122, Milan, Italy. Tel: +39-2- 50312739. E-mail address: maria.vanutelli@unimi.it

Abstract
In the last 25 years, the field of neuroscience has seen exponential growth due to technological advances, which have not only allowed for collecting more accurate data, but also for addressing a variety of innovative studies for human development understanding. Neurofeedback (NF), and particularly Brain–Computer Interfaces (BCI) applications, are among the most promising methods, since they enable individuals to interact with a computer by using their brain activity to learn implicitly and train some specific cognitive and affective functions. These applications proved to be suitable for many different fields, from research to clinical practice. However, NF was used only in individual settings, with participants interacting with a computer, while more ecological and complex phenomena could be better explored in interactive contexts. In the present work, we propose that the future of BCI provided NF may lie in the development of interactive settings where two or more participants can be informed about their inter-brain synchrony to train and reinforce them towards enhanced joint interactions and promote learning and empowerment. We propose that BCI methods should move to brain-X-brain-computer interfaces (B^2CI). In this new protocol, that we called "hyperfeedback," brain signals coming from two people involved in a joint setting are processed so to provide a compound feedback. The possible applications of such a paradigm are discussed.

Keywords: BCI, B^2CI, Interpersonal Coordination, Hyperscanning, Neurofeedback, Hyperfeedback, Dyadic Interactions

1. Introduction: Applied Neuroscience and wellbeing

In the last 25 years we have witnessed a huge progress in the field of neurosciences, with the development and improvement of sophisticated techniques, such as neuroimaging and non-invasive electrical brain stimulation, that can support the research and the understanding of human development. One of the most promising techniques is neurofeedback, a non-invasive procedure that aims to modulate learning, cognition and behaviors at a neurocognitive level making use of low-density electroencephalography (EEG), generally implemented by a normal device with a targeted montage or by brain-computer interfaces (BCI) tools, which use algorithms to process in real-time brain signals, so allowing a direct interaction with a machine (e.g., launching commands, operating on a keyboard or moving a robotic arm). Thanks to focused training sessions, individuals can learn to modulate their own brain activity eliciting purposed functional patterns. This learning process occurs at an implicit level: Trainees are rewarded with visual or auditory stimulation when the brain pattern falls within the chosen range. For example, if they can maintain brain rhythms within a range associated to states of calm (if the goal is relaxation), or concentration (focal attention), they receive a reinforcement in the form of a sound, volume change, a visual sign (e.g., a positive emoji) or a successful performance in a videogame (e.g., hitting a target with an arrow). On the other hand, undesirable patterns of activity are ignored or disincentivized (Coben & Evans, 2010), for example by producing a noise. NF was proven to be effective in different protocols and for a number of purposes, yet it presents some limitations. Indeed, the training is often perceived as too demanding and a consistent amount of participants prove to be, *de facto*, non-responders (Kadosh & Staunton, 2019). Indeed, previous research underlined that mood, motivation, but especially attention resources may affect NF success. Also, the majority of available software is rather tricky and not always simple to adjust to different experimental and clinical settings.

Generally speaking, neurofeedback studies were initially referred specifically to clinical contexts, where traditional rehabilitation programs were impossible or scarcely successful. Now, the field is expanding, following the general trend of Neuroscience research that went beyond the study of classic cognitive studies to investigate new fields. The new frontiers concern abilities, talents and contexts, including creativity, social dynamics, and interpersonal relationships, previously considered addressable only by a more qualitative approach. Applied neurosciences investigate these fields extensively, trying to translating the most recent advances about the brain functions into real-life applications and ecological settings, also with the aim of investigating the human mind/brain in its broadest expression and promoting people's wellbeing and growth. Thus, the research process does not necessary occur in the lab, but also in schools, companies, shops, clinics, and social groups, obviously opting for research methods usable in these contexts. The basic idea that supports these studies, that may be considered examples of Applied Social Neuroscience (ASN), is that human beings can be seen as energy systems in continuous interaction with each other and with instruments around them (Dennett, 2013). ASN leads to thee need of a paradigm shift, from a "one-person" to a "two-person" (Balconi et al., 2017; Balconi & Vanutelli, 2017; García & Ibáñez, 2014; Konvalinka & Roepstorff, 2012; Schilbach, 2010), or even "multi-person" settings (Hildt, 2019; Jiang et al., 2019).

In this paper, we propose a research and intervention model that, based on these principles and thanks to technological tools, could be applied in many different contexts related to the theme of cognitive empowerment, rehabilitation, education, and well-being. In the following paragraphs the theoretical rationale, the technical structure, and the possible applications will be described in detail.

