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Is Neurofeedback Really Operant Conditioning? What Conductance and Heart Rate Variability Tell Us. A Real-World Evidence

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Abstract

It is assumed that the learning mechanism used by Neurofeedback is operant conditioning. The hypothesis is not based on neurons that learn to associate brain waves with well-being or discomfort; rather, they learn to associate well-being or discomfort with those brain waves. The mean age of the sample (n = 210) was 14.13 (SD = 1.46; range 12 - 18), with 31.5% women. Each subject received 30 Neurofeedback sessions. Skin conductance response, also known as galvanic skin response or electrodermal activity as well as heart rate variability, were registered during sessions. They are recognized as markers of emotional feeling. This study shows statistically significant differences in microSiemens (conductance) between the baseline value and sessions 15 ($p = 0.01$) and 30 ($p = 0.01$). In addition, increased heart rate variability was verified with statistically significant differences in Root Mean Square of the Successive Differences between the baseline value and sessions 15 ($p = 0.01$) and 30 ($p = 0.01$). This study associated Neurofeedback with the achievement of well-being. Neuroscientific reasons are argued to explain this achievement. It is concluded that neurofeedback modifies the emotional state and, as a consequence, changes the pattern of brain waves. Brain waves are a consequence but not a cause.

Keywords

Neurofeedback, Brain Wave, Operant Conditioning, Skin Conductance, Heart Rate Variability, Emotional Behavior

1. Introduction

Neurofeedback has been effectively used in many conditions for almost a century [1] [2], but its mechanisms of action still need to be better understood. How exactly neurofeedback works remains unknown. It is assumed that the learning mechanism used by Neurofeedback is operant conditioning. It postulates that if I put the brain of an animal or a human in an environment that rewards a certain behavior, this behavior will tend to be repeated more frequently. When I'm rewarding inhibition from Beta and stimulation from Alpha, this behavior will occur more regularly and the brain will learn to do it. That is a system with feedback and reinforcement learning that rewards correct answers. More actual research is needed to support or disprove these ideas. Theories for how change occurs are not currently supported by empirical evidence [3]. Understanding the relationship between the brain and behavior is one of the main goals of neuroscience.

Maybe this explanation is far too simplistic. We claim that the learning effect of Neurofeedback is not based on neurons that learn to associate brain waves with well-being or discomfort, but rather they learn to associate well-being or discomfort with the cause of those brain waves. Brain waves are a consequence but not a cause. In any case, during a Neurofeedback session, the person manages to change a pattern of brain waves with discomfort to one with well-being. This is a key question here. The most obvious problem with the accepted theory is its lack of explanatory power.

Neurofeedback is a noninvasive brain stimulation technique [4] [5]. The measured brain activity is manipulated as an independent variable, similar to brain stimulation studies. It is the methodology developed to train participants in the self-regulation of brain regions or networks. Neurofeedback training of frequency components does affect spectral EEG topography, but these effects do not necessarily correspond to either the frequencies or the scalp locations addressed by the training contingencies [6]. Individual success rates vary, and few participants never learn to control their brain responses at all. Attentional variables appear to be of importance to both performance and learning, motivational factors and mood have been implicated as moderate predictors of success, while personality factors have mixed findings. Mood and motivation are moderate predictors of neurofeedback success. Attention, motivation, mood, and other factors affect Neurofeedback success. Attention is consistently found to be crucial for efficient Neurofeedback learning. The effect of psychological factors is complex, individual, and design-dependent [7].

The role of physical stimuli of a different nature on mental activity and behavior offers no doubt. Such is the case of invasive and noninvasive brain stimulation [8]-[10]. Particularly relevant is the effect on emotional life. Sound-including music can relieve pain, somatic symptoms, and stress in humans [11]-[16]. We know music-induced emotions, and bodily sensations [17]. There are neural correlates of music and emotion [18]. Airborne sounds are emitted by stressed plants. These sounds not perceived by humans may also be detectable by other organisms [19]. One study found that some people experienced less pain after surgery, even if the music was only played during the operation. This suggests that even though they were unconscious, something was going on [20]. In another vein, 1 minute of blue, green, or red light exposure modifies the functional connectivity of a broad range of visual and non-visual brain regions [21]. Short-term immersion in cold water facilitates positive affect and reduces negative affect [22]. Also, the role of serious video games in the treatment of disordered eating behaviors [23] [24]. These methods are widely used in neuroscience to establish causal relationships between distinct brain regions and the sensory, cognitive, and emotional functions they subserve [25]-[28].

The mechanisms by which these physical stimuli exert their therapeutic effect are still largely unknown, although more and more data are becoming available on their influence at various levels [29] [30]. Fundamentally, it seems to perform its function by replacing abnormal firing patterns [31] [32], present in certain neurological and psychiatric diseases [30] [33]. It is about resetting the pacemaker cells, thus determining the resynchronization of the functional connectivity of the cerebral hemispheres. Thalamocortical dysrhythmia is a model characterized by abnormal resting-state thalamic oscillatory patterns where the alpha rhythm is replaced by cross-frequency coupling of low and high-frequency rhythms [34].

