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Short-Form, Comedy Improv Affects the Functional Connectivity in the Brain of Adolescents with Complex Developmental Trauma as Measured by qEEG: A Single Group Pilot Study

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Abstract

Complex developmental trauma (CDT) is characterized by prolonged exposure to traumatic events in early life, resulting in the breakdown of neurobiological integration which impacts mental and physical health. The benefits of practicing short-form improvisation (improv), however, parallel the treatment needs of this population. To observe the neurobiological effect of improv, we used eyes-open quantitative electroencephalography (qEEG) to record the brains of 32 adolescents before and after participation in a 20-min intervention (One Rule Improv) consisting of short-form improv games. A paired *t*-test was used to evaluate coherence, phase, absolute amplitude, and low-resolution electromagnetic tomography (LORETA). Results indicated increases in coherence in delta, theta, alpha, and beta ($p < .05$). Phase lag showed a statistical decrease ($p < .05$) in delta, alpha, and beta. Absolute power showed significant increases in alpha frontally Fp1 ($p = .004$), decreases in delta ($p = .030$) at T4. LORETA analysis indicated significant changes in sensorimotor rhythm (SMR) at Brodmann area (BA) 6, $t(27) = 6.1$, $p < .05$. Significant delta decreased at BA 6, BA 10, $t(27) = 4.96$, $p < .05$; and BA 24, $t(27) = 3.90$. Significant delta decreased at BA 4, BA 3, and BA 40, $t(27) = 4.35$, $p < .05$. Results indicate preliminary evidence supporting improv as an intervention capable of affecting functional connectivity changes in adolescents with CDT. For developmental trauma, these results may indicate improved capacity to make meaningful connections with others and create opportunities for neuroplastic changes.

Keywords: functional connectivity; complex developmental trauma; improv; alternative therapies; adolescents with trauma; improvisational theater

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Complex developmental trauma (CDT) is a condition defined by exposure to multiple traumatic experiences most often of an interpersonal nature during early development, between the ages of zero and seven, resulting in an underdeveloped nervous system more inclined towards survival than healthy attachment (van der Kolk, 2005). The effects of this can result in poor neuronal development, and an overall inefficiency in the systems in the body and brain (Bower, 2016; van der Kolk, 2005). This mental health state of dissociation, or a disconnection of neuronal connections, limits the functional connectivity of the brain (Schore, 2014). Functional connectivity refers to the integrated relationship between spatially separated brain regions.

In normative brain development, the functional connectivity of the three sections (brain stem, limbic system, and cortex) work together. Chronic exposure to trauma moves the brain stem and limbic system into a state of hyper- or hypoarousal. Threat is perceived everywhere, triggering a fear-based survival response of flight/fight/freeze. The nervous system goes either below or above its window of tolerance and as a result of excessive stress, certain brain regions within the cortex become disorganized (Atzil, Hendler, & Feldman, 2011). This state negatively impacts emotional and behavioral regulation, motivation, cognitive function (De Bellis & Zisk, 2014) and sensorimotor integration (Stein, 2017). These deficits carry into adulthood, causing those who suffer from CDT to present with a comorbidity of emotional, behavioral, and cognitive diagnosis (Gunnar & Quevedo, 2007; Pechtel & Pizzagalli, 2011). Essentially, maltreatment during early life changes the trajectory of brain development that affects sensory systems, network architecture, and circuits involved in threat detection, emotional regulation, and reward anticipation (Teicher, Samson, Anderson, & Ohashi, 2016).

While many established therapies like cognitive behavior therapy (CBT) require higher cortical systems to be activated, like verbal acuity, those with CDT require an intervention that engages deeper centers of the brain before higher cortical systems can engage (Siegel, 2012). Successful treatment involves positive, healthy, repetitive, relational experiences in the context of safe, empathetic, and attuned relationships (Baylin & Hughes, 2016), which are all qualities developed through the practice of comedic/theatrical improvisation (improv; Ballon, Silver, & Fidler, 2007; Bermant, 2013; DeMichele, 2015; Gale, 2004).

Short-form comedic improvisation (improv) is an unscripted comedic art form that originated from the Theater Games of Viola Spolin (Spolin, 1963) and began its development into its own art form in the late 1950s in Chicago (Wasson, 2017) and early 1960s in England (Johnston, 1992). Today, short-form comedy improv is characterized by its short 30-second to 3-minute-long game structures, driven by audience suggestions and structured by the rule of saying "Yes, and…." This foundational rule of *Yes, and* (Halpern, Close, & Johnson, 1994) prompts players to unconditionally accept and add to the offers given by other players in every interaction. While performed professionally, improv with this frame of *Yes, and* is comparable to the improvisational, sociodramatic role-play of early childhood development when children develop cognitive and social skills (Sawyer, 1997).

Often misunderstood as being similar to stand-up comedy, improv, although comedic, is by contrast a positive and supportive relational activity. Its foundational rule of *Yes, and* frames the relationship between players, the audience, as well as the players to themselves. Halpern et al. (1994) describe improvisation as not merely an exchange of information between players. Instead, players share responsibility and "take care of each other" (p. 38). An interaction is not complete until a player "sees how it affects his partner" (p. 63). Spolin (1963) describes it as "communion" (p. 45), and Paul Sills, founder of Second City Improv explains that improv is the "finding of oneself in free space created through mutuality" (Sweet, 1986, p. 20). The requirement to unconditionally agree (Yes) and add to the offer of others (and), as well as oneself, encourages the practice of trust, acceptance, concentrated focus with all senses, and spontaneity (Gale, 2004). While improv has remained a comedic performing art form, parallels in several domains of applied psychology (body awareness and mindfulness, positive psychology interventions, and person-centered psychotherapy) have bolstered interest in the use of improv as an experiential therapeutic intervention (Bermant, 2013).

There is a growing body of research examining the use of improv as an intervention for a variety of clinical diagnosis or for self-identified mental health issues. Recent research exploring the effectiveness of improv has begun to report improv's positive impact on those that suffer from anxiety and depression in adults (Krueger, Murphy, & Bink, 2017) and in teens (Felsman, Seifert, & Himle , 2019). Other studies report improvement in prosocial behavior (Corbett et al., 2019; Kisiel et al., 2006; Zucker et al., 2010) and social cognition (Corbett et al., 2019). Studies involving teenagers reveal improv's ability to improve uncertainty tolerance (Felsman, Gunawardena, & Seifert, 2020; Hainselin, Aubry, & Bourdin, 2018) and affective well-being (Felsman et al., 2019; Schwenke, Dshemuchadse, Rasehorn, Klarhölter, & Scherbaum, 2020). Research involving children note a reduction in aggressive behaviors and an improvement in scholastic attention and engagement (Kisiel et al., 2006; Zucker et al., 2010).

Brain imaging technology is revealing improvisation's ability to activate the frontocortical and sensorimotor regions of the brain of musicians and rappers, who also use a *Yes, and* frame as they repeatedly accept an offer without judgment and add to it. The activation of these brain regions may benefit those who suffer the neurobiological effects of CDT (Schore, 2014). Findings, using fMRI technology, indicate that engagement in an improvisational activity increases the activation of the medial prefrontal cortex (MPFC; self-expression) and of the sensorimotor and language regions of the brain (Limb & Braun, 2008; Liu et al., 2012; McPherson, Barrett, Lopez-Gonzalez, Jiradejvong, & Limb, 2016). A 2019 study, using EEG brain mapping technology (Sasaki, Iverson, & Callan, 2019) revealed consistencies with the fMRI research (Donnay, Rankin, Lopez-Gonzalez, Jiradejvong, & Limb, 2014; Limb & Braun, 2008; Liu et al., 2012; McPherson et al., 2016) with greater power for scale in the frontal area comprising regions of the medial frontal cortex, anterior cingulate cortex, and the supplementary motor area (SMA). There are mixed results among these studies regarding activation of the dorsal lateral prefrontal cortex (DLPC). Some exhibiting its activation (Sasaki et al., 2019) and others its deactivation in relationship with the activation of the MPFC, suggesting the mental state of flow (Limb & Braun, 2008). There is, however, consensus that the different results may be due to the skill level of the subjects, as well as the level of constraint within the design of the study (Landau & Limb, 2017; Sasaki et al., 2019).

While the direction of research involving improv continues to expand, there have been no published articles looking at the nervous system of groups of adolescents with CDT before and after an intervention of improv was used. With existing research and the observation of positive emotional state changes during improv by adolescents with CDT, we hypothesized that improv changes the functional connectivity of the brain, moving individuals from a neurobiological state of survival to a state in which they are able to integrate higher cortical systems to better engage in connection with themselves and others.

Methods

Participant Characteristics

In this quasi-experimental pretest–posttest design, the experimental group consisted of 32 subjects between the ages of 15 and 18. Participants reside at a residential treatment center for adolescents, meeting the criteria for CDT. Thirty-two preassessment and postassessment qEEGs were recorded; however, four participants were excluded because of distortion in the recordings, resulting in the total number of $N = 28$. Participants included 14 female participants, 13 male participants, and 1 transgender male (female-to-male) participant (59% White, 15% Latino, 10% African-American, 10% mixed race, 6% American Indian and Asian). Races were indicated in the records of the participants as determined by their parents. All 28 participants were adopted, and all were right-handed.

Participants had a co-occurring (average of five) of clinical diagnosis as listed in the DSM-5 (APA, 2013). The most common, listed in order of prevalence: attention-deficit/hyperactivity disorder (ADHD) (65%); major depressive disorder (50%); reactive attachment disorder, (25%) parent–child relational problem (16%); anxiety disorder (31%)/Social anxiety disorder (6%); posttraumatic stress disorder (PTSD; 31%); oppositional defiance (22%); disruptive mood dysregulation disorder (16%); specific learning disorder (16%); cannabis use disorder (16%).

Assignment Method

Participants were selected from a voluntarily attended, on-site, 25- to 50-minute, weekly improv class. Experience and ability playing improv varied from 1 week to 16 months and was not a prerequisite for selection. Participants were selected based upon availability and simply asked if they would take part in what was called “Neuro Improv” (NI). One participant declined. Participants were informed they would have a qEEG, play improv while still wearing the qEEG cap, and have a postscan done after the improv session. Participants understood that their brain scans would be evaluated before and after improv and that their data was confidential. There was no further discussion or detail given about the hypothesis or purpose of the scans. An independent institutional review board (IRB), IntegReview, approved this study. All participants provided verbal consent, while written consent was provided by parents or legal guardians.

Immediately prior to the preassessment, participants were involved in unstructured social activities with peers and staff for a minimum of 15 to 45 minutes during the end of their routine day for baseline recording. The study was conducted over an 8-month period, with four participants being recorded each session for a total of eight sessions. After their prescan, each participant walked with the neuro technician approximately 2 minutes to the improv class where they began class with one to three other participants. To avoid self-consciousness due to the wearing of qEEG caps, the selection of the other one to three players in the session was based on having a neutral or positive relationship with the other participants.

EEG Data Collection
Quantitative electroencephalography (qEEG) was used to record the nervous system of 32 adolescents with developmental trauma before and after the improv intervention (ORI) to evaluate changes in the brainwave frequencies. Scalp voltages were recorded using a 19 Sn electrode cap (Electro-Cap International, Eaton, OH) according to the 10–20 international system: Fp1, Fp2, F7, F3, Fz, F4, F8, T3, C3, Cz, C4, T4, T5, P3, Pz, P4, T6, O1, O2. The ground electrode was placed on the scalp between Fpz and Fz. Electrical signals were amplified with the BrainMaster's Discovery 24 and 20 EEG systems (BrainMaster Technologies, Bedford, OH) and all electrode impedances were kept under 5 kΩ. Electrodes were referenced to linked earlobes. The EEG was recorded continuously, digitized at a sampling rate of 256 Hz, and then spectral analyzed using the fast Fourier transform (FFT). EEG data was filtered with a 0.5–40 Hz bandpass filter. Participants recorded 5–6 minutes eyes-open recordings for the preassessment, and 5–6 minutes eyes open for the postassessment.

EEG Data Processing
Using NeuroGuide 3.0.2, qEEG data was analyzed (Applied Neuroscience, 2008). Thirty-second minimum samples were collected. Elimination of artifacts were done visually by a trained professional. Coherence, Phase, and LORETA computations from NeuroStat and NeuroBatch 3.0.2 were used to analyze coherence, phase, and low-resolution electromagnetic tomography (LORETA). Coherence, which is a measurement of functional association between two brain regions (Nunez, 1981, 1995), was calculated by looking at the variability of time differences between two time series in a specific frequency band including delta (1–4 Hz), theta (4–8 Hz), alpha (8–12 Hz), and beta (12–25 Hz). Phase lag is calculated by evaluating two waves at a specific frequency at the same point in time. The difference between the waves is measured in radians, and if a difference exists the waves are considered out of phase. If the difference is π radians, then the waves are in antiphase. LORETA was used to provide insight into the dynamic functioning of the brain. LORETA utilizes a 19-channel EEG cap and three-dimensional (3-D) source imaging to determine the specific source of an electric dipole (Pascual-Marqui, Michel, & Lehmann, 1994).

Intervention
All participants experienced a 20-min improv intervention, Neuro Improv (NI), consisting of short-form improv games and using the One Rule Improv (ORI) approach (DeMichele, 2019) to learning and playing improv developed and facilitated by a co-author of this study (DeMichele). The ORI approach to learning improv explicitly focuses on the rule of *Yes, and* when teaching, playing, and facilitating improv games. While many games, including theater games and some commonly performed improv games, are improvisational as they are unscripted, experiential, and learner centered, they are not necessarily collaborative or lack the frame of *Yes, and* (DeMichele, 2015), as are the games used in this study. Initially developed to help adolescents improve learning experiences and outcomes (DeMichele, 2015), this current intervention NI uses ORI to help students with CDT to attain a better mental state as well as the essential skills to enable them to better communicate and form healthy relationships.

During each 20-min NI session, participants practiced games for the entire duration of time without any debrief or discussion. Feedback and side-coaching were limited to *Yes, and* reminders. Each session began with a 7- to 10-minute full group warm-up which opened with the theater game *1–20*, in which participants stand in a circle, looking at each other and counting consecutively from 1 to 20, randomly offering one number at a time. If two players say the same number at the same time, all must start again at one. Although considered a theater game and not an improv game by the author because it is not based upon an audience suggestion or framed by *Yes, and*, as each player's offer is prescribed to be consecutive numbers between 1 and 20, players must still listen and add, creating an attunement to each other.

Next, a series of *Yes, and*-style games in which players must say "Yes, and" before each offer were played. *One Word at a Time* games followed, in which players create sentences speaking only one word at time. Participants then played games in accordance with an appropriate challenge level for interest and enjoyment as chosen by the facilitator and the student. Games included the *Yes, and*-style and *One Word at a Time* games listed above, as well as the following: Expert-style games including Interview games whereby player(s) interview another player; Story games in which players create well-formed narratives either simultaneously as in *Mirror Story*, or by alternatively offering one word at a time or phrases and sentences at a time; Scene-based games in which players create scene like in *Alphabet*, where they must begin each line of dialogue with the next letter of the alphabet, or like in *Freeze Tag*, where players start a scene, are frozen in a position, and a new player must tag in and start a whole new scene.

Results

To assess the hypothesis and qualify if improv would change the functional connectivity of the brain, the metrics of coherence, phase lag, absolute amplitude, and LORETA were evaluated. Coherence is the measurement of the stability of phase, or the efficiency in communication between paired sites. Too much coherence at paired sites may contribute to rigidity, whereas if there is not enough coherence it may contribute to difficulty with task completion and neurological integration. Phase lag is a measurement of the speed and timing of communication between paired sites. If phase lag is too fast or too slow it impacts the usefulness of the information being communicated. Absolute amplitude is a measurement of the power of the frequencies, or µV squared. LORETA is a measurement that looks at the deeper centers of the brain related to the surface EEG. A paired *t*-test was applied to each one to look at the difference between preassessment and postassessment. The results of the averages of all participants showed noticeable changes in all the metrics.

Coherence Outcomes

Using the 10–20 international system, all 361 paired sites were evaluated. The coherence results showed a statistically significant increase in coherence both interhemispherically and intrahemispherically in many different paired sites and across all frequencies with more increases in coherence in the right hemisphere than the left, except in beta where there is almost an equal amount of change difference (see Table 1).

As shown in Figure 1, the colors of the lines represent the statistical *p*-value: the blue color represents statistically significant *p*-value in the direction of more coherence from preassessment to postassessment.

Table 1
Difference in Coherence for EEG frequency variables (delta, theta, alpha, and beta) before and after improv

Placement	Frequency	*p*-value
F7, T3	Delta	.030
Fp2, F8	Delta	.002
Fp3, T4	Delta	.032
F4, C4	Delta	.046
F4, F8	Delta	.012
C4, F8	Delta	.007
F8, T4	Delta	.016
F3, F4	Delta	.007
P3, O1	Theta	.009
O1, T5	Theta	.023
Fp2, T4	Theta	.041
F4, F8	Theta	.017
F4, T4	Theta	.028
P4, O2	Theta	.027
O2, T6	Theta	.017
F8, T4	Theta	.002
F8, T6	Theta	.031
T4, T6	Theta	.034
T5, T6	Theta	.034
Fp1, F7	Alpha	.016
Fp2, F4	Alpha	.006
F4, F8	Alpha	.007
C4, F8	Alpha	.003
P4, F8	Alpha	.001
F8, T4	Alpha	.003
Fp1, P3	Beta	.033
Fp1, o1	Beta	.030
Fp1, T3	Beta	.022
Fp1, T5	Beta	.008
Fp2, C4	Beta	.023
Fp2, P4	Beta	.043
F4, F8	Beta	.017
C4, f8	Beta	.003
P4, F8	Beta	.040
O2, F8	Beta	.036
O2, T6	Beta	.006

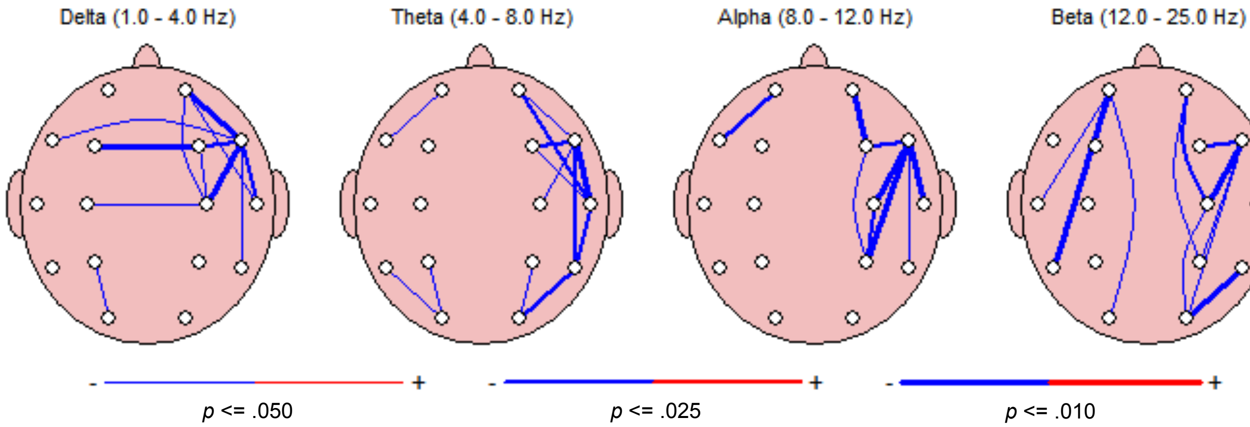


Figure 1. 10–20 results from preassessment to postassessment ($N = 28$). Any line indicates significant changes ($p < .05$) in the coherence between paired sites. Red indicates decreases, while blue indicates increases. Colored lines indicate significant changes, while the thickness of the line denotes the associated probability value ($p <= .050$, $p <= .025$, $p <= .010$).

Phase Lag

Using the 10–20 international system all 361 paired sites were evaluated. The phase lag analysis found significant change in phase lag from preassessment to postassessment, with more changes in the right hemisphere than the left. This shift indicated that after an improv session phase lag slowed down.

As shown in Figure 2, the colors of the lines represent the statistical *p*-value: the red and blue colors represent statistically significant *p*-values, where red shows a decrease in phase lag from preassessment to postassessment and blue indicates an increase in phase lag from preassessment to postassessment.

Table 2
Difference in Phase Lag for EEG frequency variables (delta, theta, alpha, and beta)

Placement	Frequency	*p*-value
C3, P3	Delta	0.034
F7, T3	Delta	0.037
C4, O2	Delta	0.050
P4, O2	Delta	0.005
C3, C4	Alpha	0.028
F4, F8	Alpha	0.032
C4, O2	Beta	0.006
P4, O2	Beta	0.001

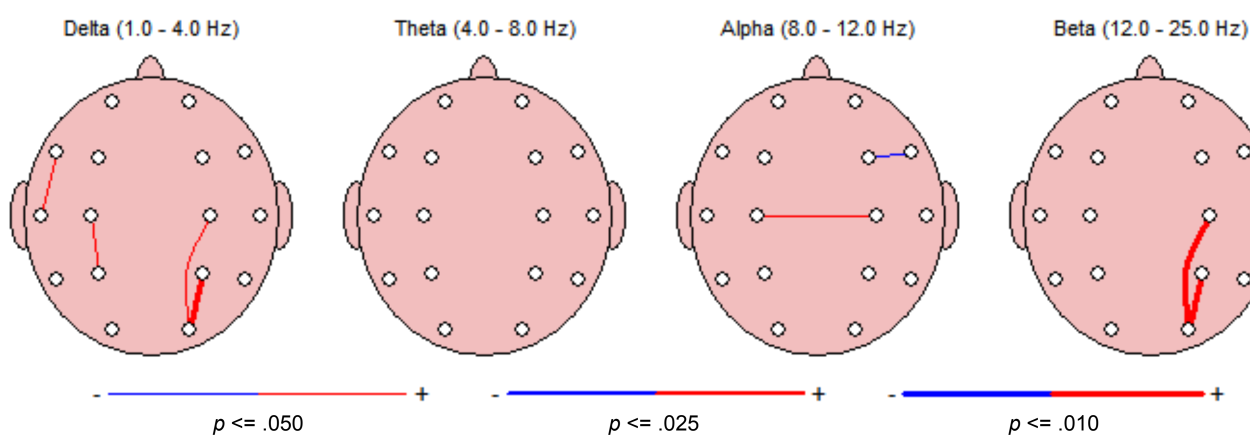


Figure 2. From preassessment to postassessment ($N = 28$). Colored lines indicate significant changes ($p < .05$) in the phase lag between paired sites. Red indicates decreases, while blue indicates increases. Colored lines indicate significant changes, while the thickness of the line denotes the associated probability value ($p <= .050$, $p <= .025$, $p <= .010$).

Absolute Power Evaluation

To investigate the difference between qEEG absolute power preassessments and postassessments, a paired *t*-test was used. It revealed a significant increase in alpha frontal at Fp1 (p = .0043), and a decrease in Delta at T4 (p = .030).

T3 showed a decrease in high beta; however, in the raw data, despite using many different methods of muscle relaxation, some participants exhibited an unconscious or chronic tension at the T3 location. It was difficult to remove all muscle artifact from the EEG at T3. It was interesting that the postassessments revealed that improv affected the participants' ability to release chronic muscle tension.

As shown in Table 3, the colors indicate statistical *p*-values and direction of change: red indicates a decrease in amplitude, while blue indicates an increase in amplitude.

