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An electrophysiological study applied to remote learning: preliminary results from an hyperscanning paradigm

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ABSTRACT

The digitalization of learning in the organization represents both a necessity and an opportunity. Little to no research explored how distance training affects cognitive and affective processes in individuals and workgroups. For this reason, in this work, we propose an hyperscanning research design where conversational analysis is used to compare neurophysiological measures (frequency band analysis: delta, theta, alpha, and beta) between an equivalent training session carried out in two conditions (face-to-face and remote), by collecting electroencephalographic data (EEG) on a trainer and three groups of trainees. We theoretically describe the protocol, and we further report initial explorative results. Data showed a significant effect of the condition on both theta and beta waves, with higher synchronization for the face-to-face setting. Also, trainees seem more impacted by the delivery modality compared to the trainer. This work highlights the relevance of neurophysiological measures to test e-learning efficacy.

Keywords: remote training; e-learning; hyperscanning; EEG; cognitive neuroscience

1. Introduction

Not all assets are recorded on a firm's balance sheet. In the long term, an organization advances also through its intangible asset: experience and employees' competence, which increase corporate value (Gu & Lev, 2011). Guarantying the maintaining of competitiveness in dynamic environments is a significant challenge and represents one of the Learning and Development (L&D)'s responsibilities. In fact, employees grow via L&D and directly sustain the company's evolution.

In the last years, we observed a digitalization of the learning process in both scholastic (Crittenden et al., 2019) and work (Harteis et al., 2020) environments. Often, team members are geographically apart (Argote and Miron-Spektor, 2011) and learn in remote conditions (Gibson and Gibbs, 2016). In this light, e-learning allows the usage of information and communication technology (ICT) to foster training (Rosenberg & Foshay, 2002). Digital learning within the organization is employed for both hard and soft skills (Panjaburee et al., 2022), at all levels. For this reason, the comparison between online and face-to-face training naturally arose and has become a natural pragmatical and academic question.

In this work, we chose to focus on this relevant dichotomy. Should we fully convert training and learning experiences into digital and remote settings?

The literature highlighted three main divergences in the two considered conditions (Hogle, 2017). First is their dissimilarity in the role of technology. Remote learning is indeed massively grounded on the usage of several software components, that allows the creation of a shared workspace (or workplace) where participants can collectively communicate and exchange thoughts, materials, and feedback. Another divergence lies in the psychological and motivational domains. Sustaining learners' engagement has to follow strategies that are different based on the setting conditions. Lastly, the necessity, by the participant in remote settings, to manage more tasks, such as technical specifics, handling personal space and the surroundings, and other stimuli (e.g., emails, notifications) from their devices, at once.

Although literature appears to be contradictory, if not opposite, at times (e.g., Waytz & Gray, 2018). Thereby, we suggest considering evidence not as conclusive, due to its lack of clarity. For example, a review showed that telecommuting is linked to diminished mental effort (e.g., O'Brien & Yazdani Aliabadi, 2020). Furthermore, distance training allowed, during physical and social distancing (i.e., COVID-19 pandemic) to keep active education and training in companies, sometimes guaranteeing 100% education (Al-Asmari & Khan, 2014). Also, face-to-face interaction can be perceived as stressful to some individuals, depending on personal traits (Shalom et al., 2015). Unfortunately, according to other available data, this is not the whole story. Approximately 80% of a sample of American students attending online classes reported experiencing isolation, depression, and anxiety (Peper et al., 2021). They also found it harder to focus and stay present. Literature has sometimes referred to it as "Zoom fatigue", where multitasking, notifications, and lack of body and environmental configurations induced reduced arousal and cognitive attention for synchronous communication.

It also appears that participants in remote settings are often non-responsive and present weakened levels of empathy (Wellman et al., 2003). Distance training can trigger lower satisfaction and work engagement (Bali & Liu, 2018), with increased allocation of cognitive resources to register, interpret, and perceive others' communication. Miscellaneous communication issues are present, and they inhibit the learner-instructor interactions. Online settings seem to negatively impact the nonverbal dynamics in relation to lack of facial expression, body appearance, and movements (e.g., sitting upright and creating cues). Interestingly, even secondary video-audio delays can force a person's brain to restore communicative synchrony, with added cognitive load (Riva et al., 2021). Indeed, some explanations for this phenomenon can be linked to four clusters of reasons: the amount of close-up gaze, the required cognitive load, the increased self-evaluation from staring at the video of oneself, and physical mobility constraints (Bailenson, 2021).