2. Why an interpersonal perspective?

Have you ever tried to spend a lot of time with a mate from another city, or region? Did you notice how, after a very few moments, you began modifying your own accent, prosody, even non-verbal behavior? Have you ever heard the joke for which, over time, spouses get more and more similar? These stories from everyday life are just examples of how people, when interacting with peers, automatically mimic their behaviors and feelings due to the activation of what can be described as a sort of unconscious mirroring mechanism. It has been defined with terms like alignment, behavioral matching, interpersonal or interactional coordination, behavioral resonance, which all include the idea of a spatial and temporal synchrony (Cornejo et al., 2017; Dumas et al., 2010). This mechanism can be thought as a tool devoted to facilitate emotional contagion to pursue shared goals (Hari et al., 2013) and, more generally, the construction and reinforcement of a collective cognition (Cornejo et al., 2017), a sort of social-cognitive space for mutual understanding. Actually, examples of dyadic synchrony have been observed in the very early stages, e.g. the mother-infant interactions (Feldman, 2007, 2012; Kinreich et al., 2017; Ramseyer, 2011), that will be the basis of a sound attachment (Barber et al., 2001; Ham & Tronick, 2009). From a phylogenetic point of view, interpersonal synchrony has been conceptualized as a fundamental evolutionary mechanism to promote group cohesion and collaboration, with significant effects on group dynamics (Levy et al., 2016; Vanutelli et al., 2016). Moreover, it has been suggested that the closer we perceive others, the better we can understand their behaviors, intentions, and emotions, with improved empathy and ability to make inferences and predictions (Preston & de Waal, 2002; Vanutelli & Balconi, 2015).

These synchronization patterns can take the form of a behavioral synchrony, for example at the level of facial or body movements (Gordon et al., 2020; Mayo & Gordon, 2020), but also at the level of autonomic signals such as breathing, electrodermal activity, heartbeat, and so on (Feldman et al., 2011; Levenson & Gottman, 1983; McAssey et al., 2013; Vanutelli et al., 2017, 2018). Working, learning, or even making simple actions is modulated by the mere presence of others. This fact is particularly important if we think that we are social beings but generally scientific evidence is collected within individual settings. Furthermore, since humans' brain developed essentially in social contexts, we may consider it a "social device." Thus, it is plausible that it works better in social rather than in individual settings. The former contexts are then exploitable to increase cognitive performance, foster learning, and promoting healthy lifestyle. Instead, psychological and neuroscientific setting generally use individual setting even when trying to promote or change behaviors that are social in nature.

3. Hyperscanning + Neurofeedback = Hyperfeedback

It has been proven that interpersonal synchrony can be observed also at the level of neural processes coordination of multiple social partners. A neuroscientific approach called hyperscanning (Montague, 2002) emerged in this context twenty years ago to provide a more ecological setting for real-time psycho-social processes to be measured in the lab. The idea comes from the ability of the brain to mirror others' actions, feelings or emotions, by predisposing a similar activation in the perceiver (Hasson et al., 2012) and reflects embodied cognitive processes (Szymanski et al., 2017).

We believe that advanced Brain-Computer Interface (BCI) systems could be developed starting from hyperscanning recordings as input information and using the coherence of such signals to provide a visual/auditory feedback. Indeed, neurofeedback may be used to help people experiencing neurophysiological states in real-time so to implicitly learn how to manage them. However, we claim that it could be easily applied to multiple users into a "hyperfeedback" paradigm (HF). This way, it is possible to assess and train inter-brain synchrony as a whole within a new frame: B^2CI, brain-X-brain-computer interfaces. The use of a B^2CI protocol will offer the unique possibility to give rise to a complex interaction, where two human beings (or even more in future applications) can interact with a computer in a purposed way. The role of the computer here is not simply to collect and combine data coming from the two brains. Instead, a specific software will process this information and a dedicated algorithm will be chosen and adapted to the dual task run and the goals to be reached. Thus, starting from the general idea of brains coherence (a classic index of synchronization), other computations can be performed and other indices can be used to provide a specific feedback. Furthermore, we propose that HF protocols should involve a synergy of both neural and autonomic signals, in order to monitor excessive cognitive load, stress levels and fatigue, to design calibrated interventions, and to increase the success rate.

In this frame, we believe that HF as many other ASN tools and protocols, will benefit from the use of coupled BCI tools (B^2CI), since they are conceived and implemented to process real-time brain(s) signals using them in purposed and flexible ways. BCIs are generally easier to adapt to different settings than traditional EEG systems, that are designed for clinical and research purposes and generally use proprietary software and expensive hardware. Commercial BCIs, instead, are cheaper, wearable, and often open source. These characteristics offer the opportunity to easily translate basic research into applications in educational, professional, and real-life contexts.