Table 3
Amplitude Absolute Power maps for EEG frequency variables (delta, theta, alpha, beta, beta 1, beta 2, beta 3 and high beta)

Placement	Frequency	*p*-value
FP1-LE	Alpha	.043
T3-LE	High Beta	.042
T4-LE	Delta	.030

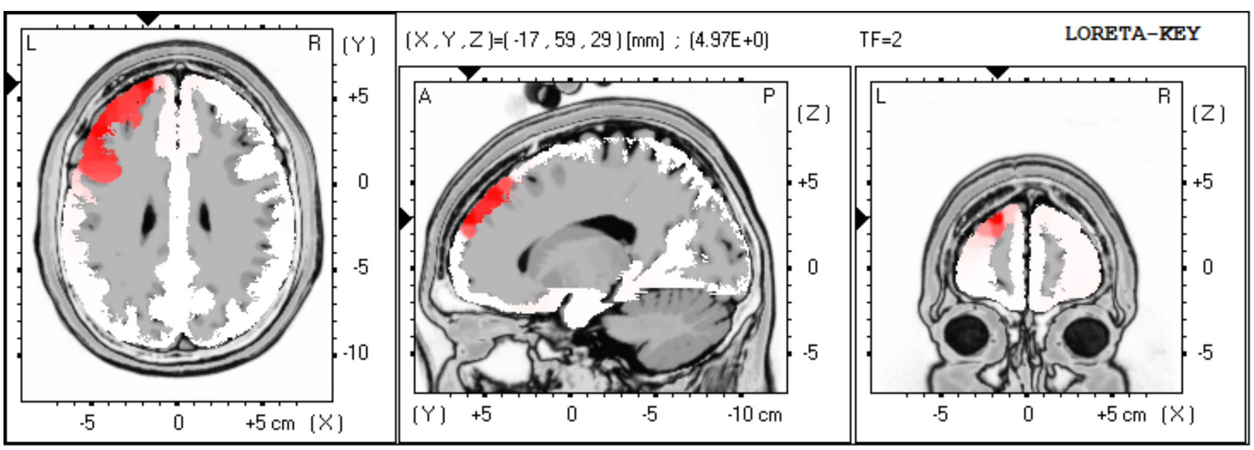
Note. Blue and red coloration of *p*-value indicate significance increases or decreases, where blue indicates an increase while red indicates a decrease in power.

LORETA Power

LORETA analysis indicated significant changes in Alpha level (p <= .05). Delta decreased in Brodmann areas (BA) 6, 10, and 24, which are medial frontal gyrus (MFG); superior frontal gyrus (SFG), $t(27)$ = 4.96; and anterior cingulate cortex (ACC), $t(27)$ = 3.90. Delta decreased from preassessment to postassessment in BA 4, BA 3, and BA 40, which are the precentral gyrus (PCG) and inferior temporal gyrus (ITG), $t(27)$ = 4.35; df = 27; p < .05. Sensorimotor rhythm (SMR) decreased in BA 6 which is the SFG, $t(27)$ = 6.1.

Figure 3
LORETA brain images: Red coloration indicated a significant decrease in activation

A



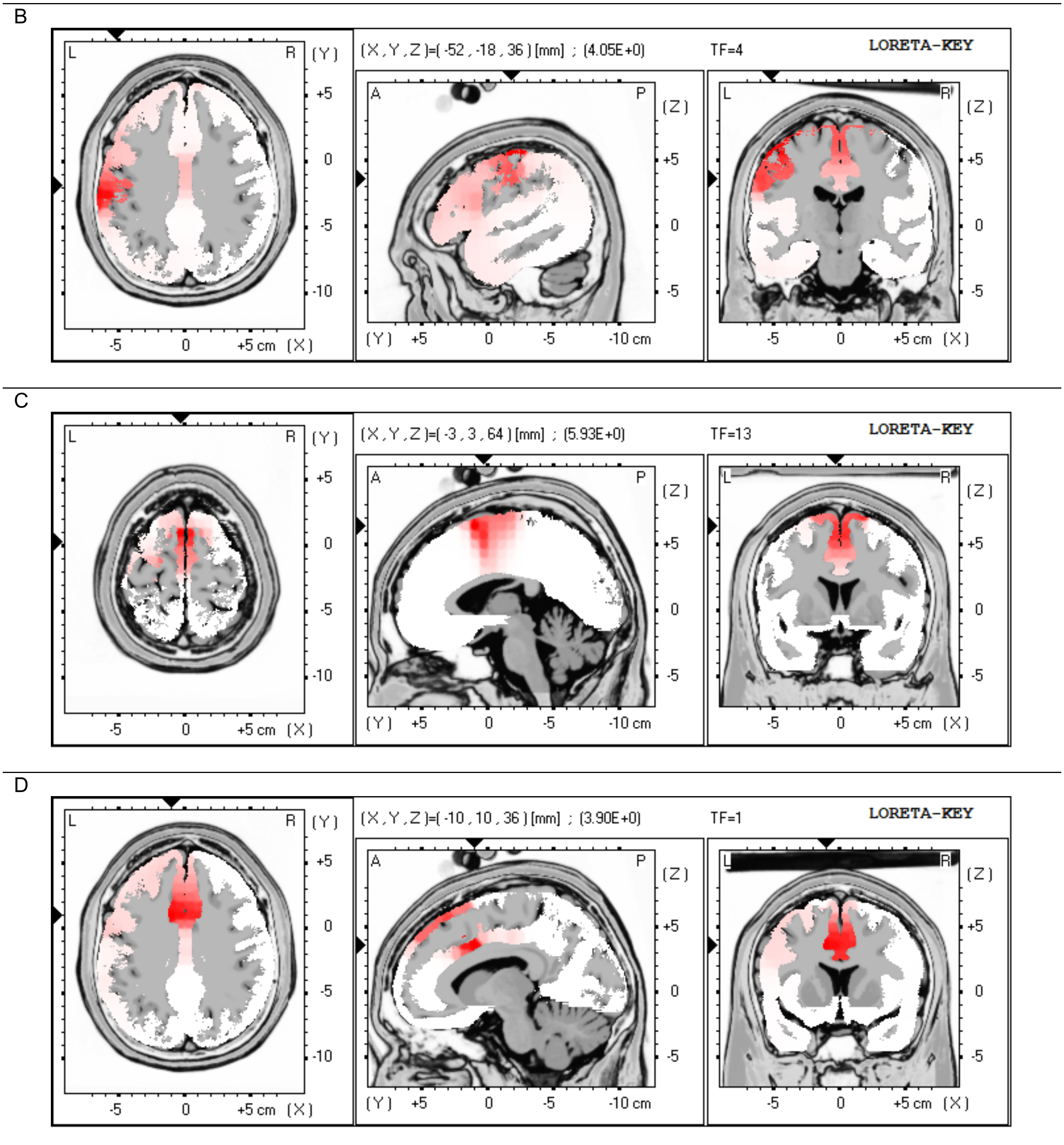


Figure 3. (A) EEG frequency 2 Hz. BA 6, BA 10 medial frontal gyrus, superior frontal gyrus: $t(27) = 4.96$; $df = 27$; $p < .05$. (B) EEG frequency 13 Hz. Red coloration indicated a significant decrease in activation. BA 6 superior frontal gyrus: $t(27) = 6.1$; $df = 27$; $p < .05$. (C) EEG frequency 4 Hz. Red coloration indicated a significant decrease in activation. BA 4, BA 3, BA 40 precentral gyrus, inferior parietal lobule: $t(27) = 4.35$; $df = 27$; $p < .05$. (D) EEG Frequency 1 Hz. BA 24 anterior cingulate: $t(27) = 3.90$; $df = 27$; $p < .05$.

Discussion

This is the first qEEG study to evaluate CDT and improv, and how it affects functional connectivity in the brain. Results indicate that improv affects the functional connectivity of the brain, activating higher cortical systems and moving individuals from a neurobiological state of survival to a state in which they are able to integrate complex problem-solving skills, to better engage in connection with themselves and others. Differing from the observation of ongoing events as seen in the existing studies involving musicians (Limb & Braun, 2008; Liu et al., 2012; McPherson et al., 2016; Sasaki et al., 2019) and those with autism (Corbett et al., 2019), a qEEG recorded before and after an improv intervention revealed results related to sustained effects of improvisation.

After one 20-min session of practicing short-form improv games framed by *Yes, and*, and participants having varying degrees of experience, results showed a change in the nervous system. While use of play to encourage epigenetic changes in the brain (Panksepp & Panksepp, 2013) may help to correct some of the effects of early life adversity when used in attachment-focused therapies (Baylin & Hughes, 2016), improv's foundational rule of *Yes, and* may be the catalyst for the observed neurobiological changes.

Coherence Discussion

The results showed an increase in coherence from preassessment to postassessment with more changes in the right hemisphere than the left. Coherence is the stability of the phase relationship between two paired sites. Too much coherence may cause the brain to become too simple and undifferentiated, impeding variation of function. Lack of coherence results in too much differentiation leading to disconnection and dissociation. While CDT impacts the right hemisphere most profoundly, promoting dissociative states, which are indicative of neuronal disconnection (Schore, 2012), increases in coherence may influence the building new neural connections (Warner, 2013), thus helping to restore normative brain function.

Since improv is setting a frame for a positive experience with the opportunity for connection, the increase in right hemisphere activation may be a shift out of disassociation and towards interpersonal connection. Improv's structure of *Yes, and* may increase coherence by creating the conditions for safety needed to shift from the survival brain to a more integrated nervous system. *Yes, and* frames each interpersonal interaction in a reciprocity of unconditional positive regard (Bermant, 2013). This positive energy and information can influence reactions of acceptance and impact coregulation. In every interaction, trust is built in oneself and with others. Additionally, *Yes, and* limits uncertainty in social interaction, thus limiting personal fear. With the conditions set for emotional safety, a shift from the survival brain to the activation of communication between other regions is possible (Baylin & Hughes, 2016). In other words, improv increases coherence and connectivity, shifting the nervous system from a predisposition of dissociation to improved stress tolerance, effectively increasing the span of the window of tolerance, and bringing arousal levels within it.

Phase Lag Discussion

Results indicated that phase decreased from preassessment to postassessment, indicating that the timing of neuronal connections decreased. Phase lag is related to the timing of communication between areas of the brain. When timing is too fast and information gets to its destination too quickly, information becomes difficult to interpret or understand. This inefficient processing may result in rumination, and obsessive thinking without clarity or understanding. This may be the reason that there is so much mental perseveration with participants with CDT. A decrease means that the brain's timing has slowed down, increasing the effectiveness of the nervous system to coordinate movement, meaning, and decisions (Warner, 2013).

Yes, and may foster the condition for the decrease in phase lag because it encourages focused attention. Focused attention is created by the spontaneity or novelty (Kagan, 2002) instigated by *Yes, and* in every interaction. With attention focused on receiving and understanding an offer, along with the increase in coherence, information becomes more efficiently timed, complex, and thus effective for personal/self-connection and social engagement.

LORETA: Sensorimotor System

Consistent with the improvisational studies involving musical and lyrical improvisation, significant activation of the sensorimotor system was observed (BA 40, BA 4, BA 6; Limb & Braun, 2008; Liu et al., 2012; McPherson et al., 2016; Sasaki et al., 2019). When underdeveloped, a sensorimotor system will negatively impact the emotional and cognitive systems; however, neuroplastic development can be experienced through play (Berghänel, Schülke, & Ostner, 2015) and improv is a form of play.

The activation of BA 6 indicates the potential for improved cognition and improved executive control (Stein, 2017) and is related to motor planning and premotor movement. This same region showed a decrease in SMR, suggesting the priming of motor cortex, essentially moving the brain to a state where movement was readily accessible. The activation of BA 40, 3, and 4 (PCG, ITG) involve the perception of space and limb location and may influence the ability to create meaning around posture and gestures, as well as access to the mirror neuron system (Carlson, 2012, p. 273–275; Reed & Caselli, 1994) and somatosensory processing (Stein, 2017). The results also indicated that improv affected the right temporal lobe, which is related to the function of auditory processing, personality, categorization, and organization (Soutar & Longo, 2011). Complex development trauma is typically characterized by a dissociation and impairment with affect regulation (Schore, 2014). The activation of these observational mechanisms within the sensorimotor system seems to be necessary conditions for attunement to oneself and others, which is essential for the formation of healthy relationships.

Yes, and may set the condition for this activation as it provides the opportunity to practice consistent and reciprocal attunement, prompting the mirror neuron system. It is plausible that with *Yes, and* the participants' brains attuned to internal and external sensory information to be better able to respond. This shift in the sensorimotor region allows for an easier experience understanding and making meaning out of verbal and nonverbal communication. Improv's effect on the sensorimotor system suggests that by participating in improv, the development of sensorimotor systems would become more refined over time.

LORETA: Medial Frontal Gyrus

Data showed the activation of the medial frontal gyrus (BA 10) which plays a critical role in human attachment neurobiology. Deficits in this region due to early adversity (Teicher et al., 2016) heighten the risk for psychiatric disorders (Schore, 2012). The activation of BA 10 is consistent with the findings of the fMRI and EEG studies of musical improvisation. This brain region is associated with higher-cognitive abilities that facilitate extraction of meaning from ongoing experiences, the organization of mental contents that control creative thinking and language, and the artistic expression and planning of future actions (Damasio, 1985; Semendeferi, Armstrong, Schleicher, Zilles, & Van Hoesen, 2001). Activation at the Fp1 location is related to the function of cognitive emotional valence, irritability, social awareness, and approach behavior (Soutar & Longo, 2011) and is important for impulse control, attention, and self-regulation. The activation of BA 10 suggests improv's ability to influence the healthy development of the brain and the orbital frontal cortex, which Schore (2012) deems essential for healthy attachment and affect regulation.

LORETA: Anterior Cingulate

Data showed an activation of the anterior cingulate. This region is implicated in motor control and emotional regulation (Etkin, Egner, & Kalisch, 2011; Landau & Limb, 2017; Pascual-Marqui, Esslen, Kochi, & Lehmann, 2002; Paus, 2001). Landau and Limb (2017) described that it "has been strongly implicated in the selection and sequencing of musical plans during improvisation" (p. 29).

While it was not determined if the DLPC quieted creating the neural signature of flow state (López-González, & Limb, 2012), the activation of MPFC (BA 10) was present. With the safety, risk, focused attention, full embodiment, and reciprocating co-creation created by *Yes, and* (Landau & Limb, 2017), improv may set the condition to exist in the span of arousal as described by Siegel (2012), which in turn triggers group flow (Sawyer, 2017) and integration. Interacting in a way where groups can exist within the span of arousal with a valence towards positive energy and information may be the pinnacle of desired human interaction and connection.

Strengths/Limitations

Neurobiological changes to the brain due to early childhood adversity are specific, depending upon the type and timing of exposure (Atzil et al., 2011; Teicher et al., 2016); therefore, those who suffer the substantial medical and psychiatric disadvantages of developmental trauma present with a comorbidity of diagnosis (Anda et al., 2006). The trauma experienced by this study's participants varied in type, timing, and origin in various domestic and international locations. While an adequate sample size of the represented individual diagnosis was not available to determine significant change specific to that diagnosis, the neurobiological changes recorded do suggest that improv may serve as a broad-based intervention to a variety of diagnosis that continue to impact health, education, correctional, societal systems, and individuals.

The main limitation to this quasi-experimental, single-group pretest–posttest study is the lack of a control. However, it can be said that based on the qEEG reliability and validity, if a participant was to receive a qEEG, spend 15 min waiting, and then receive another qEEG, that the results would look very similar, and no change would occur (Thatcher, 2010). With this in mind, it is possible to conclude that improv did change the functional connectivity of the brain. The second limitation is that there were no reliable and validated subjective surveys or cognitive assessments used. This limits the qualitative evaluation of perceived decrease in symptoms.

Conclusion

Data suggests that improv affected the functional connectivity of the brain. This impact may help the brains of adolescents with CDT, restoring their course for normal development and their ability to form healthy, connected relationships. Improv's rule of *Yes, and* is the access point to the brain as it creates the safety, attunement, and flexibility needed to achieve these neurobiological changes. Whether one's trauma has created a state of hyperarousal or hypoarousal, the conditions created by *Yes, and* drives the nervous system to self- organize towards integration and balance, thus shifting the individual from the mental state they are in to one better able to function cognitively, physically, behaviorally, and psychologically. Future research may focus on improv's effectiveness on specific diagnoses, as well as the use of longitudinal studies to determine if improv can create lasting neural change.

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NeuroRegulation

Analysis of the Quality of Diet and Academic Performance in Rural Primary School Students

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Abstract

The aim was to analyze the relationship between the quality of diet and academic performance in rural primary school students, a cross-sectional study made up of 181 rural schoolchildren (8.75 ± 1.79 years) from the island of Fuerteventura. Academic performance was calculated through the average grade in the subjects described in Royal Decree 126/2014, February 28th. The quality of the Mediterranean diet was assessed through the KIDMED questionnaire. The one-way analysis of variance (ANOVA) test did not reflect statistically significant differences in academic performance as a function of the quality of the Mediterranean diet, neither in men nor in women ($p > .005$). The multinomial logistic regression test after adjusting for sex and age, reflected that schoolchildren with a higher quality of diet were more likely to have passed the areas of Social Sciences and Natural Sciences when compared to their failed peers ($p < .05$). Thus, a higher quality of the diet in rural primary schoolchildren seems to be associated with passing the areas of Social Sciences and Natural Sciences. Health promotion professionals in the school environment must consider the positive role that diet can play in academic performance and start programs to promote healthy eating among schoolchildren.

Keywords: academic performance; cognitive health; diet; schoolchildren

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Introduction

From the current Organic Law for the Improvement of Educational Quality (LOMCE) it is extracted that one of the main objectives of the educational system in Spain is the improvement of educational quality in order to increase employability, improve results in international evaluations, unify results between communities, promote multilingualism, enhance orientation, and reduce school failure. This factor is perhaps the most significant symptom of the lack of success of the educational system (Sanz Ponce, Serrano Sarmiento, & González Bertolín, 2020).

The fact is that, in Spain, there was 24.4% administrative failure and 19% State Agency for Tax Administration (AET) in 2016 (according to the Ministry of Education and Eurostat, respectively), and that almost one in five students was below level two in PISA (in 2015). There are important individual and social consequences from compromising a generation of human capital and significantly reducing the opportunities of young people in relation to their future in the workplace (Yserte, Gallo-Rivera, & Martínez-Gautier, 2020).

In this scenario, it is especially important to focus on the processes of accumulation of knowledge and skills that occur in the successive educational stages. Also, is important to analyze what factors can explain situations of school dropout or low academic performance (AP). Since the schoolchildren will have to function as their own advocates in a world of work where low AP will translate into the development of nonroutine jobs or tasks, with low added value and, therefore, framed in a more unstable, less protected and with lower wages (Garrido-Yserte, Gallo-Rivera, & Martínez-Gautier, 2019).

In this sense, school or academic failure may be subject to different organic and environmental conditions that determine the skills and experiences of each student (Lamas, 2015). One of these factors may be the lifestyle and health behaviors adopted in childhood, since the available scientific evidence suggests that a healthy lifestyle could positively influence brain structure and function during childhood (Portolés Ariño & González Fernández, 2015; Rosa Guillamón, García Canto, & Carrillo López, 2019).

A healthy lifestyle that is suffering progressive abandonment in these age groups is the Mediterranean diet (Castells, 2008; García Cantó, Carrillo López, & Rosa Guillamón, 2019), which has been recognized as intangible heritage characterized by having a wide variety of foods rich in carbohydrates, proteins, and healthy fats such as whole grains, olive oil, legumes, nuts, fruits, and vegetables (Estruch & Ros, 2020). Some studies have described that an optimal, quality Mediterranean diet acts as a powerful indicator of cardiovascular health (Ramón-Arbués et al., 2020). Likewise, it encourages correct psychomotor and cognitive development (Bleiweiss-Sande et al., 2019; Schwingshackl, Morze, & Hoffmann, 2020).

Importantly, nutrients are critical for the developing brain; recent research on brain neurogenesis and plasticity confirms that good nutrition is important for optimal brain function throughout the lifecycle (Nyaradi, Li, Hickling, Foster, & Oddy, 2013). Figure 1 gives a diagrammatic overview of the model that informs this (Parletta, Milte, & Meyer, 2013).

In this regard, recent research in primary school students has analyzed the relationship between the quality of the diet and AP (Alfonso Rosa, Álvarez Barbosa, & del Pozo Cruz, 2018; Esteban-Cornejo et al., 2016; Faught et al., 2017; Iglesias, Planells, & Molina López, 2019; McIsaac, Kirk, & Kuhle, 2015; Nyaradi et al., 2016; Pearce et al., 2018; Vassiloudis, Yiannakouris, Panagiotakos, Apostolopoulos, & Costarelli, 2014). A systematic review reflects that there are moderate associations between the dietary intake characterized by the consumption of foods rich in energy and poor in nutrients and the general quality of the diet with respect to the results of the AP (Burrows, Goldman, Pursey, & Lim, 2017).

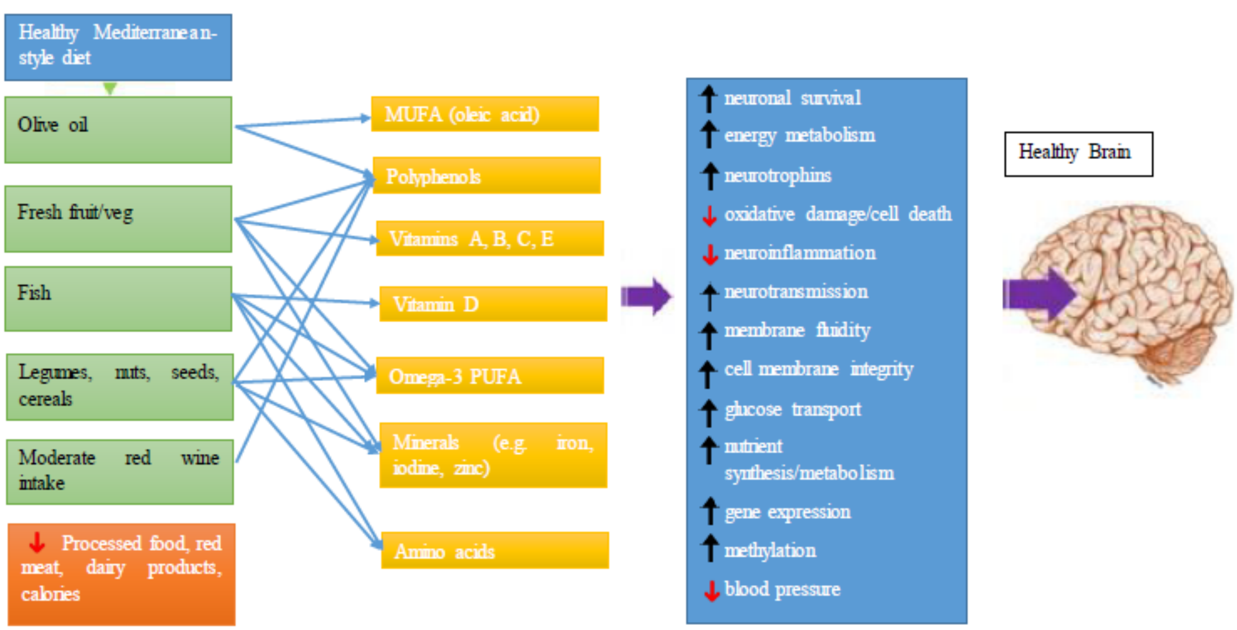

Figure 1. Overview of links between Mediterranean-style diet and healthy brain function via plant compounds/nutrients. Source: Own elaboration adapted from Parletta, Milte, and Meyer (2013).

However, there is limited evidence on the relationship between diet quality and AP in rural residence settings, in primary school children, and in AP measured over a long period of time (Bleiweiss-Sande et al., 2019), so additional research is needed (Attuquayefio, Stevenson, Oaten, & Francis, 2017; Dumuid et al., 2017; Haapala et al., 2017). Based on these precedents, the aim of this research was to analyze the relationship between the quality of the diet and the academic performance in rural primary school children of Fuerteventura.

Methods

Study Designs

A descriptive cross-sectional was designed *ex post facto* with a sample of schoolchildren belonging to a public Compulsory Education center located in a rural area (< 5000 inhabitants; LAW 45/2007, December 13th, for the development of sustainable rural environment) of the Island of Fuerteventura (Spain). The sample was made up of 181 students (99 men [54.7%] and 82 women [45.3%], with an age range between 8 and 13 years old (mean *M* ± standard deviation *SD*: 8.75 ± 1.79 years) selected in a nonprobabilistic, intentional way.