As we managed to describe till now, the considered comparison is everything but uncontroversial. Somehow, distance education can be seen as a double-edged sword (Kulikowski et al., 2021). For these reasons, we believe that remote training, only if well assessed and understood, can represent an opportunity for organizations. Besides the need for clarity, there is also limited use of multidisciplinary approaches to investigate training processes (Popova-Nowak & Cseh, 2015). For this reason, here we advocate for the consideration of the valuable intersection between education and cognitive neuroscience (Devonshire & Dommett, 2010).

In fact, studying learning processes at a neurophysiological level, while pondering the impact of technology might represent a valuable answer for some methodological issues. Past neuroscience-informed approaches supported training on specific populations (e.g., high school adolescents or children with trauma; Mikołajewska & Mikołajewski, 2011) and various neuroscientific investigations comprised heterogeneous factors such as sleep, nutrition, physical activity, and the practice of mindfulness (see Tortella et al., 2021). Assuming that learning and training are interindividual processes, social neuroscience should be logically called into question. Acknowledging the complexity that arises in social interaction, means that all agents involved should be considered (Hasson et al., 2012). Every approach that proposes to study a social group by investigating individuals as independent agents is doomed to failure. For these reasons, also due to recent hardware and software improvements, novel approaches were developed for assessing social interactions. Hyperscanning is one of them. This method refers to the simultaneous data collection of more than one individual in a joint task

(Balconi et al., 2017), a simulation, or a procedure (Balconi et al., 2022). It allows the consideration of two types of brain connectivity. Intra-brain connectivity is defined as that specific synchronization of neural activity within different cortex regions at an individual level. It can be intended as a proxy for functional specialization of an individual's brain activity (e.g., Balconi & Caldiroli, 2011). The second indicator derived from an hyperscanning design (Balconi & Vanutelli, 2017) is inter-brain connectivity, which is identified as that functional connectivity between individuals' brains related to interpersonal coupling mechanisms during social exchanges (e.g., Balconi et al., 2020; Kawasaki et al., 2013). Interestingly, both inter-brain and intra-brain, synchrony showed to be good predictors for collective performance (Reinero et al., 2020). For these reasons, highly valuable data are derived from the study of electrophysiological synchronization within a dyad or a social group. The primary benefit is the possibility to consider an induvial in a context or a situation.

Electrophysiological neural correlates in interacting individuals have been previously studied in classrooms (e.g., Dikker et al., 2017; Bevilacqua et al., 2019). Although, the investigation of cerebral activity in two or more adult trainees is yet unexplored. In the mentioned studies, EEG spectral boundaries (see Bröhl & Kayser, 2021) are extracted (i.e., delta, theta, alpha, and beta) and interpreted in association with neurophysiological processes and their functional significance. In these studies, common EEG spectral boundaries considered are delta, theta, beta, and alpha (e.g., Bröhl & Kayser, 2021). Evidence from literature has historically associated different neurophysiological processes to these patterns. In fact, low-frequency bands (delta and theta) have been linked to the processing of emotional and mnestic information (Balconi et al., 2015; Khader et al., 2010). Instead, alpha desynchronization and beta synchronization are associated respectively with general cognitive activation and selective attentional processing for specific stimuli within the environment (Runnova et al., 2021)

Another methodological issue to address when considering our research object is how to make two training sessions comparable to each other, with a satisfying degree of reliability, while preserving a high level of ecological validity. In this sense, to extract neurophysiological data, it is imperative to identify phases that are both crucial, similar, and recurring. For this purpose, previous studies managed to qualitatively detect recurring verbal patterns in conversational interactions between agents and then combine them with EEG data (Venturella et al., 2017). The blend of EEG data with conversational information collected during the real-time dialogues can add value to the assessment of a training session.

In this study, we intended to propose a theoretical research design, further supported by initial explorative data, that aims at studying the learning experience in trainees and a trainer, comparing remote and face-to-face conditions. More specifically, we intend to develop a neurocognitive paradigm that allows the comparison between remote and face-to-face settings during two equivalent training sessions in trainees and a trainer. A necessary condition is preserving acceptable levels of ecological validity. To ensure it we chose to use wearable EEGs, and to apply a bottom-up approach to detect comparable phases, via the integration of qualitative (conversational) and quantitative (frequency powers) data

To address set aims, we recorded the EEG data in a group of trainees interacting with a trainer, in two longitudinal sessions, one delivered remotely and one in presence., using an hyperscanning paradigm. Secondly, we applied a conventional qualitative content analysis (Hsieh & Shannon, 2005) to map the discourse and topics arisen during the two sessions. To verify the comparability between the sessions, preliminary explorative content analysis was applied, selecting analogous topics and processes in the two conditions. We then proceeded to compare the two sessions using neurophysiological data.