The hyperfeedback protocol takes advantage of the benefits of the well-known and validated neurofeedback technique, adding the expected benefits of a social context, that can improve achievement both at a dyadic, and at the individual level. In fact, within the HF protocol the collaboration between trainees (co-activity) is totally implicit and does not necessarily lead to a joint outcome. Consequently, the expected advantage is for each individual involved. In this way, the paradigm of hyperfeedback aims to exploit the potential of implicit learning on the double side of neuro-cognitive modulation (i.e. the neurofeedback-related learning) and on that of social facilitation. It is possible to define the combination of these protocols as "connected cognition", as if the two cognitions were connected at a deep, implicit level. Connected cognition, more generally, can be thought as the consequence of the innate tendency of the human brain to resonate with the brains of others. From an evolutionary point of view this phenomenon represents a process which is capable of enhancing some fundamental cognitive processes, such as mind-reading, empathy and linguistic comprehension. In addition, synchronization phenomena may also be linked to some predictive coding processes. In few words, connected cognition allows us to "see" the brains functioning as a dance, in which one dancer leads the other towards a certain goal or, more simply, within a shared experience without any explicit instructions, but letting one carrying the other.

From a cognitive point of view, the study of connected cognition can be linked to the classical work of Zajonc (1966), who showed that performing a cognitive task in an individual context or with the presence of others substantially changes cognitive performance. This is referred to as the Social-Facilitation-and-Impairment Effect, since the presence of others can both increase and decrease performance. In fact, the social facilitation effect, from a neuro-cognitive point of view, is based on the automatic and therefore implicit activation of an attentional gradient, able to increase the general cortical excitability of the individual, and channeling cognitive resources towards the task at hand (Belletier et al., 2019). In particular, as suggested by Baron's model (Baron et al., 1996), the presence of others would allow a greater attentional focus and an increase in the performance of simple and repetitive tasks, while an opposite effect (worsening of performance) would occur in the case of complex tasks, requiring the development of new cognitive algorithms or a deep adaptation of those previously developed.

From this theoretical overview, it appears evident that the HF paradigm, and more generally ASN, may serve not only for research purposes in the lab, providing new insights into shared cognitive and emotional experience in a social-cognitive setting. Indeed, it has a significant application potential. We believe that HF may be developed and applied in different fields and that applications related to the clinical contexts are particularly interesting. In the present paper, we propose two hypotheses of intervention in relation to clinical practice (I), and to education and training (II).

3.1. Hyperfeedback and B^2CI in clinical practice

In clinical practice, HF may be applied to enhance the quality of parent-child relationships especially dealing with developmental disorders associated with social or emotional impairment. Let’s consider, for example, the possible positive effects in the case of Autism Spectrum Disorders (ASD), characterized by difficulties in social interaction, communication, and empathic mechanisms (Baron-Cohen et al., 1994). Previous research (Koehne et al., 2016) underlined that the degree of behavioural synchrony can be associated with higher cognitive empathy performance in ASD children. In this framework, HF could reinforce mirroring mechanisms and help the acquisition of competencies such as the capacity to share others’ feelings and to understand intentions and emotions at an implicit level. In fact, for people with ASD the explicit learning of such competences is particularly impaired or even impossible. The same principles could be applied to other meaningful dyadic problem interactions, with the aim to improve emotional engagement, tuning, and connectedness.

Another important clinical application may be linked to learning disorders. In this case, traditional NF programs have been implemented to improve reading abilities, including innovative methods to restore inter-hemispheric balance (Cancer et al., 2021). However, NF trainings are usually rather demanding. In this context, a HF paradigm may be more effective, since it could facilitate the implicit learning typical of NF, but with the boost of social facilitation, thus decreasing attentional and cognitive resources needed to obtain a good outcome. Furthermore, HF could be used coupling typical readers with people with dyslexia. The starting hypothesis here is that the typical and atypical readers may achieve implicitly a brain synchronization such that the “typical” inter-hemispheric balance is reached with much less effort and time than required by a traditional NF protocol.