Procedure

Parents of participating students were informed about the aim of the study, risks and benefits, confidentiality of data, and privacy of information. Parents were asked if they were willing to participate in the study and were told that they had the right to refuse to participate or that they could interrupt the question at any time if they felt uncomfortable answering the question. The signed and written informed consent to participate in this study was obtained from parents and guardians since our study population was children under 18 years old.

Academic performance was assessed by means of the average grade obtained by the students in the first and second evaluation of the academic year 2019/2020, carried out in the different compulsory subjects to be taken according to what is indicated in the Primary Education curriculum (Royal Decree 126/2014, February 28th): Natural Sciences, Social Sciences, Spanish Language and Literature, Mathematics, and English. The values of all the variables ranged between a score between 1 and 10 points. Depending on the grade they obtained, the students were categorized into failed (A; ≤ 4 points) and passed (B; ≥ 5 points).

On the one hand, through the KIDMED questionnaire the quality of the Mediterranean diet was assessed (Serra-Majem et al., 2004). This questionnaire, composed of 16 dichotomous questions, has been widely used in the infant and young population (García Cantó et al., 2019; Rosa Guillamón et al., 2019). Its score can have a range between 0 and 12 points. Questions with a negative connotation acquire a negative value of one point, which are then summed with the positive scores; the sample is classified into three levels according to its diet quality: (I) ≥ 8, optimal; (II) 4–7, to improve; (III) ≤ 3, low quality.

The KIDMED questionnaire was completed by the participants in a large room with the presence of the research doctor from the Department of Plastic, Musical and Dynamic Expression of the University of Murcia, Spain. This expert on the subject explained and resolved all doubts before distributing the instrument, which also contained the sociodemographic variables: sex, age, and school year.

The protection of personal data was taken into account in order to safeguard the rights, safety, and well-being of the respondents. All of the students participated voluntarily, respecting the Helsinki research ethics agreement (2013), the current Spanish legal regulation 118 that regulates clinical research in humans (Royal Decree 561/1993 on clinical trials) and the ethical code of good practices in internships at the University of Murcia.

Data Analysis

The mean (*M*) and standard deviation (*SD*) are reported for all quantitative variables. The normality of the distributions was verified by the Kolmogorov-Smirnov test with Lilliefors correction, as well as the homogeneity of the variances by the Levene test. Subsequently, when observing a normal distribution in part of the distributions of the registered values, a parametric analysis has been chosen. A simple analysis of variance (one-way ANOVA) was used to analyze the AP values as a function of the quality of the Mediterranean diet (*Low, Medium, High*). The effect size was calculated using Cohen's *d* (.20, small; .50, medium; and .80, large effect). In addition, an analysis of bivariate and partial correlations (Pearson's test) was carried out between the quality of the diet and the different academic subjects grouped and without grouping. Finally, it was decided to perform a multinomial logistic regression to observe the probability of obtaining different results depending on whether the students failed or passed the subject. This analysis was set to an adjusted odds ratio (OR), without adjusting for the variables of age and sex. The data were analyzed with the statistical program SPSS (v.25.0). Statistical significance was set at $p < .05$.

Results

Data on age and mean score obtained in academic subjects according to adherence to MD are shown in Table 1, for both men and women. The only statistically significant differences were found for age, being in favor of women ($p = .032$; $d = .22$).

Table 2 shows the different bivariate and partial correlations observed according to the KIDMED index score and the academic subjects, adjusting and without adjusting for age and sex. No statistically significant correlation was found between the KIDMED index score and adjusted academic subjects or without adjusting for age and sex.

Finally, Table 3 presents the results of the multivariate analysis to provide a predictive analysis of the quality of the diet on academic performance. Adjusting and without adjusting for age and sex, having a higher quality of diet is associated with a greater probability of passing the areas of Natural Sciences ($p < .05$) and Social Sciences ($p < .05$).

Table 1
Sample descriptive data according to the quality of the Mediterranean diet.

	Males (*n* = 99; 54.7%) (Mean ± *SD*)					Females (*n* = 82; 45.3%) (Mean ± *SD*)				
Variables	Low QD *n* = 13 (%)	Medium QD *n* = 59 (%)	High QD *n* = 27 (%)	*p*	*d*	Low QD *n* = 12 (%)	Medium QD *n* = 49 (%)	High QD *n* = 21 (%)	*p*	*d*
Age (years)	7.85 ± 1.4	8.92 ± 1.8	9.15 ± 1.5	.071	.03	9.83 ± 1.6	8.29 ± 1.9	8.81 ± 1.6	.032	.22
Natural Sciences	6.76 ± 1.5	6.28 ± 2.1	6.18 ± 2.2	.702	.02	7.16 ± 1.6	7.10 ± 1.9	6.19 ± 1.9	.164	.16
Social Sciences	6.46 ± 1.7	6.32 ± 2.2	5.96 ± 2.5	.737	.01	6.75 ± 2.0	7.22 ± 2.0	7.04 ± 1.8	.747	.02
Spanish Language and Literature	6.38 ± 1.7	6.28 ± 1.9	5.91 ± 2.2	.701	.03	7.33 ± 1.4	6.67 ± 2.2	6.52 ± 1.9	.542	.08
Mathematics	6.84 ± 1.7	6.52 ± 2.0	6.40 ± 2.3	.827	.01	7.58 ± 1.3	6.95 ± 2.0	6.57 ± 2.0	.366	.11
English	6.76 ± 1.7	6.52 ± 2.2	6.55 ± 2.1	.936	.01	7.41 ± 1.7	7.04 ± 1.8	6.81 ± 2.0	.691	.09
Artistic education	5.92 ± 1.0	6.00 ± 1.1	6.29 ± 1.0	.444	.10	6.66 ± 0.9	6.59 ± 0.8	6.47 ± 0.8	.810	.02
Physical education	7.61 ± 1.1	7.96 ± 0.9	8.03 ± 0.8	.423	.10	8.25 ± 0.8	8.24 ± 0.8	8.19 ± 0.8	.967	.01
Core subjects	6.64 ± 1.5	6.39 ± 1.9	6.21 ± 2.0	.795	.05	7.25 ± 1.5	7.00 ± 1.8	6.62 ± 1.7	.579	.09
Specific Subjects	6.87 ± 1.1	6.92 ± 1.1	7.07 ± 1.0	.802	.06	7.47 ± 1.0	7.42 ± 0.9	7.33 ± 0.9	.909	.01

Note. One-way ANOVA statistical test.

Table 2
Bivariate and partial correlations between the mean score of the KIDMED index and the different variables of the study.

Variables	Not Adjusted R (*p*-value)	Adjusted * R (*p*-value)
Natural Sciences	.080 (.283)	.075 (.317)
Social Sciences	.025 (.738)	.039 (.603)
Spanish Language and Literature	−.072 (.820)	−.068 (.367)
Mathematics	−.065 (.384)	−.060 (.428)
English	−.012 (.868)	−.060 (.428)
Artistic education	.111 (.138)	.119 (.113)
Physical education	.067 (.371)	.078 (.298)
Core subjects	−.045 (.550)	−.038 (.617)
Specific Subjects	.059 (.431)	.076 (.314)

Note. Adjusted for sex and age *

Table 3
Academic performance according to the quality of the Mediterranean diet.

	Model I	Model II
Variables	OR (IC 95%) *p*-value	OR (IC 95%) *p*-value
Natural Sciences	0.556 (0.37–1.07) .053	0.535 (0.29–0.97) .041
Social Sciences	1.867 (1.04–3.20) .030	2.131 (1.17–3.87) .013
Spanish Language and Literature	0.836 (0.47–1.46) .529	0.758 (0.42–1.35) .347
Mathematics	0.779 (0.46–1.30) .342	0.776 (0.46–1.29) .334
English	0.940 (0.61–1.40) .773	0.934 (0.60–1.43) .754
Artistic education	1.331 (0.57–3.09) .507	1.211 (0.49–2.97) .676
Physical education	1.694 (0.72–3.96) .225	1.686 (0.71–3.96) .231
Core subjects	0.621 (0.22–2.60) .456	0.635 (0.28–3.10) .779
Specific Subjects	0.966 (0.23—3.97) .966	1.235 (0.28–5.37) .799

Note. Multinomial logistic regression considering the approved category. Model I: not adjusted for sex and age. Model II: adjusted to the sex and age of the participants.

Discussion

The aim of this study was to analyze the relationship between the quality of the Mediterranean diet and academic performance in rural schoolchildren on the island of Fuerteventura considering and without considering sex and age. The main findings of the study show that, after adjusting for sex and age, schoolchildren with a higher quality of diet were more likely to pass the areas of Social Sciences and Natural Sciences when compared to their failing peers.

These results coincide with those found in other investigations both in primary school students (Dumuid et al., 2017; McIsaac et al., 2015; Vassiloudis et al., 2014) and secondary education (Ibarra Mora, Hernández Mosqueira, & Ventura-Vall-Llovera, 2019), as well as in the university stage (Gimeno Tena & Esteve Clavero, 2020), where they detected a higher AP in the group of schoolchildren with the highest quality of diet.

It should be noted that in another investigation only an association was found between adherence to the Mediterranean diet and the grades obtained in Art Education, Mathematics, and Social Sciences in schoolchildren in Spain (Alfonso Rosa et al., 2018); while in Australian schoolchildren, a better quality diet was only associated with significantly higher scores in math, reading, writing, and spelling (Nyaradi et al., 2016). Considering compliance with international nutritional recommendations, (Faught et al., 2019) reflected that children who met current recommendations for protein-rich foods obtained an average of 5.67% and 3.45%, respectively, better in exams. Although the results indicated that adherence to dietary recommendations was beneficial for girls' AP, no results were statistically significant.

In a systematic review, only moderate associations were found between lower intakes of energy-rich and nutrient-poor foods and overall diet quality with respect to AP results (Burrows et al., 2017), and unlike Pearce et al. (2018) where they only found that AP was negatively associated with a nutrient-poor, energy-dense diet, but not with a nutritious diet. In this sense, Esteban-Cornejoet al. (2016) reflected that the benefits of adherence to the Mediterranean diet over AP seem to be stronger as young people adhere to the optimal levels of the Mediterranean diet. For example, Iglesias et al. (2019) only found that a low consumption of fruits, vegetables, and dairy products was related to a worse AR.

In this regard, a systematic review of micronutrient supplementation evaluated through randomized controlled trials suggested that only certain micronutrients appear to be associated with a marginal increase in fluent intelligence (based on reasoning skills, comparable to mathematics) but not with crystallized intelligence (verbal comprehension and vocabulary, comparable to ELA; Eilander et al., 2010). For its part, a dietary intervention rich in saturated fat for 4 days caused reductions in learning and memory dependent on the hippocampus and interoceptive sensitivity (Attuquayefio et al., 2017). In addition, the Mediterranean diet has been shown to be antioxidant, given the high consumption of fruits and vegetables. Highly toxic molecules can lead to alterations in cell lipid membranes and cellular functions, and oxidized proteins, DNA, RNA, and cell death, contributing to a variety of chronic degenerative diseases, including cardiovascular disease, cancer, and premature aging (Gandhi & Abramov, 2012). Figure 2 gives a diagrammatic overview of the model that informs this.

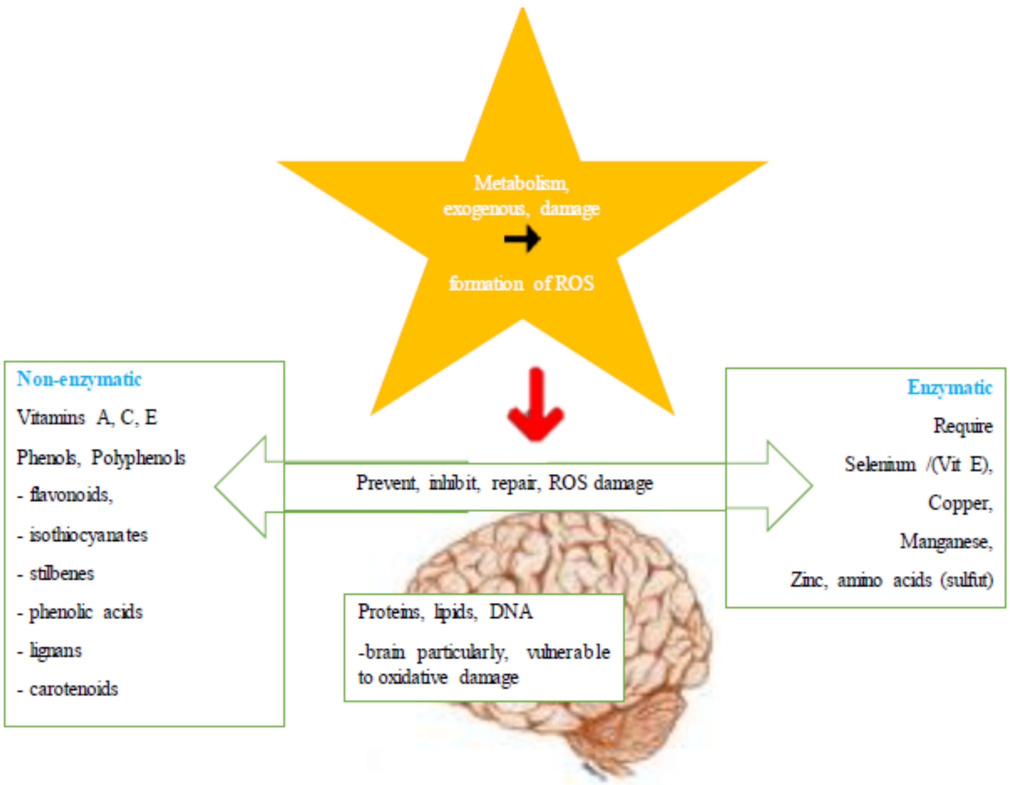

Figure 2. Antioxidant and brain overview. ROS = reactive oxygen species. Source: Own elaboration adapted from Parletta, Milte, and Meyer (2013).

Therefore, the results obtained in this study may be due to the fact that within the brain, the hippocampus is particularly sensitive to the modulation of lifestyle factors such as the Mediterranean diet. It is known that this brain structure is essential for learning and memory and for progress in the classroom, which is why it can condition AP (Hassevoort, Khan, Hillman, & Cohen, 2016).

In this sense, in schools where programs to improve the quality of the diet have been included, an improvement in AP has been obtained (Nathan et al., 2016). However, and inconsistent with this substantial evidence base, there has been a growing trend to decrease the encouragement of activities in school that promote health and to view these activities as nonessential rather than activities fundamental to the academic activity of schools (Schwingshackl et al., 2020). Therefore, the results of this study add to the growing understanding of the associations between health behaviors and AP and provide further justification for the importance of health promotion interventions to support learning goals and health in schools. In turn, it should be noted that our current study has several strengths, including the use of a population-based sample of rural schoolchildren aged 8 to 13 years and the use of academic performance scores obtained during an entire academic quarter.

However, our findings should be interpreted with caution due to the fact that this study was not interventionist but was based on data reported by schoolchildren, with an unknown quality and quantity of the food consumed daily by them. In turn, it is difficult to infer a cause-and-effect relationship between diet and AR, since there are confounding factors that probably influence AR that were not considered in this study, which would explain why our study did not find any partial or bivariate correlation between AP and diet quality. In this sense, Sørensen et al. (2016) reflected that the effects of healthy school meals on reading, impulsivity, and inattention were modified according to gender, education home, and reference reading skills. Therefore, these differential effects could be related to environmental aspects and deserve to be further investigated in future school meal trials. Likewise, the disparity of results in the set of investigations on these relationships may come as a consequence of the way of measuring or quantifying the AR.

Conclusion

The present study contributes to the scientific literature that investigates the relationship between healthy lifestyle habits, such as the quality of diet, and academic performance. Based on these results, it is concluded that a lower quality of the diet is associated with a lower academic performance in the areas of Social Sciences and Natural Sciences in rural primary school students. Future studies should shed more light on this association. Mainly, long-term and intervention studies are needed. Meanwhile, health promotion professionals in the school environment must consider the positive role that diet can play in academic performance and initiate programs to promote healthy eating among schoolchildren.

Author Disclosure

Authors have no grants, financial interests, or conflicts to disclose.

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NeuroRegulation

Is There Evidence for EEG-Neurofeedback Specificity in the Treatment of Internalizing Disorders? A Protocol for a Systematic Review and Meta-Analysis

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Abstract

Background: Mental illnesses are increasing worldwide with the internalizing disorders (IDs; e.g., anxiety disorders, depressive disorders) being the most prevalent. Current first-line therapies (e.g., pharmacotherapy) offer high failure rates and substantial side effects. Electroencephalographic neurofeedback (EEG-NFB) has been shown to be an effective and safe treatment for these conditions; however, there remains much doubt regarding the existence of specificity (i.e., clinical effects specific to the modulation of the EEG variables of interest). This is a protocol for a quantitative review that will attempt to determine if there is evidence for EEG-NFB specificity in the treatment of IDs. **Methods**: We will consider all published and unpublished randomized, double-blind (i.e., trainees and raters), sham/placebo-controlled (i.e., feedback contingent on a random signal, the activity from a different person's brain, or an unrelated signal from the trainee's own brain) trials involving humans with at least one ID diagnosis without exclusion by language, locality, ethnicity, age, or sex. Effect sizes will be calculated for individual studies and combined in a meta-analysis. **Discussion**: This protocol outlines the research methodology for a quantitative review undertaken to assess for evidence of EEG-NFB specificity in the treatment of IDs. **Registration**: This review was registered with the International Prospective Register of Systematic Reviews (PROSPERO; registration number: CRD42020159702).

Keywords: EEG; neurofeedback; internalizing disorders; emotional disorders; affective disorders

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Background and Rationale

Internalizing disorders (IDs; e.g., anxiety disorders, ANX; depressive disorders, DEP; posttraumatic stress disorder, PTSD; obsessive–compulsive disorder, OCD) are the most prevalent psychopathologies (Demyttenaere et al., 2004; Kessler et al., 2009; Kessler et al., 2007; Kessler et al., 2005; Wells et al., 2006) and can be broadly characterized by a proclivity to direct distress inwardly (Buchan, Sunderland, Carragher, Batterham, & Slade, 2014; Carragher, Krueger, Eaton, & Slade, 2015; Kotov et al., 2017; Krueger & Eaton, 2015; Rhee, Lahey, & Waldman, 2015). There are numerous shortcomings with traditional frontline ID treatments (i.e., pharmacotherapy and psychotherapy) including substantial long-term failure rates (Haller, Cohen Kadosh, Scerif, & Lau, 2015; James, James, Cowdrey, Soler, & Choke, 2015; Peters, Dunlop, & Downar, 2016; Pinter et al., 2015; Peters, Dunlop, & Downar, 2016; Pinter et al., 2019), lack of access (Andrade et al., 2014; Bandelow & Michaelis, 2015; Haller et al., 2015; Möller et al., 2016; Schoenberg & David, 2014), and marked adverse side effects (Alvares, Quintana, Hickie, & Guastella, 2016; Haller et al., 2015; Möller et al., 2016; Pinter et al., 2019; Tiller, 2013). Moreover, a decades-long drought in the discovery of new agents has prompted pharmaceutical companies to abandon the neuropsychiatric space (Buzsáki & Watson, 2012), leading to appeals from around the world for innovative interventions (Haller et al., 2015; Kris, 2018; Lancet Global Mental Health Group et al., 2007; Pinter et al., 2019).

With aberrations in the brain's electrical activity well recognized in IDs (Alhaj, Wisniewski, & McAllister-Williams, 2010; Buzsáki & Watson, 2012; Iosifescu, 2011; Jokić-Begić & Begić, 2003; Pizzagalli et al., 2002; Wahbeh & Oken, 2013), electroencephalographic neurofeedback (EEG-NFB) has been touted as a possible solution. EEG-NFB is a noninvasive form of biofeedback that teaches the brain to modify its function via a closed-loop brain–computer interface, whereby an exogenous sensory stimulus (e.g., audible tone) is fed back to the participant in real time following some predetermined electrical activity recorded from the scalp (Arns et al., 2017; Collura, 2013; Marzbani, Marateb, & Mansourian, 2016; Orndorff-Plunkett, Singh, Aragón, & Pineda, 2017; Sitaram et al., 2016). EEG-NFB is widely believed to work predominantly through operant conditioning, a type of associative learning whereby the probability of some given electrical behavior is modified via a temporally associated reinforcing stimulus (Alkoby, Abu-Rmileh, Shriki, & Todder, 2018; Enriquez-Geppert, Huster, & Herrmann, 2017; Orndorff-Plunkett et al., 2017). Although the use of EEG-NFB for IDs in routine clinical psychiatric practice has yet to receive widespread support (Arns et al., 2017; Begemann, Florisse, van Lutterveld, Kooyman, & Sommer, 2016; Omejc, Rojc, Battaglini, & Marusic, 2019), there is substantial evidence that EEG-NFB is efficacious (e.g., Askovic et al., 2019; Bell, Moss, & Kallmeyer, 2019; Cheon et al., 2017; Chiba et al., 2019; Hou et al., 2021; Noohi, Miraghaie, Arabi, & Nooripour, 2017; Orndorff-Plunkett et al., 2017; Panisch & Hai, 2018; Reiter, Andersen, & Carlsson, 2016; Ros et al., 2017; Schoenberg & David, 2014; Tolin, Davies, Moskow, & Hofmann, 2020; van der Kolk et al., 2016; Wang et al., 2019).

That said, skeptics claim that EEG-NFB's effects stem entirely from nonspecific factors (e.g., expectations, demand characteristics, context) based on multiple randomized, sham/placebo-controlled trials of attention-deficit/hyperactivity disorder (ADHD) showing comparable clinical improvements in both experimental and control groups (Ghaziri & Thibault, 2019; Neurofeedback Collaborative Group et al., 2020; Schönenberg et al., 2017a, 2017b; Thibault, Lifshitz, & Raz, 2016; Thibault, Veissière, Olson, & Raz, 2018). Among other criticisms, EEG-NFB proponents point out that evidence of EEG-learning (i.e., improvement in the targeted electrophysiological variable) in the active groups and a lack thereof in the controls, considered by many a prerequisite for the evaluation EEG-NFB's specificity (Arns, Heinrich, & Strehl, 2014; Holtmann, Sonuga-Barke, Cortese, & Brandeis, 2014; Kerson & Collaborative Neurofeedback Group, 2013; Sherlin et al., 2011; Szewczyk, Ratomska, & Jaśkiewicz, 2018; Witte, Kober, & Wood, 2018; Zuberer, Brandeis, & Drechsler, 2015), was conspicuously absent in the trials presented as evidence for wholly nonspecific effects (Pigott, Cannon, & Trullinger, 2018; Trullinger, Novian, Russell-Chapin, & Pradhan, 2019).

Objectives

The aim of our review is to comprehensively evaluate all relevant and available ID-focused randomized, double-blind, sham/placebo-controlled trials for evidence of EEG-NFB specificity via clinical outcome measures.

Eligibility Criteria

We will consider all EEG-NFB published and unpublished trials involving humans with at least one ID diagnosis per the Diagnostic and Statistical Manual of Mental Disorders (DSM; American Psychiatric Association, 2013) or the International Classification of Diseases (ICD; World Health Organization, 2018) with no exclusion by language, locality, ethnicity, age, or sex. To minimize bias and control for nonspecific effects, all trials must be randomized, double-blind (trainees and raters), and sham/placebo-controlled (i.e., feedback contingent on a random signal, the activity from a different person's brain, or an unrelated signal from the trainee's own brain).

Information Sources

Studies eligible for review will be identified in a literature search from earliest dates within multiple databases including Scopus, PubMed, Ovid MEDLINE, Cochrane Central Register of Controlled Trials (CENTRAL), Embase, Allied and Complementary Medicine (AMED), PsycInfo, and PsycExtra. The electronic database searches will be supplemented by searching for trial protocols through the World Health Organization's International Clinical Trials Registry Platform (ICTRP), ClinicalTrials.gov, and the Australia New Zealand Clinical Trials Registry (ANZCTR). Additionally, citation lists of relevant articles and previous systematic reviews will be hand-searched for trials meeting our criteria but not located by the electronic database searches.