Specifically, EEG frequency powers (delta, theta, beta, and alpha) were collected and compared from electrode sources (AF7, AF8, TP9, and TP10) in the participants for their functional significance Lastly, we will compute correlational coefficients (r_n), assuming a linear relationship between the trainer's and participants' brain activity within the training session.

Initial explorative hypotheses were also set. Regarding theta activity, we conjectured that the face-to-face condition presents increased activation in the power compared to the remote one. In fact, we expect higher emotional engagement, marked by a theta synchronization (Balconi et al., 2015) in the first condition where nonverbal language is also part of the participants' communication.

Instead, regarding, beta, here considered as an attentional marker, we hypothesize higher synchronization in all the groups of trainees for the face-to-face condition in comparison to the remote setting. Participants, when remotely attending the session, might tend to be non-responsive, less cognitively engaged, and more easily distracted by their surrounding environment.

2. Methods

2.1 Participants

The research activity was conducted according to the principles of the Helsinki Declaration (1964) and approved by the local Ethical Committee institution where the work was carried out.

A total of eight participants [$(M)_{age}$ = 43.6, $(SD)_{age}$ = 6.26] were recruited. The sample included two independent populations, those of professional trainers (n= 1 participant) and trainees (n= 7 participants). Subjects voluntarily took part in the experiment after signing the written informed consent. The following inclusion criteria were considered for the trainer and trainees respectively: being a senior Human Resource (HR) trainer, with more than 5 years of experience in managing training and educational settings; having experience of more than 5 years in HR management. Exclusion criteria involved: i) having a history of psychiatric and/or neurological disorders; ii) being involved in concomitant therapies with psychoactive drugs that might affect the central nervous functioning; iii) presenting clinically relevant distress or a history of burnout.

2.2 Procedure

All participants, after signing the written consent, took part in two training sessions carried out by a counseling firm, one delivered remotely via Zoom Video Communications and a second one, in face-to-face condition. Both sittings, synchronously performed, were video-recorded, and consisted of a 3-hour course where an HR trainer taught methods for the delivery of distance learning in organizational contexts.

Regarding the remote condition, participants remotely attended the training session from their personal computers. At the beginning of the session, a researcher requested and checked that each participant was able to fully join the training in a quiet and dimly lit room. For the face-to-face condition, participants were introduced to a standard classroom where training sessions are generally carried out.

In both conditions, participants were asked to wear the EEG device to simultaneously gather their EEG brain activity during the training (more details are presented in the EEG signal acquisition section). Wearable EEGs were supplied from the research team to all participants, and they were connected to their smartphones via Bluetooth. Before the experiment, all participants were trained on the needed technical specifics and could wear, start, and stop the EEG system. For both conditions, a 120-second baseline was recorded. At the end of the single session, recorded data were saved and shared with the researcher. The output was then deleted from the participant's mobile phone. During the sessions, a member of the research team was constantly available and managed the introductory and final phase, and any requests related to the use of the device.

2.3 EEG signal acquisition

EEG data were recorded using multiple Muse™ Headband version 2 (InteraXon Inc., Toronto, ON, Canada). These wearable recording systems are constituted of 4 gold-plated cup bipolar dry electrodes to detect EEG signals in a low-invasive way. The electrodes are located according to the international

EEG placement system: three are used as a reference, the other four are positioned in the frontal (AF7 and AF8) and temporoparietal (TP9 and TP10) regions. The system is also equipped with an accelerometer, a gyroscope, and pulse oximetry and connected to the personal participant's personal smartphone using the mobile application Mind Monitor (Clutterbuck, 2022).

Data were sampled at a constant of 256 Hz and a 50 Hz notch frequency filter is applied. The software automatically processes raw data and applies Fast Fourier Transform to obtain brain waves computing the logarithm of Power Spectral Density (PSD) from each of the four channels (as processed by Mind Monitor, all EEG PSD values tend to lie within the -1: +1 range). Extracted frequency bands were delta (1-4 Hz), theta (4-8 Hz), alpha (7.5-13 Hz), beta (13-30 Hz), and gamma (30-44 Hz).