Another possible application refers to the treatment of social anxiety, as recently proposed by an interesting paper by Saul and colleagues (2022). Indeed, studying and treating the psychological and behavioral reactions of people suffering from social anxiety in a social setting might be beneficial, since a straightforward and focused intervention might be easily implemented. This dual approach would show a high ecological validity, and the achievements obtained during the training could be easily extended to real-life contexts. Our HF approach could be used in a similar setting as well, incorporating both a social context and an algorithm able to foster improvements in emotional management when cooperating with others. Furthermore, our approach is based on mutual learning, so it is possible to set an HF protocol to include couples made by individuals with different levels of social anxiety to develop focused expectations and coherently guide the therapeutic journey. For example, at the beginning of the training it is unlikely to expect that a person with a high level of social anxiety may find benefits in a dual neurofeedback training with a low anxiety person. Instead, better results are expected when little differences are present. Also, the integration in our protocol of autonomic measures such as electrodermal activity thought to prevent excessive treatment-related stress, but also to be a measure of anxiety level in social contexts.

3.2. Hyperfeedback and B^2CI for group dynamics and training

A study by Dikker and colleagues (Dikker et al., 2017), thanks to the simultaneous acquisition of EEG activity from 12 students, showed that brain-to-brain group synchrony was associated with classroom social dynamics. Accordingly, a hyperfeedback training could be proposed in schools to promote group engagement and empathy, to enhance mutual understanding and to discourage social exclusion, bullying, and discrimination. Similarly, hyperfeedback may be applied at the workplace, including both horizontal (colleague-colleague), and vertical dynamics (leaders-employees) to enhance perceived closeness and symmetry, as well as to identify the best practices for groups formation, so to increase collective intelligence and facilitate teamwork. B^2CI could also be used for training purposes. For instance, in negotiation training it's important to learn how to regulate emotions and to be empathetic with the counterpart to accomplish a timely settle achievement. We propose that the use of a B^2CI might accelerate the training also improving emotional and relational skills (Cominelli et al., 2017, 2020). Indeed, HF protocol's benefits are generally expected in contexts where social learning is required.

A similar situation may be described when a physician meets a patient to discuss a diagnosis and set a treatment. We believe that the doctor/patient encounter is a kind of implicit negotiation. In the era of patient empowerment (Tomes, 2007), patients and doctors must be considered at the same level. They must collaborate to set and share goals, since the doctor's interest is to treat the disease, and the person's interest is to reach a good quality of life. Most of the work needed to achieve this settlement is implicit since overt communication is generally hindered by technical, emotional, social, and personal issues that are not commonly discussed and often are simply unmanageable in a clinical setting (Ranjan et al., 2015). As in the case of negotiators training, it is not possible to use HF protocols in a real situation; However, we believe that HF may be beneficial during doctors' education, especially in the area of communication. Using HF training, doctors could test their ability to communicate with a person about significant health-related issues, or evaluate how the emotional reactions of others influence the communication process and the achievement of a proper therapeutic relationship. This aim can be pursued in an educational setting by the use of B^2CI protocol. It is enough to set the synchronization parameters and the hyperfeedback to tune the communicator 1 (doctor role) and communicator 2 (patient role) so to achieve implicitly a proper cognitive and emotional empathy, a skill considered playing a key role in clinical contexts (Dehning et al., 2013). This way, a doctor learns how to resonate with a patient and communicate properly without any explicit instruction or intention.

A last significant application in this context could be the use of HF using simulated agents. This is an extension of the B^2CI HF protocol that we have designed, and we are going to test in different applications. Using an agent-based simulated model, doctors may be trained to improve communication skills and empathy with the use of simulated patients with different emotional, social, and personal characteristics (e.g., values, preferences, expectations, and so on). Doctors would learn how to regulate communication and emotions within these different conditions and develop a focused emotional intelligence skill that would be fundamental in any doctor's psychological toolbox, beyond technical skills and scientific knowledge. This training might be completed in a few weeks and could be repeated during the doctors' education even during her professional career when needed or desired. In this protocol, hyperfeedback is provided combining the real data coming from the trainee's brain and a simulated dataset, designed to associate brain patterns with personal characteristics, such as emotional stability and personality traits.

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Declaration of interest

None

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Mayo, O., & Gordon, I. (2020). In and out of synchrony—Behavioral and physiological dynamics of dyadic interpersonal coordination. *Psychophysiology*, *57*(6), e13574. https://doi.org/10.1111/psyp.13574 REVIEWIn and out of synchrony—Behavioral and physiological dynamics of dyadic interpersonal coordinationOded Mayo1| Ilanit Gordon1,21Department of Psychology, Bar-Ilan University, Ramat-Gan, Israel2The Gonda Multidisciplinary Brain Research Center, Bar Ilan University, Ramat-Gan, IsraelCorrespondenceIlanit Gordon, Department of Psychology, Bar-Ilan University, Ramat-Gan, Israel.Email: ilanit.gordon@biu.ac.il; ilush.gordon@gmail.comFunding informationIsrael Science Foundation,

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