Search Strategy

The search strategies were peer reviewed by the University's Health Sciences Librarian with expertise in systematic review searching but not otherwise associated with the project. Literature search strategies were developed using medical subject heading (MeSH) and text words related to internalizing disorders and neurofeedback. When possible, limits imposed included participant type (i.e., human) and study design (e.g., randomized controlled trial, controlled clinical trial). As an example, our search strategy for Ovid MEDLINE will use exploded subject headings linked by Boolean operators (i.e., OR, AND) as follows: exp depression/ OR exp anxiety/ OR exp fear/ OR exp anxiety disorders/ OR exp mood disorders/ OR exp neurotic disorders/ OR exp "Trauma and Stressor Related Disorders" OR exp anorexia/ OR "Feeding and Eating Disorders"/ AND exp Biofeedback, Psychology/ with limits *Humans* and *Randomized Controlled Trial*. A detailed account of the search strategies for the various databases can be found in Supplement 1.

Data Management, Selection Process, and Data Collection Process

A single reviewer will collate the list of possible studies for inclusion and export them to EndNote (version X9) where duplicates will be removed. Two independent reviewers (TP & JM) will screen titles and abstracts for eligibility. Each reviewer will independently assess full reports of trials that appear to meet the inclusion criteria, or where there is any uncertainty. We will seek additional information from study authors, via a maximum of three email requests, where necessary to resolve questions regarding eligibility. Disagreements will be resolved in discussion between TP and JM, otherwise a third team member (DA) will become involved to make the final decision. Reasons for excluding trials will be recorded. The independent reviewers will not be blinded to the journal titles, trial authors, or institutions. Data will be extracted by independent reviewers (TP & JM) via a table generated in Word (Microsoft 365). A synthesis of the findings will be generated.

Data Items

The data items extracted will include (a) first author and publication/completion year, (b) primary condition(s) under study, (c) participant demographics (e.g., ages, sexes, etc.), (d) sham/placebo type, (e) EEG-NFB protocol (e.g., targets, reward rate, number/frequency/duration of sessions), (f) clinical outcome measure, and (g) evidence of targeted EEG-learning.

Outcomes and Prioritization

Our primary outcome of interest is between-group mean difference in change/final scores collected from clinician ratings or self/parent/teacher reports. In the event of a combination of the latter, the order of preference is self > parent > teacher. In the case of multiple rating scales for a given condition, the scale querying the most central aspects of the condition under study will be selected. In the case of multiple values for a single scale (i.e., total vs. subscale scores), total scores will be used. In the case of multiple posttreatment data collection time points, values obtained furthest from treatment termination will be given preference as it is believed that long-term outcomes may help to clarify the issue of specificity (Van Doren et al., 2019). To date, standard EEG-NFB protocols have not been established for the treatment of IDs (Banerjee & Argáez, 2017); therefore, no protocols will be excluded.

Risk of Bias in Individual Studies

Two independent reviewers (TMP & JM) will assess the risk of bias using the Cochrane Risk of Bias tool version 2 (RoB 2) which covers five domains (domain 1: risk of bias arising from the randomization process; domain 2: risk of bias due to deviations from the intended interventions; domain 3: risk of bias due to missing outcome data; domain 4: risk of bias in measurement of the outcome; domain 5: risk of bias in the selection of the reported result) as well an overall risk of bias. A judgment as to the possible risk of bias (i.e., low, some concerns, or high) on each of the domains will be made from the report. If there is insufficient detail reported in the study, the original study investigators will be contacted for more information. These judgements will be made based on the criteria for judging the risk of bias (Higgins et al., 2020). Disagreements will be resolved in discussion between TMP and JM, otherwise a third team member (DA) will become involved to make the final decision.

Synthesis

If enough studies are available, a meta-analysis will be performed utilizing inverse variance and random effects modelling to generate an overall standardized mean difference (95% CI). Effect sizes (95% CI) will be calculated and displayed in a forest plot using RevMan (version 5.4.1). In cases of missing data, we will attempt to contact the trial authors to obtain the missing data. Statistical heterogeneity will be tested using the Chi^2 test (significance level: 0.1) and I^2 statistic (0% to 40%: might not be important; 30% to 60%: may represent moderate heterogeneity; 50% to 90%: may represent substantial heterogeneity; 75% to 100%: considerable heterogeneity). If high levels of heterogeneity among the trials exist (I^2 >= 50% or $p < 0.1$), important characteristics of the included studies (e.g., overall level of bias) will be analyzed via meta-regression or sensitivity analysis to try to explain the source of heterogeneity.

Meta-bias(es)

The potential for publication and small sample biases will be explored by funnel plots and Egger's test if ≥ 10 studies are available.

Confidence in Cumulative Evidence

The quality of the cumulative evidence will be assessed using the Grading of Recommendations, Assessment, Development and Evaluations (GRADE). Quality will be adjudicated as high (there is a lot of confidence that the true effect lies close to that of the estimated effect), moderate (the true effect is probably close to the estimated effect), low (the true effect might be markedly different from the estimated effect), or very low (the true effect is likely to be substantially different from the estimated effect).

Discussion

Neuropsychiatric disorders are among the most common causes of morbidity and mortality (Kessler et al., 2009) with rates markedly increasing worldwide in recent years (Duffy, Twenge, & Joiner, 2019; Haidt & Allen, 2020; Keyes, Gary, O'Malley, Hamilton, & Schulenberg, 2019; Pfeifer & Allen, 2020; Twenge, Cooper, Joiner, Duffy, & Binau, 2019). Among them, the IDs, which are characterized by distress experienced inwardly (Buchan et al., 2014; Cosgrove et al., 2011), are the most prevalent. Recently, a government inquiry here in New Zealand has shed light on the shortcomings of traditional frontline treatments (e.g., pharmacotherapy) and called for wider implementation of nonpharmaceutical approaches in treatment of mental health problems (Kris, 2018). Moreover, scientists around the world are calling for research into "novel interventions that may be based on altering plasticity or returning circuitry rather than neurotransmitter pharmacology" (Insel & Wang, 2010). EEG-NFB appears to be a safe, noninvasive, and efficacious that can be used as an adjunct or stand-alone treatment; however, there are questions regarding the nature of those effects. Specifically, there is much controversy surrounding the existence of specific effects. We hope that our review helps bring some clarity to this debate.

Author Declarations

This systematic review is part of a PhD thesis supported by the Department of Surgical Sciences, University of Otago, Dunedin, New Zealand. The department had no role in the design, implementation, analyses, interpretation, or dissemination of the results. All data generated or analyzed during this study are included in this published article and its supplementary information files. The authors declare that they have no competing interests. TMP is the guarantor and drafter of the manuscript. All authors contributed to the development of the selection criteria, the risk of bias assessment strategy and data extraction criteria. TMP developed and implemented the search strategy. PG provided expertise on mental health disorders. JM assisted with the article selections. All authors read, provided feedback, and approved the final manuscript.

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NeuroRegulation

Presession Posterior Alpha Enhancement May Accelerate Neurofeedback Learning and Response

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Abstract

Alpha band oscillations are characterized phenomenologically by a state of relaxed, unfocused attention and are implicated in enhanced learning and memory performance. Alpha power may reflect cortical inhibition in task-irrelevant brain regions, thus leaving more neural resources available to task-relevant regions and processes. In this paper we propose that a short priming session with a posterior alpha upregulation protocol may accelerate subsequent neurofeedback learning with the client's main training protocols. Neurofeedback relies to a large extent on implicit learning processes mediated by the basal ganglia and frontal cortical regions. Alpha uptraining posteriorly may inhibit task-irrelevant cortical regions dedicated mostly to explicit processing and externally oriented attention, thereby clearing the way for cortical and subcortical regions directly involved in neurofeedback learning to process the feedback more efficiently. It may thus serve to accelerate the learning process and efficacy of neurofeedback training. Various considerations and possible side effects are discussed.

Keywords: neurofeedback; EEG biofeedback; alpha upregulation; implicit procedural learning; neurofeedback priming; attention

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Background

Neurofeedback, a nondrug, noninvasive form of neurotherapy often used to treat attention-deficit/hyperactivity disorder (ADHD; Moriyama et al., 2012), anxiety (Hammond, 2005; Kerson, Sherman & Kozlowski, 2009), depression (Hammond, 2005), epilepsy (Sterman & Egner, 2006), and other neurological and neuropsychological disorders, is based on the principles of operant conditioning of brainwave patterns (Sherlin et al., 2011; Vernon et al., 2009). In this treatment paradigm, information about brainwave activity is fed back to clients, who in turn use this information to regulate their brainwave activity and bring deviant neural activity closer to age-group norms. As a result, alleviation of symptoms may ensue, along with other cognitive, emotional, and performance gains.

Training protocols in neurofeedback are usually determined by a combination of neurometric assessment (a qEEG test and brain maps) and the client's chief complaints (Hammond, 2011). Protocols may include upregulating (enhancing) or downregulating (suppressing) different EEG frequency bands in various brain regions with the aim of bringing them closer to age-group norms. EEG bands may be standard and preset (i.e., delta: up to 4 Hz, theta: 4–8 Hz, alpha: 8–12 Hz, beta: 13–30, etc.), or individually determined for each client (Bazanova & Aftanas, 2010).

While neurofeedback is an effective, efficient treatment for a host of different neuropsychiatric disorders (Niv, 2013) and has good response rates, it is a fact that some clients do not respond to this treatment modality and are unable to self-regulate their brainwaves (Emmert et al., 2016; Sitaram et al., 2017), while among responders, the speed of response and effect size vary, with some clients requiring a large number of sessions to achieve significant clinical results (Barabasz & Barabasz, 1995; Emmert et al., 2016). Accelerating the learning process in neurofeedback may prove beneficial: if clients respond to neurofeedback training faster and see clinically significant effects sooner, the chances of client retention during the critical first weeks of training increase and hence the probability of success in treatment dramatically improves.

Here we would like to suggest that presession posterior alpha upregulation may accelerate the learning process in subsequent neurofeedback training with the client's main training protocols and may therefore enhance the training efficiency and effectiveness. The main points pertaining to this proposal are as follows: alpha brainwaves have been correlated with neural inhibition of task-irrelevant cortical brain regions (Jensen & Mazaheri, 2010; Klimesch, Sauseng, & Hanslmayr, 2007). This neural inhibition may enhance learning and performance by reducing interference from task-irrelevant brain regions and processes, thereby allowing better information flow and allocation of neural resources to task-relevant brain regions (Jensen & Mazaheri, 2010). While some of the evidence for the cortical inhibition theory is correlative, there is empirical evidence that it may be causative as well: causing the brain to enhance alpha with different endogenous and exogenous methods on task-irrelevant brain regions has been shown to improve performance on a variety of different cognitive tasks. Neurofeedback has been defined as procedural skill learning, a form of nondeclarative, implicit learning, which engages cortical and subcortical regions, including a significant role of the striatum of the basal ganglia (Birbaumer, Ruiz, & Sitaram, 2013; Koralek, Jin, Long, Costa, & Carmena, 2012; Scharnowski et al., 2015; Sulzer et al., 2013; Veit et al., 2012). By actively inhibiting posterior cortical areas that are not directly involved in the implicit task of neurofeedback learning per se, presession posterior alpha upregulation just prior to (or at the same time as) the training session with the client's main training protocols may in fact reduce interference and allow more optimal information processing by task-relevant regions and networks during the subsequent self-regulation session. This priming protocol, when used on parietal brain regions involved in explicit cognitive processing, conscious awareness, and externally oriented attention, may elicit an open attentional state and facilitate the implicit, unconscious learning processes involved in neural self-regulation. Once clients start responding to this protocol, subsequent training with other training protocols may be facilitated and accelerated. Support from other adjunctive techniques that enhance the effect of neurofeedback training by modulating attention is also discussed.

Needless to say, alpha enhancement should only be performed if such a protocol is not contraindicated by the client's presenting symptoms and qEEG test, and when it does not clash with the client's other treatment protocols. Also, for clients who do not respond to neurofeedback at all, such priming may not help. For the nonresponders, depending on the cause of their inability to learn from neurofeedback, alternative exogenous and endogenous techniques that enhance alpha and do not rely on neurofeedback may achieve a facilitatory effect.

In what follows, we will elaborate on each of the points made above. In addition, we will also briefly discuss different variables pertaining to this proposal, namely electrode placement, individual versus standard alpha band upregulation, as well as a word of caution about possible iatrogenic effects that may result from excessive or contraindicated alpha upregulation. But let us first begin with a short description of the alpha band, its neural correlates and phenomenology.

The Alpha Band Frequency

The alpha band is nestled between the brain's slow waves (delta and theta) on the one end and fast waves (beta and gamma) on the other. While delta and theta are characterized by a state of drowsiness and daydreaming (and are prevalent in sleep), and the range of beta and gamma frequencies is characterized by a state of focused attention, high alertness, and concentration, reflecting neuronal processing (Jensen & Mazaheri, 2010), alpha is the "bridge" between these different brain-states and is characterized by a relaxed, calm state of open, unfocused attention (Alhambra, Fowler, & Alhambra, 1995). High alpha amplitudes may reflect an internal focus of attention (Ray & Cole, 1985), whereas low-powered alpha may indicate externally oriented attention (Hanslmayr, Gross, Klimesch, & Shapiro, 2011).

The alpha wave morphology is that of a sinusoidal wave (Klimesch, 1999; Kropotov, 2009) and is usually defined as ranging from 8 to 12 cycles per second. However, this fixed frequency band is not exhaustive of all possible alpha ranges. The alpha frequency of young, healthy adults may be somewhere between 7 Hz and 13 Hz (Klimesch et al., 2004), but a wider alpha range (6–16 Hz) has also been acknowledged (Bazanova & Aftanas, 2008). The alpha rhythm is believed to be generated and modulated by both thalamocortical and corticocortical pathways (Bollimunta, Mo, Schroeder, & Ding, 2011; Hammond, 2002).

There are different alpha rhythms in the brain, each in a different location (Kropotov, 2009). The posterior alpha rhythm, consistently localized parieto-occipitally, is the most dominant rhythm in the wakeful resting EEG in humans (Romei, Gross, & Thut, 2010). Normally, alpha has maximal power in posterior brain regions in the wakeful resting state with eyes closed, and its power decreases dramatically when the eyes are open, to allow faster waves to engage the brain in visual information processing (Adrian & Matthews, 1934), a phenomenon that has come to be known as *alpha blocking*. Posterior alpha oscillations have been found to be partly generated by areas around the calcarine fissure and secondary visual and parietal cortices (Thut, Nietzel, Brandt, & Pascual-Leone, 2006).

The alpha rhythm has been linked to memory performance (Klimesch, Doppelmayr, Pachinger & Ripper, 1997), problem solving (Jaušovec, 1996), internally directed attention (Cooper, Croft, Dominey, Burgess, & Gruzelier, 2003; Ray & Cole, 1985), creativity (Fink et al., 2009; Hardt & Gale, 1993) and hypnotizability (Faymonville, Boly, & Laureys, 2006), among other phenomena.

The alpha rhythm has also been associated with intelligence (Doppelmayr et al., 2005; Jaušovec, 1996), as research shows that highly intelligent people display more alpha power compared to those with average intelligence (Doppelmayr, Klimesch, Stadler, Pöllhuber, & Heine, 2002; Doppelmayr et al., 2005). The alpha frequency is believed to reflect the speed of an individual's cognitive processing capabilities and memory performance, since it was found to significantly correlate with an individual's response times in cognitive tasks (Surwillo, 1961). Also, experimental studies show that individuals who are deemed good performers on memory tasks have an alpha frequency that is about 1 Hz higher than that of age-matched individuals who are less competent on such tasks (Klimesch, 1999). In addition, in adults, the power and frequency of the individual alpha band decrease with age (Hammond, 2002), and greater decreases are evident in people with mild memory impairment (Jelic et al., 2000).

Alpha is not a unitary rhythm. It is composed of several frequency bands (Klimesch et al., 2007). The alpha rhythm may be divided into two subbands: lower alpha (8–10 Hz), and upper alpha (10–12 Hz; Verstraeten & Cluydts, 2002), and some researchers divide the individual alpha band further, to three different subbands (Klimesch, Doppelmayr, Russegger, Pachinger, & Schwaiger, 1998; Wu & Liu, 1995). Findings from empirical studies suggest that the lower alpha band is related to general, tonic attention, whereas the upper alpha band is related to memory (specifically, semantic memory), sensory processes, and a phasic (i.e., event-related) mode of attention (Capotosto et al., 2015; Klimesch, Doppelmayr, & Hanslmayr, 2006).

A decrease in alpha power (i.e., event-related desynchronization, or ERD) is associated with active cognitive processing, whereas an increase in alpha oscillatory power (i.e., event-related synchronization, or ERS) is associated with cortical inhibition or deactivation and internally oriented brain states and attention (Cooper et al., 2003; Hanslmayr et al., 2011; Klimesch et al., 2007) and may reflect top-down control processes (Bazanova, 2012). It was demonstrated that ERD of the lower alpha band is not restricted to a certain location, but is widespread on the scalp, whereas upper alpha ERD tends to appear in more restricted cortical regions (Klimesch et al., 2006).

An important measure that is often considered in neurometric assessments is the individual alpha peak frequency (iAPF; Arns, 2012; Bazanova & Vernon, 2014), which is the discrete frequency with the highest power within the alpha band (Angelakis et al., 2007), and as such, it is normally the most prominent rhythm in the brain in the wakeful resting state with eyes closed (Klimesch, 1999). The iAPF changes with age in an inverted u-shape fashion: low in infancy and old age and high in young adulthood and middle age (Angelakis et al., 2007), and is a little over 10 Hz for healthy, young adults (Klimesch, 1999). The iAPF may reflect processing speed (i.e., higher iAPF reflecting higher processing speed; Arns, 2012) while lower iAPF may be a characteristic of neurodegenerative diseases, anoxia, and age-related decline (Arns, 2012; Klimesch, 1999). The iAPF may also serve to define the individual alpha band and the individual theta band, and it is the anchor point between the individual lower alpha and upper alpha bands (Klimesch, 1999).

In neurofeedback, alpha may be downregulated or upregulated, depending on the client's symptoms, qEEG test and training goals. Alpha downregulation has been performed with stroke patients suffering from visuospatial neglect (Ros et al., 2017) and adults suffering from ADHD (Deiber et al., 2020) and anxiety (Kerson et al., 2009), among other disorders. Alpha upregulation may be performed to improve memory (Kober et al., 2015; Nan et al., 2012) and get clients into deeper states (as in the alpha/theta protocol) in the treatment of alcoholism, depression (Saxby & Peniston, 1995) and posttraumatic stress disorder (PTSD; Peniston, & Kulkosky, 1991). Posterior alpha enhancement protocols have also been associated with an induced sense of calm and pleasant relaxation (Angelakis et al., 2007; Norris, Lee, Cea & Burshteyn, 1998), reduced stress and anxiety among highly anxious individuals (Hardt & Kamiya, 1978) and reductions in stress response indices such as blood pressure (Norris, Lee, Burshteyn, & Cea-Aravena, 2000). Given the correlation of alpha power with cognitive performance and processing speed, alpha upregulation, especially in the upper alpha band, is a popular protocol for peak performance and cognitive enhancement (Escolano, Aguilar, & Minguez, 2011; Zoefel, Huster, & Herrmann, 2011). Alpha upregulation may be performed with eyes open (Putman, 2000) or with eyes closed (Fell et al., 2002; Hardt & Gale, 1993), and there are differing opinions among clinicians and researchers as to the most effective way to perform such training (Vernon et al., 2009).

Alpha Oscillations as Cortical Inhibition

When the brain encounters incoming stimuli, what determines how they are subsequently processed is not only the nature of each stimulus, but also the baseline neural state and ongoing neuronal dynamics in the brain at the time of stimulus presentation (Buonomano & Maass, 2009; Scharnowski et al., 2015; von Stein & Sarnthein, 2000). Research demonstrates that ongoing oscillatory activity before or during a perceptual event or a cognitive task influences subsequent perception and task performance (Angelakis et al., 2007; Hanslmayr, Sauseng, Doppelmayr, Schabus, & Klimesch, 2005; Jensen & Mazaheri, 2010). Although prestimulus alpha power may have a detrimental effect on stimulus detection under difficult perceptual conditions (Ergenoglu et al., 2004; van Dijk, Schoffelen, Oostenveld & Jensen, 2008; see Klimesch et al., 2007 for an interpretation of this finding along the lines of the cortical inhibition hypothesis), it has been found to have an enhancing effect on learning, memory, and other complex cognitive functions (Klimesch et al., 2007). Here we will focus on the enhancing effect that alpha oscillations have on learning, memory, and cognitive performance.

The functional meaning of alpha oscillations is still debated, and several hypotheses have been put forward to explain the role of this prominent EEG rhythm. Alpha oscillations were traditionally defined as the idling rhythm of the brain, reflecting reduced sensory and cognitive processing. Support for this view came from studies showing that alpha power decreases when subjects perform a task (Pfurtscheller, Stancák, & Neuper, 1996). However, an alternative, more recent hypothesis, suggesting that the role of alpha oscillations in the brain is to actively inhibit task-irrelevant brain regions in a top-down fashion, has been gaining ground and receiving substantial research support. Jensen and Mazaheri (2010) suggested that alpha oscillations (alpha ERS) reflect a state of cortical inhibition or deactivation which suppresses distractions from task-nonessential processes by actively inhibiting task-irrelevant brain regions. This inhibition gates information and routes it to task-relevant brain regions, a mechanism termed *gating by inhibition* (see also Cooper et al., 2003; Worden, Foxe, Wang, & Simpson, 2000; van Dijk et al., 2008; but see Knyazev, Savostyanov, & Levin, 2006). In this model, alpha reflects top-down control and is used to actively inhibit task-irrelevant processes and brain regions, thus increasing the signal-to-noise ratio and improving the efficiency of information processing and task performance.

Highly intelligent people exhibit more alpha (and therefore less cortical activation) in task-irrelevant brain regions during task performance compared with people of average intelligence. This may be due to the fact that more intelligent people may use only task-relevant brain regions while inhibiting other, task-irrelevant areas, whereas people with average intelligence may activate also task-irrelevant brain regions during task performance, which interferes with their ability to perform (Jaušovec, 1996). Thus, more efficient cognitive processing occurs when task-nonessential processes and brain regions are inhibited (Doppelmayr et al., 2005; Vernon et al., 2009). In support of this, alpha ERS can be seen over brain regions that are not essential for the task being performed (Klimesch et al., 2007). It is also seen in tasks in which a learned response must be withheld or inhibited, and research has demonstrated that large upper alpha ERS in a reference interval just prior to a task trial is related to large alpha ERD during the trial and to better performance (Klimesch et al., 2006; Klimesch, Doppelmayr, Röhm, Pöllhuber, & Stadler, 2000).

There are numerous studies that demonstrate this. For example, in a word sequence memorization task, word sequences that were encoded while there was an increase in parieto-occipital alpha power were better remembered than sequences that were encoded during trials of lower-voltage posterior alpha. The authors even managed to predict which words would be remembered based on the encoding-stage posterior alpha activity alone. They attributed this to the fact that the parietal and occipital lobes are not directly needed for the cognitive processing in the word-sequence encoding stage, so an efficient inhibition of these brain regions (as reflected by increased posterior alpha power) reduces interference and thus enhances performance by allowing better processing of information in task-relevant brain regions (Meeuwissen, Takashima, Fernández, & Jensen, 2011). In addition, Haegens and colleagues demonstrated alpha power increases in the somatosensory cortex ipsilateral to tactile stimuli in validly cued trials, which were associated with participants' increased accuracy and reaction speed (Haegens, Händel, & Jensen, 2011). It was suggested that such an effect may have been mediated by top-down attentional control by the frontal cortex over somatosensory alpha activity, that caused the disengagement of task-irrelevant regions (Haegens, Osipova, Oostenveld, & Jensen, 2010).