2.4 *Data analysis*

Macroscopically, data analysis included three major phases: conversational semantic mapping; EEG frequency band analysis; and correlational analysis between participants (trainer and trainees) based on their EEG activity during the different phases.

2.4.1 Conversational semantic mapping

Using the videotape data from the two sessions, we performed conversational semantic mapping based on the relevant phases of the process in which the participants were communicating. The mapping was carried out by two independent judges, who had transcribed the audio of the videotape. A conventional qualitative content analysis approach was used to analyze the transcripts (Hsieh & Shannon 2005). Verbatim transcripts were also checked

Independent researchers ensured that transcriptions provided an accurate description of the dialogues. Researchers examined the verbatim multiple times, comparing their analysis with the other judge until the transcripts descriptively coincided with the dialogue. The aim of this analysis was to identify common topics in the verbatim content, in the two conditions. Following the repeated reading of interview transcripts, a thematic analysis of their content was performed, consisting of a first coding through the identification of the recurring elements. This analysis suggested that the verbatim content concerned specific phases (n= 29) of the training process, and the following five topics were identified: group 1, group 2, group 3, trainer, and feedback. The first three topics (group 1, group 2, group 3) corresponded to the three teams presenting their project proposal for the distance learning approach. The fourth topic (trainer) was constituted by the trainer personally describing and teaching approaches and tools for a distance learning method. The fifth topic (feedback) corresponded to the moments in which participants provided general feedback on the training session.

The salient phases of the training process, present in both two training conditions (face-to-face and remote) were used to form a time-block on recorded EEG trace to be analyzed (for this procedure, see also Venturella et al., 2017).

2.4.2 EEG frequency band analysis

EEG recording was divided into time-blocks according to the different salient phases of the training process for each topic, to obtain the data of the corresponding electrophysiological activity. Each of the five topics contained the EEG signal corresponding to the different salient phases of the training process, grouped according to the following specific topic: group 1, group 2, group 3, trainer, and feedback. The average length of each topic was twenty minutes and was homogeneous among the topics.

Regarding the statistical data analysis, four Analysis of Variance (ANOVA) models were run, one per each frequency band (delta, theta, alpha, and beta). The sphericity was assessed via Mauchly's test and, if violated, the Greenhouse-Geisser correction was considered.

The following independent variables were inserted: condition (2: face-to-face, remote) electrodes (4: AF7, AF8, TP9, TP10) as within factor, and topic (group 1, group 2, group 3, trainer; feedback) as a between factor. Post-hoc analysis (contrast analysis for ANOVA, with Bonferroni corrections for multiple comparisons) was successively applied. The size of statistically significant effects has been estimated via partial eta squared (2) indices. Initial partial significant results are reported and interpreted for beta and theta waves.

2.4.3 Correlational analysis

Finally, in order to explore the inter-brain synchronizations, we assumed a linear relationship, between the brain activity between the trainer and the trainee. We performed a correlational analysis by computing of Pearson correlation coefficient, between the EEG activity of the single participant and the trainer's considering all phases of the training session in the remote condition. Considering electrophysiological brain activity is informative of the interaction between individuals. Inter-brain connectivity is an indicator of the inter-personal coupling mechanisms during social exchanges (Balconi et al., 2020).

3. Results

3.1 Theta band

The main effect of condition was found significant (F[1, 24] =14.43, p ≤.05, 2 =.38). Specifically, increased theta power was found in the face-to-face [M= .91, ± 0.13 (SE)] condition compared to the remote setting [M= 0.45 ± 0.11 (SE)]. Data is reported in Figure 1a.

3.2 Beta band

The effect of condition was found significant (F[1, 24] =14.43, p ≤.05, 2 =.38. Higher beta power was found in the face-to-face [M= 1.01, ± 0.08 (SE)] condition compared to the remote one [M= 0.69 ± 0.05(SE)]. Data is reported in Figure 1b.

The interaction condition*topic was found significant (F[4, 24] =5.546, p ≤.05, 2 =.48).

From post-hoc analysis, we found that in two groups of trainees out of three there was a significant difference between face-to-face and remote conditions. Specifically, group 1 (p ≤.05) and group 2 (p ≤.05) showed increased beta power in the face-to-face [respectively, M=1.24 ± 0.17(SE); M=.82 ± 0.22 (SE)] condition compared to the remote one [respectively, M=.42 ± 0.11(SE); M=.26 ± 0.14(SE]. Data is reported in Figure 1c.