Similarly, in tasks that project stimuli in one visual hemifield at a time, alpha ERD appears in the hemisphere contralateral to the cued and attended hemifield, and at the same time, alpha ERS appears in the ipsilateral hemisphere (Kelly, Lalor, Reilly & Foxe, 2006; Worden et al., 2000). The functional meaning of this phenomenon may be that, with alpha ERD, the contralateral hemisphere is activated to process the stimulus, whereas in the ipsilateral hemisphere, alpha ERS inhibits task-irrelevant brain regions to suppress distracting stimuli and processes in order to allow for better information flow to the task-relevant hemisphere (Thut et al., 2006). The same principle seems to hold true also when it comes to brain regions dedicated to different sensory modalities. While performing tasks that require allocation of attention to one sensory modality, task-nonessential brain regions dedicated to the processing of another sensory modality show increased alpha power (Foxe, Simpson, & Ahlfors, 1998) and decreased regional cerebral blood flow (Haxby et al., 1994; Kawashima, O'Sullivan, & Roland, 1995), which reflects functional inhibition, thus leaving more resources available to the task-relevant brain regions to perform the task. Even within the same sensory modality, this dichotomy of brain activation in task-relevant regions and deactivation in task-irrelevant brain regions occurs. For example, when subjects direct their attention to a linguistic task, decreased activation is found in unrelated brain regions dedicated to the processing of motion stimuli (Rees, Frith, & Lavie, 1997). Lastly and of importance to our proposal, Ray and Cole (1985) found parietal alpha increases during cognitive and emotional tasks that did not require attention to the external environment, thus permitting more efficient processing of internal tasks.

Correlation, however, should not be equated with causation. Demonstrating that increased alpha activity in task-irrelevant brain regions improves learning and task performance does not necessitate that causally increasing alpha power will do the same. To prove causality, a few studies were conducted, demonstrating that causally enhancing alpha power in task-irrelevant brain regions may indeed improve performance. For instance, Sauseng and colleagues enhanced alpha (10 Hz) power causally with repetitive transcranial magnetic stimulation (rTMS) over the posterior parietal cortex ipsilateral to visual items to be retained in memory and found that it enhanced short-term visual memory performance, whereas a similar treatment on homologous brain regions contralaterally actually hampered performance on the task. This effect was specific to the 10 Hz stimulation over parietal brain regions (Sauseng et al., 2009). Similarly, Lustenberger and colleagues demonstrated that transcranial alternating current stimulation (tACS) to enhance frontal alpha activity bilaterally during a divergent thinking test enhanced creativity. This effect was specific to the alpha rhythm (10 Hz), as tACS at 40 Hz did not yield similar results (Lustenberger, Boyle, Foulser, Mellin, & Fröhlich, 2015). This may mean that inhibition of the rational, critical thinking frontal brain is conducive to original thinking and ideation and that it prevents internal information processing being disturbed by external stimuli (Fink, Grabner, Benedek, & Neubauer, 2006).

Evidence for the causal role of alpha oscillations in improving performance were obtained also through studies utilizing neurofeedback alpha upregulation protocols to improve performance on different tasks. For example, Bazanova, Verevkin, and Shtark (2007) found that musicians who underwent neurofeedback training to increase their upper alpha power demonstrated both increased alpha power and improved musical performance. Also, Hanslmayr and colleagues reported that using neurofeedback training to enhance the individual upper alpha band resulted in improved performance on a mental rotation task after only one session (Hanslmayr et al., 2005). Both music performance and mental rotation are skills that depend on inner control of information processing (Alexeeva, Balios, Muravlyova, Sapina, & Bazanova, 2012). These findings demonstrate how causally increasing alpha power may improve performance on such tasks. It appears that higher levels of baseline alpha power allow better flexibility in inhibiting (or not inhibiting) different processes, according to the needs of the task (Vernon et al., 2009).

Neurofeedback is considered to be a form of nondeclarative, implicit learning, with a critical role of the striatum of the basal ganglia (Birbaumer et al., 2013; Emmert et al., 2016; Koralek et al., 2012). In what follows, we suggest that presession posterior alpha upregulation may help to relatively deactivate posterior cortical regions that are not directly involved in the implicit aspects of neurofeedback learning, thus decreasing interference from task-nonessential processes and leaving more neural resources available to other brain regions and networks relevant to self-regulation learning. This may accelerate response to neurofeedback with the client's main treatment protocols and may also increase effect size. This may be compatible with both the "alpha as idling" and "alpha as cortical inhibition" hypotheses. But before we discuss this suggestion, let us briefly explore the difference between implicit and explicit types of learning and their neural correlates.

Implicit Versus Explicit Learning

The brain is a learning apparatus. There are many different types of learning, and while they can be divided and grouped by different criteria, one of the most basic divisions is between explicit, declarative learning and implicit, nondeclarative learning (Squire & Zola, 1996). Explicit learning is the kind of learning that learners have conscious awareness of, so that they can think about what they learned and articulate it to themselves and to others. Tulving (1972) divided explicit memory into episodic memory (i.e., memory of personal events) and semantic memory (i.e., memory of facts and common knowledge). Implicit (nondeclarative) learning, on the other hand, is achieved unconsciously and is hard to verbalize to others (and even to oneself). That is, implicit learning involves the acquisition of tacit knowledge which is inaccessible to conscious awareness and is expressed through performance (Reber & Squire, 1994).

Explicit and implicit learning exhibit different neural correlates and rely on qualitatively distinct neural systems (Rugg et al., 1998), with explicit memory relying more on the medial temporal lobe (the hippocampus; Eichenbaum, 1999) along with frontal and parietal cortices (Yang & Li, 2012), and certain types of implicit memory relying more on subcortical structures such as the striatum of the basal ganglia (Heindel, Salmon, Shults, Walicke, & Butters, 1989; Poldrack et al., 2001) and engaging fronto-striatal networks (Yang & Li, 2012). It was demonstrated that during implicit inferences, prefrontal regions deactivate parietal networks involved in externally oriented attention (which appears as prefrontal alpha ERD and parietal alpha ERS), while during tasks involving explicit learning and memory, the opposite pattern (i.e., prefrontal alpha ERS and parietal alpha ERD) can be seen (Wokke & Ro, 2019). It is important to note, however, that implicit and explicit learning systems may overlap and share a significant portion of the same networks (Yang & Li, 2012) and that, very often, tasks may rely on both systems (Destrebecqz et al., 2005), such as when one learns to play music (Rohrmeier & Rebuschat, 2012) or acquires a new language (Peigneux, Laureys, Delbeuck, & Maquet, 2001).

One illuminating demonstration of the functional and anatomical division between implicit and explicit learning is the double dissociation between these two types of learning in different patient populations (Packard & Knowlton, 2002). For instance, people with amnesia, who have a temporal lobe dysfunction, tend to perform well in tasks requiring implicit inferences but not in tasks requiring explicit learning and memory (Graf, Squire, & Mandler, 1984; Milner, Corkin, & Teuber, 1968), whereas Parkinson's disease patients, who have basal-ganglia dysfunction, display the opposite pattern (Knowlton, Mangels, & Squire, 1996).

Implicit, nondeclarative learning is not a single entity, but rather a set of heterogenous phenomena (Seger, Prabhakaran, Poldrack, & Gabrieli, 2000). There are different types of implicit learning, and they rely on different cortical and subcortical circuits. Under the broad category of implicit learning are different types of learning, such as: procedural learning (skills and habits), instrumental learning (reinforcement learning or operant conditioning), perceptual learning, priming, classical conditioning, classification learning, probability learning, artificial grammar learning, and more (Heindel et al., 1989; Reber & Squire, 1994; Seger et al., 2000; Sigala, Haufe, Roy, Dinse, & Ritter, 2014; Squire & Zola, 1996). Each of these engages different cortical and subcortical brain regions.

Procedural learning is the learning of automatic skills and sensorimotor habits which are mostly unconscious, such as when one learns how to juggle three or more balls or ride a bicycle (Baars & Gage, 2010). The dorsal striatum (comprised of the putamen and caudate) functions as the basal ganglia's interface to the cortex (Zotev, Misaki, Phillips, Wong, & Bodurka, 2018) and is implicated in procedural skill learning (Squire & Zola, 1996). The striatum of the basal ganglia has also been implicated in feedback learning (Grahn, Parkinson & Owen, 2008; Peters & Crone, 2017), stimulus response learning (Packard & Knowlton, 2002), and instrumental learning (Liljeholm & O'Doherty, 2012). Neurofeedback involves these types of learning and, as we will see next, it can be viewed as a complex type of nondeclarative, procedural learning.

Neurofeedback as a Form of Implicit Learning

Neurofeedback has been defined as a form of procedural skill learning (Kober, Witte, Ninaus, Neuper, & Wood, 2013; Sitaram et al., 2017) and instrumental learning (Gruzelier & Egner, 2004), and as such, it may not be an explicit conscious process, but rather an implicit type of learning (Birbaumer et al., 2013). Participants in neurofeedback training can recognize mental states and body sensations and use these to infer their brain states, but they do not have direct conscious knowledge of the neurophysiological activity in their brains per se. Indeed, it has been suggested that the role of explicit learning mechanisms in neurofeedback may be limited (Kober et al., 2013). In addition, the basal ganglia have been shown to be involved in skill learning (Squire & Zola, 1996) and instrumental learning (Yin & Knowlton, 2006), and studies of functional magnetic resonance imaging (fMRI) neurofeedback have shown the consistent involvement of the basal ganglia in neurofeedback learning as well (Emmert et al., 2016; Lawrence et al., 2014; Scharnowski et al., 2015; Sulzer et al., 2013; Veit et al., 2012).

The term implicit learning in the context of neurofeedback may be somewhat misleading. Implicit learning does not necessarily mean that the learning occurs without any conscious awareness. Rather, implicit learning involves conscious input that is processed with implicit inferences. It is these inferences and computations that are performed without conscious awareness (Baars & Gage, 2010). While some aspects of the neurofeedback training are conscious (i.e., the sensory feedback, the training room, the presence of the practitioner, and even some mental states and overt cognitive strategies during session), what constitutes the actual learning, that is, the inferences made by the brain concerning the neuronal activity that is being rewarded or inhibited (and the computations and physiological changes that have to be made to enhance or suppress such activity), is unconscious and constitutes implicit, nondeclarative learning. The fact that small children (Mohagheghi et al., 2017), toddlers (Cannon, Strunk, Carroll, & Carroll, 2018), and even animals (Kobayashi, Schultz, & Sakagami, 2010; Sterman, 1977) can successfully attain brainwave self-regulation in neurofeedback attests to the fact that neurofeedback learning is based on implicit processes. Indeed, operant conditioning of one single cortical neuron in an unanesthetized animal was shown to be feasible (Fetz, 1969), and successful neurofeedback learning was attained unconsciously by participants who were unaware that they were being trained and who had no intent to learn (Ramot, Grossman, Friedman, & Malach, 2016). In support of this, there is ample evidence that trying to employ explicit strategies during neurofeedback training may actually hamper the attainment of self-regulation (Wood, Kober, Witte, & Neuper, 2014), whereas having no conscious strategies during training may facilitate such learning (Kober et al., 2013; Sitaram et al., 2017; Witte, Kober, Ninaus, Neuper, & Wood, 2013; but see: Hardman et al., 1997). It may be that the use of overt mental strategies to try to consciously control the feedback leads to a cognitive overload, and this overload interferes with the neurofeedback learning and impedes it (Kober et al., 2013). A similar suggestion was made for other types of implicit learning as well (Chafee & Crowe, 2017; Packard & Knowlton, 2002).

Alpha Upregulation to Facilitate the Efficiency and Efficacy of Neurofeedback

In light of the inhibitory role that alpha oscillations have been shown to play at task-irrelevant brain regions (i.e., reducing interference and increasing the signal-to-noise ratio in the brain) and due to the fact that neurofeedback learning can be achieved unconsciously, relying on implicit learning mechanisms that are mediated to a large extent by subcortical structures such as the basal ganglia (along with other cortical and subcortical regions), it seems plausible to suggest that presession alpha upregulation at posterior electrode sites may accelerate subsequent neurofeedback learning with the client's main training protocols. The posterior (parietal and occipital) brain regions are known to be involved in vision, sensory perception integration (Konen & Haggard, 2014), spatial cognition, motor planning (Freedman & Ibos, 2018), visual imagery (McNorgan, 2012), conscious cognitive processing, and externally oriented attention (Wokke & Ro, 2019). Enhancing alpha power over these areas may relatively deactivate these brain regions that are not directly involved in the neurofeedback learning per se, thus allowing task-relevant brain regions to receive and process the feedback information with less interference. This may enhance the brain's ability to perform the brainwave self-regulation more efficiently and effectively. This proposal may be valid also when considering the "alpha as idling" hypothesis: idling of task-irrelevant brain regions may leave more cognitive and neural resources available to task-relevant regions and cause less distractions and interference from task-nonessential processes.

In support of this, Wood and coauthors suggest that suppressing conscious cognitive processes that are not necessary for neurofeedback is a key to improving self-regulation in neurofeedback (Wood et al., 2014). Similarly, Ninaus et al. (2013) suggested that during neurofeedback, top-down control of task-irrelevant brain regions takes place to reduce interference from such networks while the task-relevant networks perform the neurofeedback learning. Also, Rauch et al. (1997) suggested that in implicit learning, the striatum of the basal ganglia relieves corresponding cortical areas of their computational load, which could probably reflect the parieto-striatal dynamics during neurofeedback as well, since the striatum has neural connections with different regions in the parietal cortex (Cavanna & Timbler, 2006; Jarbo & Verstynen, 2015; Liljeholm & O'Doherty, 2012).

In their meta-analysis, Emmert and colleagues found consistent basal-ganglia and frontal activations during neurofeedback across the different studies that they surveyed (Emmert et al., 2016), and this confirms the important role of these regions in neurofeedback processing. In fact, in Ninaus and colleagues' study of the neural correlates of "neurofeedback" done with sham feedback only, the authors did not find any basal-ganglia activations, possibly reflecting the fact that no real feedback was given, therefore no real learning was taking place (Ninaus et al., 2013).

While the role of the basal ganglia in the implicit processes involved in neurofeedback may be established, the picture is less clear as to the role of posterior brain regions in such learning. Different studies have reported different, sometimes contradicting, patterns of parietal activations and deactivations during neurofeedback (Emmert et al., 2016; Haller, Birbaumer & Veit, 2010; Lam et al., 2020; Scharnowski et al., 2015). These differing patterns may be the result of the different target regions of interest (ROIs) focused on in these studies, as well as the different experimental and baseline conditions, modalities and forms of feedback and the instructions given to participants. They may also be the result of the different types of mental imagery used by participants (McNorgan, 2012). The parietal lobes were found to be engaged in explicit processing and externally oriented attention, and inhibited under internal implicit control through processes of executive control by the frontal lobes (Wokke & Ro, 2019). Also, alpha increases were found in the parietal lobes during tasks that do not require attention to the external environment (Ray & Cole, 1985). We would have therefore expected to see parietal deactivations during neurofeedback. However, the fact is that in some of these studies (see meta-analysis by Emmert et al., 2016) dorsal parietal activations were reported along with deactivations of areas in the medial portions of the parietal lobe (i.e., the precuneus and posterior cingulate cortex, PCC) that make up the main posterior node of the default mode network (DMN; Zotev et al., 2018). This pattern of activations and deactivations could perhaps be explained by the fact that, in these studies, participants employed overt, explicit cognitive strategies trying to *consciously control* the feedback by exerting cognitive effort. This means that they focused their attention intently on the external sensory feedback in an attempt to consciously, explicitly control it, rather than letting go, keeping an open focus and allowing their brain to process the neural feedback implicitly. It has been shown that exerting cognitive effort in goal-directed, attention-demanding tasks deactivates the precuneus and PCC (Raichle et al., 2001). It could be, therefore, that the pattern of activity revealed in Emmert et al.'s meta-analysis is a result of the explicit mental strategies and conscious, deliberate cognitive effort employed by the participants to control the feedback. In support of this, posterior brain regions involved in attention were found to be activated in explicit processing (Aizenstein et al., 2004), and the posterior parietal cortex was suggested to be involved in executive control processes during neurofeedback (Sitaram et al., 2017). Also, Veit et al. (2012) found parietal cortical activations for task conditions in neurofeedback that demanded more cognitive effort. Therefore, it may be cautiously conjectured that posterior cortical regions are not inherently involved in the implicit aspects of neurofeedback but may rather be more related to explicit cognitive strategies employed by some participants in an attempt to consciously control the external sensory feedback.

Interestingly, Scharnowski et al. (2015) found that during fMRI neurofeedback on different ROIs and in opposing directions (i.e., upregulation and downregulation of the blood-oxygenation-level-dependent, or BOLD, signal), there was unexplainable consistent deactivation of the superior and ventral visual cortices in the occipital lobe, bilaterally, even though the visual displays in the training and baseline blocks were identical. It is possible that in order to learn the neurofeedback task efficiently, the brain relatively deactivated posterior brain regions as a means to suppressing the processing of irrelevant visual information.

Further support for this idea comes from Lam et al. (2020), who found that successful learners of fMRI neurofeedback were those participants who showed greater fronto-striatal activation and decreased temporo-occipital-cerebellar activation during a response inhibition task, presumably reflecting better top-down cognitive control abilities. Similarly, an association between the ability to inhibit task-irrelevant brain regions and success in kinesthetic motor imagery fMRI neurofeedback was found by Chiew, LaConte, and Graham (2012). These findings indicate that top-down attentional and executive control processes are related to better self-regulation ability in neurofeedback (Lam et al., 2020). Indeed, in accordance with this and in line with our suggestion regarding the facilitatory effect of posterior alpha upregulation, LORETA neurofeedback parietal alpha training was found to have a positive effect on executive functions (Cannon, 2012) and LORETA neurofeedback with an alpha upregulation protocol at the precuneus was found to be related to novel learning and improvements in self-regulation, in the broader sense of the word (Cannon et al., 2014). In addition, alpha activity indices were suggested to be related to self-regulation ability (Bazanova, 2012; Bazanova, Kondratenko, Kondratenko, Mernaya & Zhimulev, 2007).

While the above-mentioned findings of the neural correlates of neurofeedback were found using fMRI-neurofeedback, it is likely that a common brain network is involved in the regulation process itself (Emmert et al., 2016) and that several aspects of neurofeedback training are constant, regardless of the method used (Ninaus et al., 2013), and may therefore be at work also in EEG-neurofeedback.

Alpha and the Facilitatory Power of Attention

The alpha upregulation priming suggested here involves attentional changes. Similar attentional changes induced by other methods have been shown to accelerate neurofeedback learning. One such attentional technique that has been used to enhance neurofeedback success is a computer-assisted mindfulness instruction just prior to a neurofeedback session (Da Costa, Bicho, & Dias, 2019, 2020). Chow and colleagues showed that mindfulness meditation is associated with an increased global full-band alpha amplitude, comparable to that achieved in an alpha upregulation neurofeedback session (Chow, Javan, Ros, & Frewen, 2017), which suggests that the facilitatory effect of mindfulness on neurofeedback may be mediated by increases in the alpha band power. Similarly, Stieger et al. (2021) demonstrated that mind-body awareness training increased participants' alpha power during rest and also accelerated their subsequent brain-computer interface (BCI) learning, a form of open-looped neurofeedback. Findings of accelerated BCI learning following mind-body awareness training were reported also by Cassady, You, Doud, and He (2014). In addition, Kober et al. (2017) demonstrated that people who are regularly involved in a spiritual practice, such as prayer, learn brainwave self-regulation faster than people who rarely pray. The authors suggest that people who regularly engage in a spiritual routine are more skillful at gating and routing incoming information about their brainwaves during neurofeedback and thus manage to avoid distracting, task-irrelevant thoughts (and hence task-irrelevant neuronal processing). Another adjunctive attentional technique suggested to be facilitatory of subsequent neurofeedback training is the Open Focus technique (Fehmi & Robbins, 2008), which proposes that when clients keep their attention open, without narrowing or focusing it on anything in particular, their alpha power increases and their subsequent neurofeedback training accelerates and improves dramatically. In line with this, it was found that, in alpha upregulation neurofeedback, participants who succeeded in enhancing their alpha power were those who kept an open focus and did not pay too much attention to the feedback tone (Biswas & Ray, 2019).

The facilitatory effects that the above cited studies found were demonstrated with an alpha or sensorimotor rhythm (SMR) uptraining neurofeedback protocol. However, an attention-modulating technique that primed and accelerated neurofeedback with different frequency bands (theta and beta) was also reported, which suggests that the priming power of attention may not be restricted to protocols enhancing the alpha band or related rhythms alone. Barabasz and Barabasz demonstrated that their Instantaneous Neuronal Activation Procedure (INAP), a short alert hypnosis procedure lasting as little as 45–90 seconds just prior to neurotherapy sessions with a theta suppression and beta enhancement protocol, yielded similar or better results than neurotherapy alone and did this in less than half the number of sessions (Barabasz & Barabasz, 1995, 1999). Although these researchers found that INAP was related to increased frontal beta (14–20 Hz), independent of neurofeedback, this technique, based on the principles of hypnosis, achieves its effect by manipulating attention networks in the brain and may therefore be related to other EEG correlates of attention as well, such as an increased alpha power. Indeed, alpha power was found to be associated with hypnotic states (Williams & Gruzelier, 2001) and hypnotizability (Faymonville et al., 2006; London, Hart, & Leibovitz, 1968).

A Word of Caution — Possible Side-Effects of Alpha Enhancement

Overtraining with any protocol is not recommended, and extra care should be taken when it comes to protocols enhancing local synchrony in slow (i.e., alpha and theta) oscillations (Sherlin, 2009). Caution should be exercised especially when performing neurofeedback with anxious or emotionally unstable individuals using an alpha enhancement protocol (Hammond, Stockdale, Hoffman, Ayers, & Nash, 2001) to avoid phenomena of unintended emotional release. Also, long sessions may cause clients to become drowsy and fatigued (Vernon et al., 2009), and this, in turn, may negatively affect alpha power (Biswas & Ray, 2019). Research has shown that after as little as 2 or 3 minutes of neurofeedback training, participants managed to increase their alpha band amplitude (Travis, Kondo, & Knott, 1974, as cited in Vernon et al., 2009), which means that short presession training of alpha upregulation may be a safe place to start. However, 10-min presession blocks may be more effective (Ancoli & Kamiya, 1978), and depending on the client's response, longer durations (20 minutes or more) may be plausible as well (Vernon et al., 2009).

The decision of whether to perform presession alpha upregulation should be made based on the client's qEEG test and presenting symptoms and should be avoided in cases in which such a protocol is contraindicated. For example, if a client's alpha power is high compared to age-group norms, enhancing alpha further should be avoided. Also, while alpha upregulation is normally associated with a sense of calm and relaxation, for some clients it may be accompanied with increased agitation, irritability, hyperarousal, and impatience. Some may experience sleep-onset delays (Bednár, 2018). Others may be disoriented and unfocused following alpha enhancement, and in some cases alpha uptraining may enhance feelings of anxiety (Thompson & Thompson, 2009) and temporary sadness (Ibric & Davis, 2007). Therefore, performing short priming sessions with an alpha upregulation protocol and increasing their duration gradually while watching the client's response would be a safe way to go about it. Also, since we do not know with certainty right from the outset how each of the clients' main training protocols would affect them, we may not want to accelerate learning too fast too soon.

Summary and Discussion

Neurofeedback is a relatively safe neurotherapy method that offers clients abundant clinical, cognitive and overall well-being advantages. However, one of the main deterring points for clients who consider whether to begin neurofeedback or not is the average time it normally takes to achieve a lasting, significant clinical effect. An average neurofeedback training series may consist of 40 to

80 sessions, which, at a rate of twice or three times a week, can take between 6 and 8 months (Barabasz & Barabasz, 1999). In addition, especially when it comes to small children, 6 to 8 months to get the desired clinical results is a relatively long period of time and, when the effects of the training start to manifest, parents sometimes attribute the changes to the natural maturation of their child. Finding a way to accelerate neurofeedback learning would yield results faster in a way that would help keep clients committed to the process and deem the maturation misjudgment in the case of children implausible (Barabasz & Barabasz, 1995).

In this paper we suggested that the learning process in neurofeedback training may be facilitated and accelerated by a short presession training with an alpha enhancement protocol over posterior brain regions. As shown here, the basal ganglia are directly involved in neurofeedback learning along with other cortical and subcortical regions. Achieving relative deactivation of posterior cortical regions dedicated to externally oriented attention and explicit sensory and cognitive processing through alpha uptraining may allow information to flow with better efficiency to the task-relevant regions involved in neurofeedback, where it would be subsequently processed with less interference and better effectiveness.