3.3 Correlational analysis

Regarding high-frequency bands, a significant negative correlation between the trainer's beta activity and group 2 alpha power EEG activity was found in the right anteriofrontal activity (AF8) [r(56) = -.614, p<.001]. Data is reported in Figure 2.

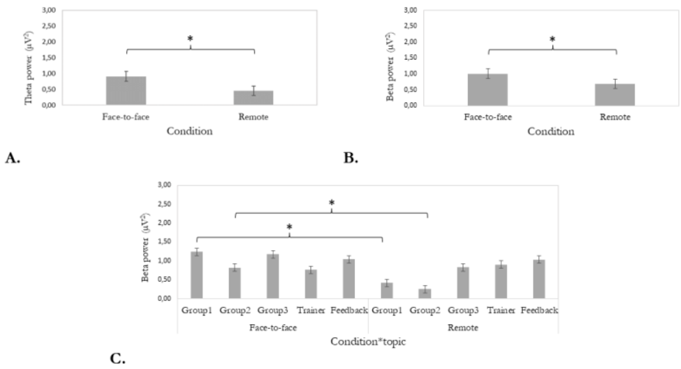

*Figure 1. a. Bar graph shows differences in theta power for condition. Bars represent ±1SE. Stars mark statistical significance. b. Bar graph shows differences in beta power for condition. Bars represent ±1SE. Stars mark statistical significance. c. Bar graph shows the interaction Condition*Topic in beta power. Bars represent ±1SE. Stars mark statistically significant pairwise comparisons*

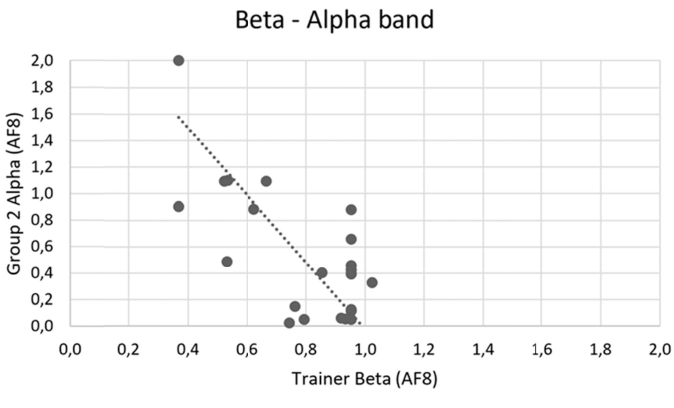

Figure 2. The scatterplot represents the statistically significant negative correlation between beta power in the trainer and alpha in Group 2 of trainees in the right anteriofrontal region

4. DISCUSSION

This study explored the benefits of applied neuroscience for the investigation of training in the organizational domain, carried out either remotely or in face-to-face conditions. Electrophysiological indices were considered to investigate cognitive and affective states on a trainer and trainees during two real sessions, by providing them with wearable EEG devices.

Macroscopically, three steps for data analysis were included: conversational semantic mapping, EEG analysis in the frequency domain, and inter-agents (trainer and trainees) correlational analysis. EEG data showed initial interesting results for theta and beta power when considering the extracted phases from the discourse analysis Furthermore, the correlational analysis highlighted first observations on the trainee-trainer relationship. The qualitative content analysis allowed the selection of compatible phases between the two considered conditions. Three out of the five identified topics were related to different groups of trainees (group 1, group 2, and group 3), while they were presenting their project and case studies. The fourth topic coincided with the trainer's activity, comprised of teaching, class discussion, and exploring managerial techniques. Lastly, the fifth topic (i.e., feedback) included all moments where participants, trainer and trainees, were exchanging feedback.

As performed in previous studies (Venturella et al., 2017), starting from what emerged in this first qualitative analysis, EEG recording was divided into time-block, according to these temporal segments, and we then selected and extracted the corresponding electrophysiological activity for each subject.

EEG data showed interesting initial data. As expected, we detected a general increased activity in the theta power in the face-to-face condition compared to the remote setting. Cognitive neuroscience has consistently highlighted the role of theta rhythm in emotional regulation functioning (e.g., Uusberg et al., 2014; Balconi et al., 2015). Its inherent role as a foundation for interindividual communication and as a social connector from an emotional perspective is known. In this sense, it is plausible to consider the added value of face-to-face settings. This evidence comes supporting other studies' conclusions that highlighted weakened levels of empathy (e.g., Wellman et al., 2003) and lower work engagement (Bali & Liu, 2018) in remote communications. Other relevant factors could be explanatory for this difference in the learner-instructor interaction at an emotional level. Distance communication might have negatively impacted the nonverbal dynamics between the individuals. Remote settings can be linked to interaction issues between agents, due to lack of facial expression, body appearance, miscellaneous body movements.

Concerning beta, we found general increased activity in the face-to-face condition compared to the remote setting. Now, we also found descriptive differences in all three considered groups, even though we could only detect statistical significance in two out of three groups of trainees, probably due to a reduced number of statistical cases. Beta activity is generally correlated to focused and selective attention processing (Wróbel, 2000). Often, beta can be directly considered as an efficient proxy for attentive accuracy to internal or external stimuli (Gola et al., 2013), or used to compute specific ratios (e.g., Putman et al., 2013), then operationalized as biomarkers for certain cognitive processes. These observations are supported by the cortico-thalamic role in attentional perception and by the contribution of the lateral geniculate nucleus (LGN) and the primary visual cortex (V1) for higher visual processing.

From this early observation, we could conclude that the setting conditions play an important role in the attentional modulation and accuracy in the learning process, not only at a general level but with a particular weight on trainees. Feedback exchange and trainer's activity instead, seem not to be particularly impacted by the condition factor.

Finally, regarding the inter-brain synchronization, we detected and reported a negative strong correlation in the high-frequency bands, between the trainer and the trainees' group. The mentioned correlation was found in the right anterior frontal, between beta activity in the trainer and alpha desynchronization in the trainees. Higher levels of beta activity in the trainer are linked to alpha desynchronization in the trainees. Even if not conclusive, this result can be interpreted as cognitive attentional interdependence between trainees and the trainer during the phases of a training session. From what we observed, when the trainer shows higher attentive accuracy in terms of beta synchronization, the trainees exhibit alpha desynchronization, which is linked to increased general arousal (Balconi et al., 2017). This relation might describe the interconnection at a neurophysiological level that occurs during a learning experience between a trainer and multiple trainees for the cognitive dimensions, linking general arousal in the trainees and selective attention in the trainer.

The research protocol, fusing a bottom-up conversational approach to EEG analysis seems to show promising potential, correctly addressing the set aims and highlighting interesting results. Both cognitive and affective processes were investigated, revealing their altered modulation due to the condition factor (Balconi & Lucchiari, 2005)

Naturally, this research comes with strengths and weaknesses. Methodologically, the research design can be considered highly innovative. First, the employment of multiple (i.e., eight) wearable EEGs to assess two (remote vs. face-to-face) training sessions, represents an innovation. Secondly, the proposed approach considered mixing quantitative and qualitative data. In this light, the adoption of electrophysiological correlates to assess covert processes together with an in-depth analysis of the conversation content might represent a robust solution to assess extremely complex social interactions, such as professional training. From what we initially observed, it allowed a successful comparison between the two considered conditions. Lastly, the involvement of a real trainer and trainees preserved the ecological validity.

Regarding the limits of the study, internal validity might represent a weakness since confounding variables are possibly present, due to the complexity of the considered social interaction Also, external validity should be further assessed. In fact, these initial explorative results would benefit from replication and further investigation, with appropriate sampling. To compute the needed sample size, a power analysis should be run. Lastly, more complex analyses can be carried out on the recorded signal (Cassioli & Balconi, 2020). Also, to higher the statistical power, other contributing factors should be considered and controlled. Psychometric dimensions (e.g., motivation, psychological traits), training style,

Pragmatical implications for practitioners are now briefly discussed. The data showed how the setting condition is possibly an important factor to consider when managing a training session. Attention to the targeted population of trainees should be put when establishing the training specifics. Also, if further confirmed by future research, the employed commercial EEG devices showed to be useful for practitioners, even with limited technical expertise for the conduction of evidence-based practices, at an affordable cost.

Availability of data and material

The dataset is available from the corresponding author on reasonable request.

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Competing interests

The authors declare that there are no competing interests regarding the publication of this paper.

Authors' contributions

M.B. and F.C. designed the experiments and analyzed the data. Both drafted and approved the final manuscript.

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