The presession alpha upregulation priming can be performed in different ways, and the training variables may vary between clients. For each client, clinicians should determine such training variables as: the duration of the presession alpha upregulation training; whether the protocol should utilize the standard alpha band or the individual alpha band (Bazanova, 2012; Bazanova & Aftanas, 2010); the lower alpha (reflective of an unaware state of relaxation), the upper alpha (reflective of an alert state and an open awareness with no focus on anything in particular in the external or internal environment; Sherlin, 2009), or the entire alpha band; whether the presession alpha training should be performed with eyes open or eyes closed (Vernon et al., 2009); as a single-channel protocol or with more than one channel (Sherlin, 2009); the exact electrode site (parietal, occipital, or another); just prior to the beginning of the session or at the same time as the client's main training protocols (if the main protocols involve a posterior placement), etc. In the question of standard versus individual alpha band, it seems that the latter is preferred, as it reflects the client's functional alpha more faithfully (Bazanova, 2012; Klimesch, 1999) and research has shown that training with the client's individual alpha is more effective than training with the preset, standard alpha band (Bazanova & Aftanas, 2010). In addition, since the individual alpha frequency changes with age, when the clients are young children, their individual alpha frequency may be much lower than the standard 8–12 Hz band (Niedermeyer, 1999). In terms of the electrode site to be trained, it seems that posterior placements are good candidates, for all the reasons detailed above, namely, the role of these cortices in externally oriented attention and explicit cognitive and sensory processing. Alpha at central sites is related to the SMR band (Kropotov, 2009) and tends to be accompanied by motor inhibition and reduced sensorimotor interference. However, SMR upregulation is related to enhanced *externally* oriented attention, as it was shown to improve performance in tasks such as shooting (Gong, Nan, Yin, Jiang, & Fu, 2020) and gulf putting (Cheng et al., 2015). Therefore, it seems that alpha enhancement in posterior sites is the preferred option, due to these regions' role in externally oriented attention and explicit cognitive and sensory processing. Experience shows that parietal alpha enhancement with eyes open may be effective. In terms of the training montage, one-channel referential alpha upregulation may lead to transient phenomena of emotional imbalance among vulnerable individuals, which is the reason why some researchers and clinicians prefer to start with either a bipolar protocol or a two-, four- or multi-channel alpha synchrony training (Sherlin, 2009).

Not in every case is a presession priming with an alpha upregulation protocol indicated. Some clients may exhibit excessive alpha power, which may be the case, for example, in some subtypes of ADHD or in depression (Byeon, Choi, Won, Lee, & Kim, 2020). Also, alpha upregulation should be avoided when there is a reason to believe that it may clash with the client's other training protocols or overall training goals. However, in cases when there is no obvious reason to decide against alpha enhancement, alpha upregulation should be considered as an adjunctive, priming protocol to be performed just prior to neurofeedback sessions. This protocol affects the client's attentional networks and thus may increase the brain's receptivity to subsequent brainwave self-regulation training. Still, for some clients, this protocol may be accompanied by iatrogenic effects, so it is recommended to start with short periods of presession alpha upregulation and to gradually increase their duration according to the client's reaction and treatment response.

To establish this suggestion empirically, controlled, large-sampled studies should be conducted, comparing the speed, efficacy, and effect size of brainwave self-regulation training with and without the priming effect of presession posterior alpha upregulation. Such studies should be performed with different training protocols following the presession training. They should be conducted with a sample of healthy subjects as well as with specific clinical populations (preferably divided by electroencephalographic endophenotypes). In addition, research should try to determine what may be the most efficient way to conduct such priming sessions in terms of the different variables outlined above.

Some clients are deemed nonresponders to neurofeedback training, and trying to prime their brain with a neurofeedback protocol may prove futile, for obvious reasons. Depending on the reasons for this inability to learn self-regulation through neural feedback (and these may vary between clients and may be cognitive, emotional, or physiological in nature), it may be that perhaps at least some of these clients would respond to neurofeedback if their brain is driven by other means, exogenous or endogenous, to produce cortical alpha brainwaves. This, in turn, may decrease resistance, modulate attention, inhibit task-irrelevant cortical regions and increase the signal-to-noise ratio, and thus clear the way for task-relevant regions to take the lead role during the subsequent neurofeedback session. This may be done just prior to the neurofeedback session (or during the session) with techniques such as audio-visual entrainment (AVE; Collura & Siever, 2009), rhythmic visual stimulation ("flicker"; Gulbinaite, van Viegen, Wieling, Cohen, & VanRullen, 2017), cranial electrotherapy stimulation (CES; Kirsch & Nichols, 2013), binaural beats (Foster, 1990) and various other brain-driving methods mentioned earlier. Even though the effects of these methods are not always apparent as alpha in posterior regions, they may induce a sense of calm and modulate attention in a way that would prove beneficial for subsequent neurofeedback training. Since the use of some of these techniques is not always feasible for every client (or for every clinician), it may also be the case that readily available endogenous, attention modulating techniques would achieve a facilitatory effect; for example, autogenic training, breathing exercises (Green & Green, 1977), mindfulness meditation (Da Costa et al., 2019, 2020), relaxation, meditating on a positive affirmation, effortless mental imagery such as pleasant scenes (Foster, 1990), and keeping an open focus without thinking of anything in particular (Fehmi & Robbins, 2008). In cases in which the clinicians are licensed hypnotherapists, the INAP (alert hypnosis) technique (Barabasz & Barabasz, 1995) may prove useful as well. The key point is to induce attentional changes that will allow implicit learning processes to take place during neural self-regulation with minimal interference from externally oriented attentional networks.

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NeuroRegulation

Avoid Zoom Fatigue, Be Present and Learn

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Abstract

This paper explores plausible reasons why some students report having more difficulty learning online, predominantly in Zoom synchronous classes, and suggests strategies that students can do to optimize their learning. During anonymous classroom observations, approximately 80% of 350 college students polled indicated it was harder to focus their attention and stay present while taking classes online. They also reported experiencing more isolation, anxiety, and depression compared to face-to-face classes, although much of this may be due to COVID-19 social isolation. Students often appear nonresponsive when attending online synchronous Zoom classes that negatively impacts the nonverbal dynamics of student–instructor interactions. Communication issues includes internet challenges, lack of facial expressions, body appearance, and movement. Students also report that it is more challenging to maintain attention, especially when they are multitasking. Suggested strategies are to optimize learning that includes arranging the camera so that you are visible, using active facial and body responses as if you are communicating to just one person face-to-face, configuring your body and environment (sitting upright and creating unique cues for each specific task), reducing multitasking and notifications, and optimizing arousal and vision regeneration.

Keywords: Zoom fatigue; communication; attention; learning

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Introduction

Overnight, the pandemic transformed college teaching from in-person to online education. Zoom[1] became the preferred academic teaching and learning platform for synchronous education. Students and faculty now sat and looked at their screens for hours. While looking at their screens, the viewers were often distracted by events in their environment, notifications from smartphones, social media, and email, which promoted multitasking (Solis, 2019). The digital distractions caused people to respond to twice as many devices with half as much attention—a process labeled *semitasking*—meaning getting twice as much done half as well.

For many students synchronous online learning was more challenging, especially after teaching was shifted to a Zoom environment without adapting the course materials to optimize online learning. During polling of 325 undergraduate university students at a metropolitan university who were all taking synchronous online Zoom classes, the vast majority reported that learning was somewhat to extremely difficult, with only the minority of students (approximately 6%) preferring online learning, as shown in Figure 1.

The increased self-report on difficulty experienced in synchronous Zoom online learning may also affect

[1] In this paper will use Zoom as the example for synchronous online teaching, although the concepts apply equally to other platforms, such Microsoft Teams and Google Meet.

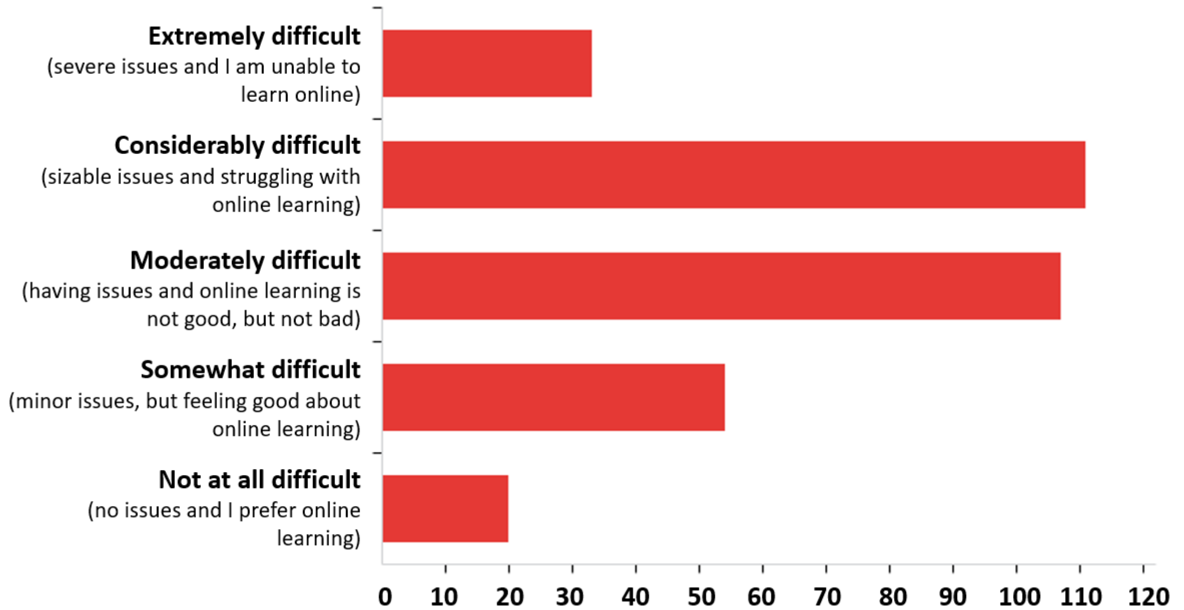

Figure 1. Survey of 325 Undergraduates comparing Zoom online learning compared to the previous in-person classes. Approximately 94% had moderate to considerable difficulty with online learning.

academic achievement. Kuhfeld et al. (2020) reported that there appears to be a significant loss in learning gains for reading and mathematics compared to a typical school year for junior and senior high school students. The actual reduction in academic achievement may depend upon multiple factors such as access to internet and computer and social support. At the same time, many people have reported an increase in physical, behavioral, and psycho-emotional problems; for example, backache, headache, stomachache, eyestrain, sore neck and shoulder pain, over- or undereating, over- or undersleeping, over- or underexercising, ruminative thoughts related to categories of anxiety or fear, boredom or numbness, depression or sadness, anger or hostility, etc. (Fosslien & Duffy, 2020; Intolo et al., 2019; Lee, 2020; Leeb et al., 2020; McGinty, Presskreischer, Anderson, Han, & Barry, 2020; Peper & Harvey, 2018; Peper, Harvey, & Faass, 2020).

This paper explores differences in communication and factors that can enhance learning during synchronous Zoom online education. The concepts are derived from our teaching athletes to sustain peak mental and physical performance, with the implication that the same concepts can help students towards sustaining on-topic attention during online learning (Wilson & Peper, 2011). In sports, the coach can help guide the athlete; however, the athlete needs to be present and motivated. Faculty have a responsibility to support, encourage, and engage students, while students have the responsibility to configure themselves into an optimum learning state.

Differences in Communication Between Live and Computer Communication

Until the 20th century, almost all communication included nonverbal expressions. The speaker used verbal and nonverbal expressions, while the respondent would immediately show a reaction to the speaker. There was a continuous dynamic verbal and nonverbal exchange. The listener would respond to the speaker. If listeners agreed, they nodded their heads. If they disagreed or were intimidated, they would provide alternative body movements (e.g., shake their head) or facial expressions (e.g., look away or frown).

During normal conversations, both the speaker's facial expression and body language are noticed and responded to, which in turn can be used as feedback by the other person. Although Zoom, Microsoft Teams, or Google Meet provide dynamic visual and auditory feedback, especially in a one-to-few session, in large group sessions with many participants, the visual feedback is reduced and facial responses are difficult to distinguish, especially when in Gallery view.

In a Zoom environment, both the sender and receiver are watching the computer screen without awareness that nonverbal cues are essential for the purpose of understanding not only what is being said but also for the implied meaning and its importance.

These nonverbal cues are usually processed without awareness in live person-to-person exchange. While sending and receiving are usually simultaneous, there can exist a disconnect between the attached meanings of the encoded information and that of the decoded information due to the inconsistent existence of important nonverbal components. In a Zoom environment, the end result could mean multiple images of receivers providing the sender with little or no nonverbal cues with which to interpret the meaning they have attached to the presenter's message. The audience may appear to look at him; however, he does not know whether they are attending to him, have a neurological disorder and cannot respond, are reading their emails, watching YouTube videos, or texting on their phone. Additionally, the nonverbal cues they are sending may not be related to his message but rather to their reaction to other media, people, or distractions not seen by the presenter.

This mode of communication is different from communication patterns that through natural selection have allowed the human species to thrive and survive. For the first time in human history we learn, teach, work, socialize, and entertain in front of the same screen. In many cases, communication in the era of smartphones has been reduced to texting, writing digital responses, or reacting to media content on any screen. Over the past few decades, it is possible for people to communicate through more disembodied, off-topic, and external modes of interaction. So many types of learning activities vie for our attention and can occur without leaving our chairs; thus, it may be difficult to stay on-topic in online Zoom classes (Keller, Davidesco, & Tanner, 2020).

Normal communication typically involves whole body movements (face, head, arms, and hands) which tends to energize or sometimes distract the speaker or listener (Kendon, 2004). When communicating with friends, we often move our bodies dynamically and responsively during the discussion. With synchronous large online lectures, students tend to be passive and just sit and watch.[2] This state of sitting and just watching the screen is similar to watching video entertainment where we sit for a long time and are covertly conditioned not to act. Thus, we have trained ourselves not to initiate action since the screen does not provide feedback to our responses—a process so different from talking and responding spontaneously in groups of participants. For many students it is more challenging to respond in an online large group, as the person becomes the focus of the group and sometimes is self-conscious and concerned about what others will think of them.

When communication is safe, people interact, respond, and chime in. In large groups, just like in large lectures, Zoom tends to inhibit this process because it delays social feedback since most people mute their microphones to avoid extraneous noise. This is usually the rule for large groups; in small groups, people often unmute themselves. The physical act of unmuting is an additional barrier to spontaneous verbal responses. This shift of attention induces a delay before responding. From a communication perspective, a delay before responding reduces the spontaneity and is often interpreted more negatively by the listener (Roberts, Margutti, & Takano, 2011).

Facial Expressions and Auditory Processing

Facial expressions are a critical part of nonverbal feedback, signaling to the other person that they are being listened to and providing cues that the interaction is safe. We unknowingly react to facial expressions—processed unconsciously through neuroception (Porges, 2017)—to indicate whether the person is signaling safety or danger. Usually when the person's facially responsiveness shows expression, it signals safety and allows communication and intimacy to be developed. If the person shows no facial expressions (a still/flat face), we unconsciously interpret this as a signal of danger (Porges, 2017). The importance of responsive feedback is illustrated in the study by Tronick, Adamson, Als, and Brazelton (1975), where mothers were instructed not to respond with facial and body cues to their infant. The babies rapidly became highly disturbed when the mother stayed nonresponsive, as dramatically illustrated in the YouTube video, *Still Face Experiment: Dr. Edward Tronick* (Tronick, 2009). In adults, lack of verbal and nonverbal feedback during social evaluations is extremely stressful (Birkett, 2011; Gruenewald, Kemeny, Aziz, & Fahey, 2004). This response is the basis of the Trier Social Stress Test (TSST) that many researchers use to explore the effect of social stress (Allen et al., 2016). The TSST requires a person to prepare a presentation, deliver a speech, and verbally respond to a challenging arithmetic

[2] Zoom and other synchronous online platforms provide tools to indicate that you would like to speak (e.g., electronic hand raising); however, it is an issue of how the class session is designed (e.g., do you use breakout rooms, are there structured requests for interaction).

problem in the presence of judges who show no emotional and nonverbal responses (Kirschbaum, Pirke, & Hellhammer, 1993).

The absence of social facial and body feedback often makes teaching and learning more challenging. Namely, are the receivers—the invisible (only their picture or name is shown), partially visible (facial features are indistinct due to backlighting), or ghosting (those whose picture and name are shown but are physically absent from the session)—understanding the information the way the sender intended? Unlike traditional classroom settings where one has the benefit of seeing and sensing nonverbal cues, often in the Zoom Gallery view the speaker may not know what how the audience is responding and this contributes to Zoom fatigue. In addition, the communication bond is often reduced when the speaker does not look at the audience and the listener does not respond to the speaker with facial expressions. Zoom fatigue can also be reduced when online teaching tools are used appropriately by involving active feedback responses through polls, chat, etc. as well as by asking specific participants to speak and give feedback.

What is unique to the synchronous online environment is that the speakers and participants view themselves. This is the first time in human history that people are seeing themselves while speaking.[3] For some people, seeing themselves may increase anxiety and negative self-judgement—a process that is even more prevalent in teens. Some are self-conscious, and some have social anxiety and do not want their face to be shown (Degges-White, 2020). In the past, most of us had no idea how we looked when we were communicating—it is totally novel experience to see yourself while talking and communicating.

Reduced Physical Activity and Increased Near Vision Stress

> *Before sheltering in place, I would walk from my house to the BART station, take the train to Daly City station, and then walk to the university. At the university, I would climb stairs to go to my office, meet with other faculty, and walk to the classroom. At the end of the day, I would walk back to the Bart station and eventually walk home. Without any thinking or trying to do any exercise, I usually would do 12,000 steps and about 25 stairs. Now, I am lucky if I do 3,000 unless I will myself to do more exercise.*

The move to a Zoom environment and sheltering in place means that we sit more and more, which tends to increase mortality, decrease subjective energy, and contribute to an attitude of passive engagement, more as an observer than as a participant (Oswald, Rumbold, Kedzior, & Moore, 2020; Patel, Maliniak, Rees-Punia, Matthews, & Gapstur, 2018; Stamatakis et al., 2019; Yalçin, Özkurt, Özmaden & Yagmur, 2020). While sitting, we also tend to slouch as we look at the screen that may be a covert factor in the increasing rates of depression and anxiety. This slouching position tends to decrease access to positive memories and allow easier access to negative memories (Peper, Lin, Harvey, & Perez, 2017) as well as interfere with academic performance. Peper, Harvey, Mason, and Lin (2018) found that students have more difficulty performing mental math in the slouched as compared to upright sitting position. To reduce the impact of sitting, Peper and Lin (2012) found that when students perform some physical activities (e.g., skipping in place) for just a minute they report significantly increased subjective energy and attention levels.

When looking at the screen our eyes only focus on the screen, which is different from in-person communication where you look at the person and then look behind or to the side of the person. Only focusing at the screen requires the muscles of the eyes to tighten for the eyes to be able to converge and the ciliary muscles around the lens contract so that the lens curvature is increased, resulting in near visual stress. This continuous looking at a near object is different from normal eye function in which we alternately focus on nearby objects and then look far away, which allows the muscles of the eyes to relax.

Student Issues

Factors that contributed to negative experiences of pandemic distance learning included obvious concerns such as social isolation, challenges with maintaining attention during distance learning classes, as well as uncontrollable disruptions and related technical issues (e.g., limited Wi-Fi, inadequate bandwidth or appropriate computer power). Typical negative experiences included reports of having little or no control over technical issues or the necessity of distance learning formats.

[3] Zoom has a feature to hide yourself when you start or join a Zoom meeting. The meeting automatically begins in Speaker View, where you can see your own video. Right-click your video to display the menu, then choose Hide Myself.

They also reported a lack of control related to job loss or receipt of any financial support to deal with income loss. A third common report included lack of a private workspace at home. Together, ruminations about various negative experiences plus lack of privacy resulted in reduced attention, especially when others in the household caused disruptions of the learning space or disruptions to other scheduled daily activities. In addition, the perceptions of loneliness may have resulted from the de facto isolation imposed by shelter-in-place pandemic policies (Jelaca, Anastasovski, & Velickovska, 2020; Lemay, Doleck, & Bazelais, 2019).

Numerous students reported that it was much easier to be distracted and multitask, check Instagram, Facebook, and TikTok, or respond to emails and texts than during face-to-face classroom sessions as illustrated by two students' comments.

> *"Now that we are forced to stay at home, it's hard to find time by myself, for myself, time to study, and or time to get away. It's easy to get distracted and go a bit stir-crazy."*

> *"I find that online learning is more difficult for me because it's harder for me to stay concentrated all day just looking at the screen."*

Students often reported that they had more difficulty remembering the materials presented during synchronous presentations. Most likely, the passivity while watching Zoom presentations affected the encoding and consolidation of new material into retrievable long-term memory. The presented material was rapidly forgotten when the next screen image or advertisement appeared and competed with the course instructor for the students' attention. We hypothesize that the many hours of watching TV and streaming videos have conditioned people to sit and take in information passively, while discouraging them to respond or initiate action (Mander, 1978; Mărchidan, 2019). Learning requires engagement, which means a shifting from passively watching and listening to being an active participant shareholder in synchronous online classes. However, in most cases, students have not received information, education, or training on how to be a more active and engaged participant in a synchronous Zoom class.

Instructor Issues

Instructors also have many of the same issues when presenting classes online. They engage in multiple simultaneous roles: presenter, director, and producer. While teaching, they need to engage students, monitor the chat for feedback, and look at the screen for facial responses. At the same time, they may face similar technical issues as those experienced by students such as internet connectivity, limited bandwidth, and mastering the technical features of synchronous online learning technology. At times, instructors feel that students expect each presentation to be as captivating as a TED Talk. Thus, teaching has shifted from education to edutainment.

Practical Suggestions to Optimize Learning

To optimize learning in the synchronous online environment, teachers have the responsibility to reconfigure their teaching so that it incorporates active student involvement, and students have the responsibility to be present and engaged. The following practices may facilitate learning.

Be Present to Learn

Mastering media presence is becoming even more important for everyone. The skill implemented in attending an online learning class will also be useful for professional development. Although the pandemic shifted personal interviews to online interviews, most likely synchronous and asynchronous video interviews will be part of the first automatic screening level to assess candidates for a job (Rubinstein, 2020).

Be visible for the other person looking at you to create a positive impression. Adjust your camera and lights so that your face is visible and you are looking at the person to whom you are talking. Your screen presence is representing you. Does the camera show you engaged, distracted, or lying in bed? Be aware that you and your background together create an impression. The concept of looking directly at the audience—looking directly at the camera—is not new. Everyone working in media (newscasters, politicians, actors) have been trained to make their faces visible and expressive. This means arranging your webcam at eye level right in front of you and speaking to the camera as if it is the person. Avoid looking down at the person on the screen since the viewer would see you looking look down and away. Be sure your face is illuminated and there are no bright light sources behind you (Purdy, 2020). We recommend that, in a small group, participants unmute their microphones so that people can respond spontaneously to each other unless there is excessive background noise.

Be a responsive and interactive listener to configure your brain to be engaged. Shift from being a passive absorber to an active participant, even if your camera is off or the speaker cannot see you. Imagine being physically with the speaker and activate yourself by increasing your face and body animation as you are attending a synchronous online class. Thus, when you watch a presentation, act as if you are in a personal conversation with the presenter or the material. This means that if you agree, nod your head; if you disagree, shake your head (do this naturally without making it a work task). Do this for the whole session. Our research has shown that when college students purposely implement animated facial and body responses during Zoom classes, they report a significant increase in energy level, attention, and involvement as compared to just attending normally in class (Peper & Yang, in press; see Figure 2).

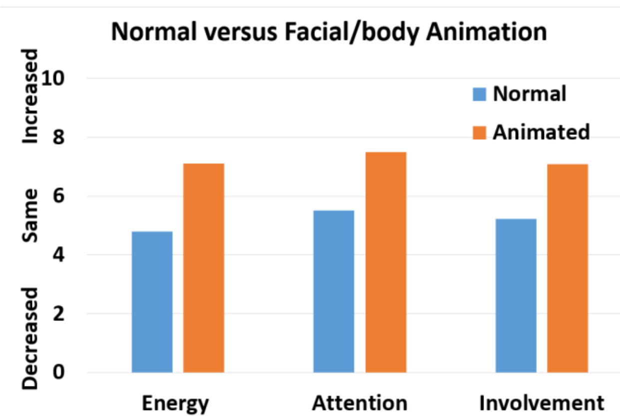

Figure 2. Change in subjective energy, attention and involvement when the students significantly increase their facial and body animation by 123 % as compared to their normal nonexpressive class behavior.

> *"I never realized how my expressions affected my attention. Class was much more fun."*
> *—22-year-old female student*

> *"I can see how paying attention and participation play a large role in learning material. After trying to give positive facial and body feedback, I felt more focused and I was taking better notes and felt I was understanding the material a bit better."*
> *—28-year-old medical student*

Configure your body to attend and perform. Sit upright and adapt a position of empowerment. When we sit upright and expanded, it is easier to have positive thoughts and detach from negative hopeless thoughts (Peper, Harvey, Mason, & Lin, 2018; Peper, Lin, Harvey, & Perez, 2017). Students also performed better in mental math when they sat upright as compared to collapsed. When students are provided ongoing feedback when they begin to slouch by an app that uses the computer camera to monitor slouching, they reported a significant decrease in neck and back symptoms (Chetwynd, Mason, Almendras, Peper, & Harvey, 2020). As one of many students reported:

> *"Before, when I didn't use the app, I had lots of shoulder and neck pain. Now when I use it, the pain went way down as I kept changing posture to the feedback signal. I had more energy and I was more alert. I did notice that when I would get the alert to sit up straight."*

Optimize Concentration and Learning

In the online environment, the structure more likely depends upon the person, unlike the externally created structure of going to work or to class. Thus, purposely creating a time structure and scheduled time periods to perform different tasks as time management skills are associated with improved school and work performance (Macan, Shahani, Dipboye, & Phillips, 1990). Create an environment to promote concentration and reduce distractions.

Stay on task and reduce interruption and practice refocusing on task. On the average we now check our phones 96 times a day—that is once every 10 minutes and an increase of 20% as compared to two years ago (Asurion, 2019). Those who do media multitasking, such as texting while doing a task, perform significantly worse on memory tasks than those who are not multitasking (Madore et al., 2020). Multitasking is negatively correlated with school performance (Giunchiglia, Zeni, Gobbi, Bignotti, & Bison, 2018). When working or attending a class or meeting, turn off all notifications (e.g., email, texts, and social media), and then block out specific times when you work on Zoom and when you respond to email, phone, or social media (Newport, 2016). Let people know that you will look at the notifications and respond in a predetermined time so that you will not be interrupted while working or studying. If you work where there are other people, arrange your workstation so that there are fewer distractions, such as sitting with your back to other people. When students chose to implement a behavior change to monitor cell phone and media use and to reduce the addictive behavior during a 5-week self-healing project, many report a significant improvement of health and performance. One student observed that when she reduced her cell phone use, her stress level equally decreased as shown in Figure 3.

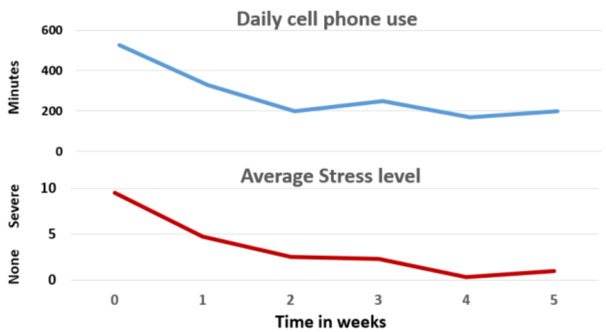

Figure 3. Example of a student changing cellphone use and corresponding decrease in subjective stress level.

During this class project, many students observed that continuous responding to notifications and social media affects their health and productivity. As one student reported,

> *The discovery of the time I wasted giving into distractions was increasing my anxiety, increasing my depression, and making me feel completely inadequate. In the 5-week period, I cut my cell phone usage by over half, from 32.5 hr to exactly 15 hr, and used some of the time to do an early morning run in the park. Rediscovering this time makes me feel like my possibilities are endless. I can go to work full time, take online night courses reaching towards my goal of a higher degree, plus complete all my homework, take care of the house and chores, cook all my meals, and add reading a book for fun!*
>
> —22-year-old college student

Approach learning with a question. When you begin to study the material or attend a class, ask yourself questions that you would like answered. If possible, put your questions to the instructor. When you have a purpose, it is easier to stay emotionally present and remember the material (Osman & Hannafin, 1994).

Take written notes while attending a Zoom meeting or class. When participants take handwritten notes versus on the computer, they tend to integrate and remember the material much more than just watching passively (Mueller & Oppenheimer, 2014). Active note-taking leads to focused attention and fewer distractions from social media content (Flanigan & Titsworth, 2020).

Review materials. At the end of the class, meet with your fellow students on Zoom or social media and review the class materials. As you discuss the materials, add comments to your notes and, if possible, do a hierarchical outline to more easily remember the relationships among the ideas.

Change your internal language. What we overtly or covertly say and believe is what we may become. When one says, "I am stupid," "I can't do math," or "It is too difficult to learn," one may feel powerless, which increases stress and inhibits cognitive function. Instead, change the internal language so that it implies that you can master the materials such as, "I need more time to study and to practice the material," "Learning just takes time, and at this moment it may take a bit longer than for someone else," or "I need a better tutor."

Create an Environment to Trigger the Appropriate Mental and Emotional State for Learning

Learning and recall are state dependent. Without awareness, the learned content is covertly associated with environmental, emotional, social, and kinesthetic cues. Thus, when you study in bed, the material is more easily accessed while lying down. When you study with music, the music becomes a retrieval cue. Without awareness, the materials are encoded with the cues of lying down or the music played in the background. When you take your exam in a different setting then you have studied, none of the covert cues are there; thus, it is more difficult to recall the material. Study and review the materials under similar conditions as where you will be tested.

To configure yourself to be ready to study, work, or socialize, create different environments that are unique to each category of Zoom involvement (studying, working, socializing, entertaining). Pre-COVID, we usually used different clothing for different events (work vs. party) or different environments for different tasks (temple, churches, mosques, or synagogue for religious practice; bar or coffee shop to meet friends). Create a unique environment with each Zoom activity. The stimuli to be associated to the specific tasks can also include lighting, odors, sound, or even drinks and food. These stimuli become the classically conditioned cues to evoke the appropriate response associated with the task, just as Pavlov conditioned dogs to salivate by pairing a sound with the meat. Taking charge of the conditioning process may help many people to focus on their tasks, as so many students use their bedroom, kitchen, or living room for Zoom work, which is not always conducive for learning or work.

Wear task-specific clothing just as you would have done going to work or school. When you plan to study, put on your study T-shirt. In time, the moment you put on the study T-shirt, you are cueing yourself to focus on studying. When finishing with studying, change your clothing.

Arrange task-specific backgrounds for each category of Zoom task. Place a different background such as a poster or wall hanging behind the computer screen—one for studying and another for entertainment. When finished with the specific Zoom event, take down the poster and change the background.

Optimize Arousal and Regenerate Vision

The longer we sit the more passive we tend to become. Teachers will benefit by interrupting the passive transfer of information by guiding students in fun short movements to increase arousal. If instructors fail to put in movement breaks, students sitting in front of screens can remind themselves to move. The challenge is that we are usually unaware of how much time has passed as we are captured by the screen. It is often helpful to use an app such as StretchBreak[4] to remind yourself to get up and move.

Get up and move every 30 min. After sitting for a 30-min stretch, wiggle and move. Do the movements with vigor or even dance, look up and reach up. When you stand up and move your legs and feet, you tighten and relax your calf muscles that pump the venous blood and lymph fluids that have been pooling in your legs back to your heart. The calf muscle is often called the second heart because in facilitates venous blood return.

Regenerate vision. Our eyes tend to get tired, and then the world looks blurry. Interrupt the near vision stress by allowing the eyes to relax and regenerate.

- **Palming.** Bring your hands to your face and cup the hands so that there is no pressure on your eyeballs. Allow the base of the hands to touch the cheeks while the fingers are interlaced and resting your forehead. Then, with your eyes closed, imagine seeing black. Breathe slowly and diaphragmatically while feeling the warmth of the palm soothing the eyes. Feel your shoulders, head, and eyes relaxing, and do this for 5 min (Peper, 2021; Schneider, 2016).

- **Look at the distance.** Interrupt near visual stress (convergence of the eyes and tightening of the ciliary muscle around the lens allows us to focus on the screen) by looking away at the far distance. Every so often look at the clouds, tops of trees, or rooftops outside the window to relax the eyes.

Summary

By activating the evolutionary communication patterns that allowed us to survive and thrive and using known performance enhancement skills derived from peak performance training, we can enhance involvement and productivity. The instructor needs to stay current on methods that keep students' attention. At the same time, students have a responsibility to configure themselves to optimize learning. We recommend practices to (1) be present and learn, (2) optimize concentration and learning, (3) create an environment to trigger the appropriate mental and emotional state for learning, and (4) optimize arousal and regenerate vision. By taking charge of your own teaching or learning process and configuring yourself to be present through active participation, learning is enhanced.

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[4] Free app available from http://www.stretchbreak.com

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NeuroRegulation

The Road Less Traveled: Integrating Neurotherapy with Holistic Neuropsychological Rehabilitation After Severe Head Injury

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Abstract

Introduction: Traumatic brain injury (TBI) is associated with physical, cognitive, emotional, and behavioral disturbances. The cognitive deficits are common after TBI, and a holistic approach to neuropsychological rehabilitation is recommended in these patients. EEG neurofeedback training (EEG-NFT) is a state-of-the-art technique for neuropsychological rehabilitation. There is a paucity of studies exploring the use of EEG-NFT integrated with holistic neuropsychological rehabilitation. **Method:** Single case design was adopted for the present study. A 25-year-old single male, diagnosed with severe TBI, presented with physical, cognitive, and emotional-behavioral disturbances after 17 months of injury. A comprehensive neuropsychological assessment was carried out. The neuropsychological rehabilitation using EEG-NFT along with psychosocial interventions with the patient and the parents was carried out for 9 months. **Results:** The patient showed significant improvement in cognitive deficits such as attention, executive functions, and visuospatial ability. Emotional-behavioral problems such as irritability, sadness, and overall dysfunction also improved significantly. **Conclusion:** The present case study highlights that integrating EEG-NFT along with holistic neuropsychological rehabilitation helps to improve cognitive, emotional, and behavioral disturbances after TBI.

Keywords: EEG neurofeedback training; neuropsychological rehabilitation; holistic neuropsychological rehabilitation; severe traumatic brain injury; neurotherapy

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Introduction

Traumatic brain injury (TBI) is a major public health concern in India. TBI not only affects the individual but it also affects the family, society, and economy at large. The rapid increase in population over the last few decades along with exponential economic growth, particularly in motorization and industrialization, has contributed to a significant increase in TBI over the years. TBI has been defined as “an alteration in brain function, or other evidence of brain pathology, caused by external force” (Menon, Schwab, Wright, & Maas, 2010). As a syndrome, it is heterogeneous in its pathophysiology and is therefore classified in terms of differing levels for severity (i.e., mild, moderate and severe) for better understanding and management (Sternbach, 2000). The Glasgow Coma Scale (GCS) is the most widely used instrument to assess the severity of TBI. A score of 8 or less after resuscitation, within 48 hours of injury is considered to represent a severe TBI (Foulkes, Eisenberg, Jane, Marmarou, & Marshall, 1991). The data across the globe shows that around 81% of all TBIs are of mild severity (Dewan et al., 2018). The impact of TBI is reflected in a wide range of physical, cognitive, emotional, and behavioral disturbances. The survivors of TBI, especially with moderate or severe TBIs, often suffer from chronic disability (Burton, 2016).

Posttraumatic Sequelae

Cognitive deficits remain at the core of problems experienced by survivors of TBI also known as posttraumatic sequelae. Studies in survivors of TBI show impairment in attention (Dikmen et al., 2009; Leclercq et al., 2000; McAvinue, O'Keeffe, McMackin, & Robertson, 2005; Reddy, Rajeswaran, Devi, & Kandavel, 2017) and speed of information processing (Madigan, DeLuca, Diamond, Tramontano, & Averill, 2000; Rassovsky et al., 2006). Deficits in complex executive functions, such as reasoning, planning, problem-solving, emotional self-regulation, decision-making, and judgment have also been reported (Dikmen et al., 2009; Rabinowitz & Lewin, 2014; Serino et al., 2006) along with impairment in memory function, predominantly in the encoding and retrieval aspects of memory (Dikmen, Machamer, Powell, & Temkin, 2003; Kersel, Marsh, Havill, & Sleigh, 2001; Rabinowitz & Levin, 2014).

Behavioral disturbances are commonly seen after TBI and often exist simultaneously along with cognitive deficits. These behavioral disturbances are seen in the form of apathy, disinhibition, agitation, aggression, and violent behavior (Rabinowitz & Levin, 2014; Stéfan & Mathé, 2016). About 50–60% of patients with severe TBI often exhibit these disturbances and have difficulties impacting multiple domains of functioning such as occupation, interpersonal relationships, and sexual functioning. Depression and anxiety are the most commonly reported emotional disturbances after TBI and can negatively affect the long term outcomes (Albrecht, Barbour, Abariga, Rao, & Perfetto, 2019; Scholten et al., 2016; War, Jamuna, & Arivazhagan, 2014). The loss of employment secondary to TBI can have further cascading effects on finances, interpersonal relationships, and quality of life (Ahmed et al., 2017; Benedictus, Spikman, & van der Naalt, 2010). Thus, as a result of these neuropsychiatric complications, several patients are left without the ability to work or to perform activities of daily living.

Neuropsychological Rehabilitation

Due to the multitude of impairments in the domains of cognition, emotion, and behavior, the neuropsychological rehabilitation of a person with TBI poses a unique challenge. Neuropsychological rehabilitation is defined as a process concerned with the amelioration of cognitive, emotional, psychosocial, and behavioral deficits caused by an insult to the brain (Wilson, 2008). Neural plasticity, the main principle underlying neuropsychological rehabilitation, refers to the ability of the nervous system to adapt itself, structurally and functionally, in response to experience and injury (von Bernhardi, Eugenín-von Bernhardi, & Eugenín, 2017). There are different forms of neuropsychological rehabilitation such as cognitive retraining, computer-based retraining, EEG-neurofeedback training (EEG-NFT). A holistic approach to neuropsychological rehabilitation is recommended which not only addresses the cognitive impairments but also equally emphasize on the emotional-behavioral, sexual, and vocational issues (Rajeswaran, 2012).

EEG-neurofeedback training (EEG-NFT) is a relatively newer neuroscience-based intervention modality, which is increasingly being used for in a wide range of clinical conditions. EEG-NFT works on the principles of operant conditioning and is deemed to be potent to modify the structural and functional abnormalities in cortico-cortical and cortico-subcortical neural networks (Munivenkatappa, Rajeswaren, Indira Devi, Bennet, & Upadhyay, 2014). Single case studies and case series of EEG-NFT in patients with TBI showed improvements in executive functions, learning and memory, anosmia, agraphia, anxiety, and depressive symptoms (Bennett, Rajeswaran, Sampath, & Christopher, 2013; Byers, 1995; Hammond, 2007; Reddy, Jamuna, Indira Devi, & Thennarasu, 2009; Thornton, 2000). The studies with larger samples have replicated these results. Another study, by Zorcec, Demerdzieva, and Pop-Jordanova (2011) examined the effects of EEG-NFT in six patients with TBI. Following 20 sessions of EEG-NFT, five of the six patients were able to return to normal education, and all reported improvements in mood, sleep, and cognition. May, Benson, Balon, and Boutros (2013) conducted a review of published studies pertaining to the utility of EEG-NFT in patients with TBI. They concluded that EEG-NFT is probably effective in the rehabilitation after TBI; however, the heterogeneity of the syndrome poses a big challenge to draw any strong inferences from the available body of literature.

The beginning of the 21st century marked the introduction of EEG-NFT in India as a method of neuropsychological rehabilitation. Since then, many scientific investigations using EEG-NFT have been carried out. Twenty sessions of EEG-NFT, each lasting for 40 min on alternate days with a protocol targeting to increase alpha and decrease theta resulted in significant improvements in a wide range of cognitive functions such as processing speed, attention, executive functions, visuospatial construction, learning, and memory in patients with TBI (Reddy, Rajeswaran, Indira Devi, & Kandavel, 2013). EEG-NFT was also found to be useful in improving subjective symptom reporting, perceived stress, and quality of life (Bennett et al., 2018; Bennett, Sampath, Christopher, Thennarasu, & Rajeswaran, 2017; Reddy, Rajeswaran, Bhagavatula, & Kandavel, 2014). These findings suggest that EEG-NFT can lead to dual benefit (i.e., by bringing about improvement in cognitive functions as well as in emotional-behavioral functioning).

EEG-NFT is used extensively in neuropsychological rehabilitation after TBI. There are recent studies attempting to unravel the mechanism of EEG-NFT. Munivenkatappa et al. (2014) reported a significant increase in the cortical grey matter volume, enhanced white matter integrity, and increased global functional connectivity in two patients with severe TBI who received 20 sessions of EEG-NFT. Another recent study had shown that 20 sessions of EEG-NFT resulted in reduced postconcussion symptoms, reduced delta–alpha, and increased theta–alpha ratio on quantitative EEG (Gupta, Afsar, Yadav, Shukla, & Rajeswaran, 2020). These findings indicate that EEG-NFT can bring about changes in neural functioning and thereby result in clinical improvement.

The published literature indicates positive effects of EEG-NFT in the improvement of both subjective symptom reporting and objective measures of neuropsychological functioning in TBI; however, the findings are primarily limited to mild and moderate TBI. More studies are needed to establish its effectiveness in patients with severe TBI. The current literature has shown the usefulness of holistic neuropsychological rehabilitation after TBI (Ben-Yishay & Diller, 2011; Cicerone et al., 2008). However, most of the studies exploring the effectiveness of EEG-NFT in TBI have taken EEG-NFT as a standalone technique of neuropsychological rehabilitation. It is widely agreed that a condition such as TBI results in disturbance in psychological and emotional functioning of the individual and also brings about significant distress and burnout in caregivers (Ahmed et al., 2017; Qadeer et al., 2017). There is a paucity of literature on the use of EEG-NFT in conjunction with holistic neuropsychological rehabilitation. Therefore, the present case study attempts to explore the role of EEG-NFT integrated neuropsychological rehabilitation in a patient with severe TBI.

Methods

The present study adopted a longitudinal case study design with repeated measurements over time. Verbal and written informed consent were obtained from the patient as well as family members.

Case Details

Mr. AB is a 25-year-old single male, who was pursuing an MBA after completing his graduation in commerce. He was apparently well until he was involved in a road traffic accident while riding his bike without a helmet in August 2017. The details of the accident were not known as there were no bystanders. He was found unconscious by other people on the road and rushed to the local medical center. He had bleeding from his mouth and left ear. There was no known history of seizure or vomiting. After an initial evaluation and life support, he was shifted to a neurosurgical facility for further evaluation and management. On arrival to the neurosurgery emergency, his GCS score was reported to be $E_1V_1M_4$(06/15), suggestive of severe TBI. A CT scan of the brain was performed immediately, and it revealed fracture of the left ramus of the mandible and left temporal bone extending to sphenoid and odontoid processes. There was evidence of bleeding in cerebral cisterns. These symptoms were managed medically. An MRI of the brain done after 10 days of injury revealed multifocal acute onset hemorrhagic contusions in the left fronto-temporal cortical region, splenium and rostrum of corpus callosum, left side of midbrain, and upper part of the pons. There was further evidence of left fronto-temporo-parietal subdural hematoma with intraventricular haemorrhage. He was diagnosed with severe TBI with diffuse axonal injury (DAI) Grade III. The patient had posttraumatic amnesia for 3 months postinjury.

He was discharged after 2 months and had been undergoing physiotherapy and occupational therapy since discharge. He was showing gradual improvement. The patient presented to our center in February 2019 after 17 months of TBI. At the time of presentation, the chief complaints were rapid forgetting (forgetting recent conversations and what he had eaten for the last meal, not being able to remember the name of the therapist despite meeting him on a daily basis), behavioural changes in the form of impulsivity, poor frustration tolerance, irritability, and anger outbursts. His parents also reported that he had frequent crying spells, would often express death wishes, and had a negative view of self. These disturbances were secondary to his cognitive deficits and were often momentary in nature. He also had partial vision loss in the right visual field and mild residual weakness in his right half of the body. These complaints were being managed through an ophthalmology consultation and physiotherapy. Furthermore, he had speech and language-related issues such as difficulty naming objects, along with mild slurring of speech.

During the initial clinical evaluation, it was noticed that Mr. AB would get impatient frequently and would keep leaving the evaluation room. A lability in affect was noticed, with short periods of irritability seen several times during the session. He would be keen on performing certain tasks during the assessment but would lose interest quickly. When unable to recall certain things and events, he would keep responding “I don’t know” and would ask the clinician to ask his parents instead. There was evidence of spontaneous confabulation, in terms of coming up with approximate answers to fill in the memory gaps. Further attempts to coax him to respond to these questions would be reciprocated with irritability. He reported feeling sad and having occasional death wishes. These complaints were associated with the termination of a longstanding romantic relationship, a sudden discontinuation of his education, and a sense of being incapacitated due to the TBI. He spoke loudly and his speech was mildly slurred. He would keep interrupting the therapist during the initial interview and assessment and would become restless quickly.

A comprehensive neuropsychological assessment (NPA) was carried out using NIMHANS neuropsychological battery for head injury (Rao, Subbakrishna, & Gopukumar, 2004). The NIMHANS neuropsychological battery for head injury is a standardized neuropsychological battery that has been validated and widely used in the Indian population. Age and education matched norms are used for interpretation of the scores. The battery evaluates a range of cognitive domains including speed of information processing, focused attention, semantic fluency, working memory, planning, response inhibition, visuospatial construction, learning, and memory. These domains are assessed using eight different tests. The scores obtained are converted into percentiles using the normative data. The variables with a corresponding percentile of 15 or below are considered to be in impaired range. The visual analogue scale (VAS) was also used to assess the caregiver's impression of the level of emotional and behavioral disturbances in the patient. In VAS, caregivers are asked to rate the severity of symptoms or concern observed by them on a scale of zero to ten (0–10), where higher scores reflect more severe problems.

The baseline NPA (Test-1) indicated impairment in the cognitive domains processing speed, focused attention, working memory, semantic fluency, response inhibition, visual-spatial construction, and learning and memory (both verbal and visual). The VAS ratings were obtained from the father and showed very severe problems of forgetfulness and disorientation, followed by irritability. The overall dysfunction rating was 40%. The findings from the baseline as well as follow-up NPA are given in Table 1.

During the process of initial evaluation and baseline assessments, it was found that there was significant helplessness and burnout present in the patient’s parents. The parents also lacked understanding about the patient’s condition, which consequently led to high expectations about recovery. Furthermore, his demanding and impulsive behavior, in conjunction with the parents’ poor knowledge about illness, resulted in the overinvolvement of the parents in terms of carrying out activities of daily living for him, restricting his social interaction, and easily giving into his demands. It is noteworthy that even before the injury there was a significant amount of overinvolvement by the mother with the patient's upbringing, as he is a single child. It was hypothesized that this long-standing parental overprotection, combined with postinjury deficits, had resulted in the patient assuming a sick role and poor motivation to actively participate in the rehabilitation. The impact of the patient’s TBI had caused a significant amount of emotional distress to the mother, who reported frequent crying spells and other depressive symptoms.

On the basis of the clinical data gathered from multiple sources, such as the review of previous records, initial interview, and neuropsychological assessment, the overall dysfunction experienced by Mr. AB was formulated using a model of postconcussive symptoms (Yeates, 2010), which is presented in Figure 1.

Table 1

Findings from neuropsychological assessment (NPA) and visual analogue scale (VAS) at various time points.

Functions	Tests	Test-1 02/01/2019	Test-2 03/21/2019	Test-3 07/02/2019	Test-4 11/19/2019
Mental Speed	Digit Symbol Test	5	8	8	21
Focused Attention	Color Trails Test - 1	10	64	30	27
	Color Trails Test - 2	49	35	49	30
Semantic Fluency	Animals Names Test	3	13	18	10
Working Memory	Spatial Span Test	40	23	23	75
Response Inhibition	Stroop Test	Not Done*	2	5	64
Planning	Tower of London	90	94	80	90
Visual-Spatial Construction	CFT - Copy	3	10	5	55
Visual Memory	CFT - Immediate Recall	3	3	3	3
	CFT - Delayed Recall	3	3	3	3
Verbal Learning and Memory	AVLT - Total Learning	3	3	3	3
	AVLT - Immediate Recall	3	3	3	3
	AVLT - Delayed Recall	3	3	3	3
	AVLT - % Retention	3	3	3	14
	AVLT - Recognition (Hits)	3	3	20	25
Subjective Report of Caregivers	VAS - Forgetfulness	9	7	6	6
	VAS - Irritability	6	4	3	1
	VAS - Sadness	7	6	7	5
	VAS - Speech	3	2	1	1
	VAS - Disorientation	9	6	5	2
	VAS - Overall Deficits	40%	25%	20%	15%

Note. * = The test was attempted but had to be discontinued as the patient was finding it extremely difficult to name the colors; CFT - Complex figure test; AVLT - Auditory verbal learning test; VAS - Visual analogue scale.

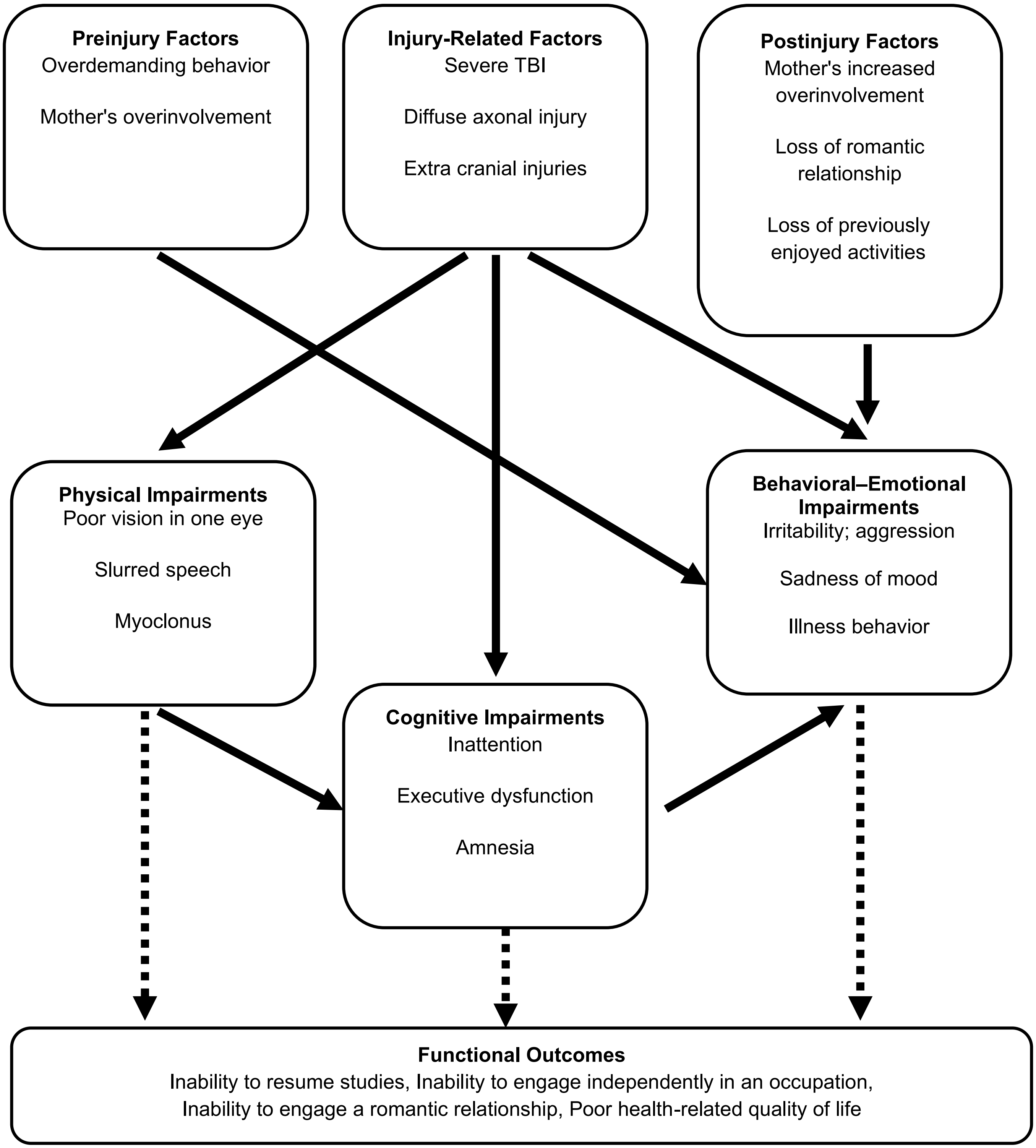

Figure 1. An integrated formulation of Mr. AB's posttraumatic symptoms.

With an all-encompassing formulation of the case in mind, the neuropsychological rehabilitation was designed using a holistic approach. It was hypothesized that, to reduce overall dysfunction in him, all of the contributing factors need to be addressed. Therefore, the neuropsychological rehabilitation aimed at the following goals: (1) enhancing his cognitive functioning, (2) managing the behavioral and emotional disturbances, and (3) optimizing parental expectations and reducing their overinvolvement.

EEG-Neurofeedback Training (EEG-NFT)

As EEG-NFT has been found to be effective in reducing the cognitive, emotional, and behavioral problems after TBI, therefore it was adopted as the technique of neuropsychological rehabilitation. Patient received 20 sessions of EEG-NFT three times per week. The training protocol was a two-channel training provided at occipital scalp locations (O_1 and O_2) in accordance with 10–20 system and targeted at increasing the alpha power and decreasing theta power. The EEG-NFT was provided using a dedicated EEG-NFT system (Atlantis system, BrainMaster Technologies, Inc., Bedford, OH). The intervention sessions were comprised of a computer simulation wherein the patient was asked to relax and focus on the screen. He was provided feedback about his performance using auditory modality (a beep tone) and visual modality (scores on screen). Initially, it was observed that Mr. AB would be very impatient during the EEG-NFT sessions. He would refuse to sit in one place any longer and would not be sufficiently engaged to focus on the task. A considerable amount of effort was invested into getting him to sit in one place and focus. Therefore, the sessions were initially carried out for a period of 20 min and, with an increase in the patient's sitting tolerance, the duration of the sessions were progressively increased to 40 min over a period of time.

Psychotherapeutic Interventions

With the patient. Supportive interventions, at a frequency of two sessions per week, were used to address the grief due to the termination of his previous relationship, the abrupt break in his education, and the restriction on performing activities he enjoyed previously (e.g., riding his motorcycle, going to the gym). The techniques used included emotional catharsis, guidance, reassurance, encouragement, and externalization of interests. Later sessions focused on collaboratively working on smaller, realistic goals, such as helping out in day-to-day chores, helping out his parents, keeping the appointment diary for his sessions, and recording his scores in the EEG-NFT. Behavioral techniques such as activity scheduling were used to implement these goals, and external aids such as using cued recall strategies were used to facilitate recall of recent events.

With the parents. In view of their poor knowledge about the patient's illness and parental overinvolvement, a supportive–educative approach to interventions was used to work with the parents. The sessions were carried out on a weekly basis for 7 consecutive weeks with both parents (Blake, 2008). The major themes of these sessions were feedback of test findings and its practical implications in daily life; shifting the focus from symptoms to functionality, neuroplasticity, and the need for neuropsychological rehabilitation; establishing practical and feasible goals for rehabilitation; and the need for developing autonomy and self-efficacy in the patient. Mr. AB's mother had symptoms of low mood and crying spells; she was referred for a psychiatric evaluation. She was diagnosed with an adjustment disorder and was started on antidepressant medications.

Results

The baselines assessments were repeated at the end of intervention. The postintervention NPA (Test-2) revealed that there were improvements noticed in processing speed, focused attention, semantic fluency, response inhibition, and visual-spatial construction. There was no significant change observed on the scores of tests assessing learning and memory. However, the performance was still in the impaired range in most of the cognitive domains assessed. The VAS showed that his orientation improved significantly. There was also improvement noticed in reduced forgetfulness and irritability. Overall dysfunction came down to 25%. The patient was sent back to home with advice to continue behavioral techniques and strategies at home and to follow up after 3 months.

The patient presented after 3 months for follow-up evaluation. Follow-up NPA (Test-3) showed that his scores on most of the cognitive tests remained unchanged, but a significant drop was noted on the tests of focused attention and planning. His father also reported only slight improvement in behavioral and emotional symptoms. The patient was offered EEG-NFT but, due to logistic reasons, the family could not stay back and therefore a home-based cognitive retraining program was provided.

Cognitive Retraining (CR)

The home-based cognitive retraining (CR) program was developed specifically for patients with head injury by Dr. Shobhini Rao in 2004 (Rao, 2004). The home-based CR intervention is based on the principles of restoration and aimed at enhancement of impaired cognitive functions through intensive and repetitive practice and drills. The CR intervention tasks targeted sustained attention, response inhibition, fluency, and working memory. These tasks included grain sorting, letter cancellation, shading, mental calculation, and word generation. The difficulty level for each of the tasks was gradually increased. All of the tasks were demonstrated to the parents in order to make them understand the administration and recording. They were advised to come back for EEG-NFT at their convenience.

Patient came back for follow-up after 3 months. Further 20 sessions of EEF-NFT were carried out using the same training protocol. Significant positive behavioral changes were observed such as reduced irritability, using requests rather than orders, reduced incidents of walk-outs from the EEG-NFT room, greater efforts for recollecting information, and overall cheerful mood.

At the end of 20 sessions a postintervention NPA was carried out. The NPA (Test-4) revealed that most of the cognitive domains (processing, speed, focussed attention, working memory, response inhibition, visual-spatial construction) had significantly improved and were no more in the impaired range of functioning. His scores (percentile ranks) on memory tests remains impaired, however; qualitatively, there was an improvement seen on raw scores on memory tests. On VAS, his father reported a significant improvement in orientation, irritability, and sadness. There was no change reported in his speech or forgetfulness. Overall dysfunction came down to 15%.

Discussion

The present case study investigates the effects of EEG-NFT integrated with holistic neuropsychological rehabilitation over a period of one year in a patient with a severe TBI. The patient presented with a multitude of problems including physical, emotional, cognitive, and behavioral problems. A comprehensive neuropsychological assessment (NPA) battery and the visual analogue scale (VAS) were administered. The plan for neuropsychological rehabilitation was formulated based on a comprehensive model of postconcussive symptoms (Yeates, 2010). EEG-NFT with the alpha-up, theta-down protocol was selected as a mainstay of neuropsychological rehabilitation and other modalities such as psychotherapy, family interventions, and cognitive retraining exercises were used to augment the EEG-NFT whenever necessary.

During the first phase of neuropsychological rehabilitation, EEG-NFT, psychotherapy, and family interventions were used. A follow-up assessment reflected significant improvement in processing speed, focused attention, semantic fluency, response inhibition, and visual-spatial construction. The scores on learning and memory, however, remained status quo. These findings are in line with the previous studies where EEG-NFT resulted in enhanced attention and response accuracy in a group of patients with mild TBI (Tinius & Tinius, 2000). Similar findings were also observed in patients with moderate TBI where EEG-NFT led to enhanced accuracy in a processing speed test and faster reaction time in a sustained attention task (Keller, 2001). Another study from the southern Indian peninsula reported similar findings where 20 sessions of EEG-NFT with a similar alpha–theta protocol were effective in improving various cognitive domains in patients with mild to severe TBI (Reddy et al., 2013).

Unchanged scores on memory tests could be explained by two factors. Firstly, memory deficits after acquired brain injury have been found to be difficult to ameliorate with cognitive rehabilitation (Doornhein & De Haan, 1998; Majid, Lincoln, & Weyman, 2000). Secondly, the patient had severe TBI with a Grade III DAI, rendering the patient to have very severe memory deficits, thereby making the recovery of memory functions even more difficult.

One of the major challenges in the present case was the overlay of cognitive and emotional disturbances in the patient. Such overlay is common in clinical practice. It has been seen through literature that physical, behavioral, and cognitive symptoms are the primary targets in neuropsychological rehabilitation, whereas psychological and emotional issues often remain neglected (Bédard et al., 2012). Cognitive disturbances have a major impact on the patient's progress in psychosocial interventions for emotional problems whereas the emotional–behavioral disturbances may block the pathway to cognitive recovery (Cole et al., 2015). It is recommended that a holistic neuropsychological rehabilitation program integrating the individualized interventions to target cognitive and interpersonal functioning should be provided to patients with TBI (Cicerone et al., 2019). Therefore, other psychotherapeutic interventions were also used along with EEG-NFT. A supportive-educative psychotherapeutic approach with use of cognitive behavioral techniques was used to work with the patient and the family.

The postassessment at the end of the first phase further revealed that there were significant changes in emotional and behavioral domains as seen on VAS scores. The improvements were reported in the problem areas of forgetfulness, irritability, and orientation. The overall dysfunction rating reduced from 40% to 25%. These improvements can possibly be attributed to a combination of EEG-NFT and psychotherapeutic interventions. Similar findings have been reported previously in other Indian studies. Twenty sessions of EEG-NFT were effective in reducing the postconcussive symptoms, perceived stress, and overall levels of dysfunctions (Bennett et al., 2017; Reddy et al., 2014). It was also found that EEG-NFT was equally effective in bringing about these changes regardless of the time since injury (Bennett et al., 2017). Memory scores on neuropsychological testing did not show any change, but forgetfulness and orientation were reported to have improved on the VAS. It is likely that the micro improvements in memory were not sufficient enough to be reflected in the change in percentile ranks on memory tests. Psychological interventions with the parents resulted in the reduction of stress experienced by them at the end of phase I. Given the lack of adequate facilities available to the patient at his hometown and the lack of feasibility of more EEG-NFT sessions, the patient was discharged to home with the recommendation to actively engage in routine indoor and outdoor activities.

A follow-up assessment completed after 3 months of rehabilitation revealed that, although his performance was stable across most cognitive domains, there was a significant drop in his performance on focused attention and planning. The VAS also indicated only minimal improvement in the emotional and behavioral symptoms. This postimprovement decline in cognitive functioning has been previously reported in a substantial proportion of patient with TBI, and this can be mediated by emotional disturbances and the number of therapy hours in the rehabilitation facility (Millis et al., 2001; Ruff et al.,1991). Of particular relevance here is the role of an enriched environment provided to the patient once the hospital-based rehabilitation is over. Past evidence is indicative of the role of an enriched environment in fostering experience dependent neuroplasticity and thereby facilitating cognitive improvement. Understandably, a lack of environmental enrichment may lead to the weakening of the neural pathways and may consequently result in cognitive decline (Frasca, Tomaszczyk, McFadyen, & Green, 2013). The factors associated with environmental enrichments may range from financial resources, social support, preparedness for transition from rehabilitation facility to home setup, and routines with cognitive, social, and physically stimulating activities (Frasca et al., 2013). The lack of cognitive stimulation in a small town in eastern India along with overprotective caregivers would have resulted in lack of environmental enrichment and finally led to decline in certain cognitive domains. Therefore, the patient was advised to continue home-based cognitive retraining and to come for EEG-NFT at their convenience.

After 3 months of home-based cognitive retraining, the patient received 20 sessions of EEG-NFT in phase II of neuropsychological rehabilitation. The NPA completed at the end of phase II revealed significant improvement in the domains of processing speed, response inhibition, visuospatial construction, and retention of verbal memory. The scores in these domains were above 15th percentile and thereby were out of the impaired range, which is a marked deviation from the trend observed throughout the previous NPAs. The VAS was also suggestive that the overall dysfunction decreased to 15%, with significant gains in the domains of orientation, irritability, and sadness. There was also significant improvement in mood, a considerable reduction in irritability, greater motivation in attempting to recall information, and a higher sense of perceived autonomy. These findings need to be interpreted in light of the fact that symptom reduction and improvement across several cognitive, emotional, and behavioral domains has been seen after 2 years of the TBI. However, the findings from the present case add to the accumulated evidence that EEG-NFT may continue to enhance functioning long after the structural damage to the brain (Hammond, 2007). Improvement in the symptom reduction and enhanced cognitive functioning has serious implications in the quality of life (QoL) of a patient with TBI. The QoL in these patients reflect the life-altering changes due to the TBI that are interwoven with near-permanent physical, cognitive, and social sequelae of the syndrome. These findings are of value in light of Heinemann and Whiteneck's (1995) linear model of QoL, which postulates that the disability and impairment in numerous domains faced by patients with TBI translates into poor functioning which in turn leads to poor QoL.

Overall the results of EEG-NFT integrated neuropsychological rehabilitation in the present case are similar to the randomized controlled trial conducted by Cicerone et al. (2008). These authors reported that holistic neuropsychological rehabilitation was effective in enhancing the work-related productivity, perceived QoL, and cognitive functioning. However, integration of EEG-NFT into neuropsychological rehabilitation program may help speed up the recovery process as it has the potential to alleviate cognitive as well as emotional–behavioral problems. Moreover in patients with severe behavioral disturbances, the individual therapies may not be feasible. In such instances EEG-NFT can be used initially in the neuropsychological rehabilitation process. Other psychotherapeutic interventions can be initiated once the behavioral disturbances have reduced.

Conclusion

Severe TBI is associated with poor long-term outcomes and chronic disability. The overlay of cognitive and behavioral disturbances in these patients may further complicate the clinical scenario. The neuropsychological rehabilitation in these patients is challenging and requires simultaneous interventions to address the multitude of problems experienced by the patient and family. EEG-NFT is a promising intervention in rehabilitation after TBI. The present case study highlights that integrating EEG-NFT along with other psychotherapeutic interventions resulted in better gains through the processes of neuropsychological rehabilitation. Though robust studies are required to establish the effectiveness of EEG-NFT integrated neuropsychological rehabilitation, a case study proves to be of immense value in delineating the finer nuances of each intervention provided in the neuropsychological rehabilitation and its contribution in overall recovery.

Author Disclosure

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Repetitive Transcranial Magnetic Stimulation (rTMS) for Decreasing Gambling Craving in Patients with Gambling Disorder: A Call for Advanced Clinical Investigations

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Abstract

Gambling disorder (GD) is an addictive behavioral disorder that alters the frontostriatal neural circuitry and prefrontal control of reward-associated brain areas. An intrusion between prefrontal cortex and the mesolimbic reward pathway has been proposed as the major mechanism behind the pathogenesis of GD. Repetitive transcranial magnetic stimulation (rTMS) is a noninvasive treatment that utilizes magnetic fields to stimulate nerve cells linked to mood and behavioral control; this stimulation is usually applied either on the left or right side of the dorsolateral prefrontal cortex of the brain. rTMS selectively modulates the activities of brain circuits and possess the ability to overturn the alterations in the neurocircuitry of the brain linked to the pathophysiology of GD. rTMS adjusts impulsivity, cognitive/attentional control, cognitive plasticity, and decision-making, which are crucial in decreasing gambling craving and relapse. However, innovative clinical investigations are needed to analyze and establish the impact of rTMS on gambling craving and cessation, using a larger sample size.

Keywords: gambling craving; gambling disorder; repetitive transcranial magnetic stimulation; neuroregulation; neurotherapy

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Gambling disorder (GD) is a complicated behavioral addiction that affects the frontostriatal neural circuitry and prefrontal control of reward-associated brain areas, a discrepancy between prefrontal cortex (PFC) and the mesolimbic reward pathway has been proposed as the major mechanism behind the pathogenesis of GD (Pettorruso et al., 2020). There is an elevated functional connectivity between the regions of the PFC and mesolimbic reward pathway in GD patients (Pettorruso et al., 2020). The distorted connection between prefrontal structures and the mesolimbic reward system in GD is similar to the pathophysiologic mechanism implicated in substances use disorders (Pettorruso et al., 2020). GD is a growing public health issue, and its aftereffects are family issues, substance misuse, suicidal ideation, suicide, and criminal activities such as robbery and drug smuggling to raise cash for gambling (Okechukwu, 2019). Individuals with GD often encounter financial difficulty and abject poverty because of relentless gambling (Okechukwu, 2019). Moreover, mood disorders such as major depressive disorder, generalized anxiety disorder, and personality disorder are associated psychiatric comorbidities of GD (Okechukwu, 2019).

Repetitive transcranial magnetic stimulation (rTMS) is a noninvasive treatment that utilizes magnetic fields to stimulate nerve cells linked to mood and behavioral control, this stimulation is usually applied either on the left or right side of the dorsolateral prefrontal cortex (DLPFC) of the brain (Lefaucheur et al., 2014). High-frequency rTMS of the left DLPFC appears to be effective, and low-frequency rTMS of the right DLPFC has possible effectiveness (Lefaucheur et al., 2014). According to the study conducted by Gay et al. (2017), they found that patients with GD had decreased gambling craving following a single session of high frequency rTMS delivered to their left DLPFC after viewing a gambling video, using a MagPro X100 stimulation system.

A key advantage of rTMS is that it selectively modulates the activities of brain circuits and possesses the ability to overturn the alterations in the neurocircuitry of the brain linked to the pathophysiology of GD (Pettorruso et al., 2021). rTMS significantly modulates impulsivity, cognitive/attentional control, decision-making, and cognitive plasticity, which are crucial in decreasing gambling craving and relapse (Zucchella, Mantovani, Federico, Lugobani, & Tamburin, 2020). rTMS has been shown to adjust dopaminergic and glutamatergic neurotransmission, and both transmissions are altered in GD patients (Pettorruso et al., 2019). rTMS causes a decrease in dopamine transporter availability in striatal regions, leading to modulation in dopaminergic pathways; this implies that rTMS has the potential to modulate brain functioning, and neural circuits associated with GD (Pettorruso et al., 2019).

Neuroimaging findings have shown similar activation defects in regions of the mesolimbic reward system in patients with GD and substance use disorders (Limbrick-Oldfield, Van Holst, & Clark, 2013). Some patients with GD often abuse cocaine (Cowlishaw, Merkouris, Chapman, & Radermacher, 2014). However, rTMS is effective in lowering cocaine use and sleep disruption (Gómez Pérez et al., 2020).

Providing 5-Hz rTMS therapy for 2 weeks significantly reduced craving and impulsivity, and improved functional connectivity between left DLPFC with ventromedial prefrontal cortex, and ventromedial prefrontal cortex with right angular gyrus in patients with cocaine use disorder (Garza-Villarreal et al., 2021). Moreover, clinical improvements were observed in patients with comorbid gambling and cocaine use disorder who had undergone a high-frequency left-DLPFC-rTMS stimulation. including diminished cocaine craving and intake and decrease in the craving to gamble. There was also improvement in sleep quality and decrease in anxiety and depression among the patients (Cardullo et al., 2019).

In conclusion, GD is an addictive behavioral disorder, in which dysfunctions in the prefrontal neural activity have been proposed as the underlying pathophysiological mechanism. Therefore, targeting the PFC for the treatment of GD using rTMS is a promising therapeutic innovation. rTMS seems to decrease gambling craving, enhance mood control, and improve cognitive function in patients with GD. rTMS could emerge as a reliable adjunct therapy in support of cognitive-behavioral therapy for the treatment of GD. However, advanced clinical investigations are needed to scrutinize and establish the impact of rTMS on gambling craving and cessation, using a larger sample size.

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