It should be remembered that both medication and psychological therapy are biological interventions. Many studies show that both change the biology of the brain. We are only just beginning to learn how existing treatments, such as medication, cognitive therapy, and other therapies, change the brain. And also what changes in the brain. This entails important implications for potential treatment effectiveness. We know the transformations that the nervous system experiences as a consequence of external actions. It is assumed that the approach to therapy works and brings about change. Proponents of different forms of psychotherapy would likely agree that each approach helps people to better manage emotions. The relationship between the therapist and the person receiving therapy is an important factor. Better outcomes are associated with a strong bond (empathy). Besides, the person receiving therapy comes with positive expectations or such expectations (beliefs) are shaped in therapy. The role of beliefs turns out to be crucial. We hypothesize that the power of focused attention and personal beliefs acting on the brain's processing of emotional sensitivity (feeling) plays a determining role in the therapeutic effect of Neurofeedback.

The main objective of the study is to verify the electrodermal activity or skin conductance response (SCR), and heart rate variability (HRV)as accepted markers of emotional processing [35]-[38] during the administration of Neurofeedback.

2. Methods

This descriptive retrospective observational study design is based on real-world historical data from routine clinical practice. Observational studies may provide credible evidence. Patient registries are a source of real-world data. A patient registry is an organized system that uses observational study methods to collect uniform data (clinical and other) to evaluate specified outcomes for a population. Each one of the patients treated at the Fundació Carme Vidal has a clinical history that is incorporated into the registry.

Participants

The urban middle-class participants were recruited from among those who come to our diagnostic-intervention center due to low academic achievement (n = 70), disruptive behavior (externalizing behavior problems) (n = 70), and somatic syndrome disorder (n = 70). The mean age of the sample was 14.13 (SD = 1.46; range 12 - 18), with 31.5% women. Low achievement was defined as achievement lower than the 25th percentile of the norm group across one academic year, according to school information. This criterion was considered the most reliable based on real-world evidence. Disruptive behavior (externalizing behavior problems) and somatic syndrome disorder were defined according to DSM-5. The vast majority of disruptive behavior is especially aggression and poor interpersonal relationships with peers and teachers.

Trained psychotherapists performed the procedure of recruitment, getting information directly from the school and health registration. Unstructured informal and open-ended interview was carried out with participants and parents of cases A pediatric neurologist assessed each case by practicing a discerning clinical history and checking registered personal medical history to confirm diagnoses of disruptive behavior and somatic disorders according to DSM-5 and rule out any other comorbidity or condition. Dyslexia, dysphasia, dyscalculia, ADHD, and psychiatric comorbidity were ruled out. As needed, the following studies were performed: both auditory and visual event-related potential, otorhinolaryngology, ophthalmological exploration, cardiological examination, thyroid study, sonography, video-EEG. Exclusion criteria were any child psychiatric disorders, comorbidity, previous medication, or other therapy in progress. Samples weren't grouped via socioeconomic background, sensory deprivation, ethnic pattern, or cultural or instructional factors.

Measures

The measuring instrument was the EEG Biofeedback NeXus-10 (Mind Media®), which is suitable for acquiring a wide range of physiological signals. Up to four channels of EEG, EMG, ECG, and EOG signals are available. Heart rate, skin conductance, respiration, and temperature can be recorded. The NeXus-10 also has an extra input for oximetry or triggers and one input for digital sensors. The NeXus-10 communicates wirelessly by Bluetooth or uses the USB extender cable to record data at higher sample rates. A high-grade lithium-ion battery pack and an SD flash memory card slot enable full ambulatory use of this portable device. The NeXus10 is equipped with a display conveniently showing the device's status. We used five bands, with ranges set at <4 Hz (delta), 4 - 8 Hz (theta), 8 - 13 Hz (alpha), 13 - 30 Hz (beta), and >30 Hz (gamma) by the literature.

This study was carried out following the recommendations of the Institutional Review Board of the Fundació Carme Vidal de NeuroPsicoPedagogia, and with their approval of the study protocol. All subjects gave written informed consent to the Declaration of Helsinki.

We performed statistical analyses by using SPSS version 24. Statistical significance was determined at P.05. The statistical significance of the data was analyzed using a paired sample t-test.

Procedure

A Neurofeedback training session consists of sitting in front of a screen. Watching a movie, the electrical activity of the brain is recorded using electrodes placed on the scalp. It is claimed that our brain, unconsciously, controls the projection of the film. If the brain emits the desired electrical activity, the movie will start moving. And when it doesn't emit the proper electrical activity, it won't get moving. In this way, our brain learns to function at an optimal level -without excesses or deficits- and self-regulation capacity is improved. It is known that the learning process, if successful, can require a considerable amount of time. Studies have reported times extending to several weeks.

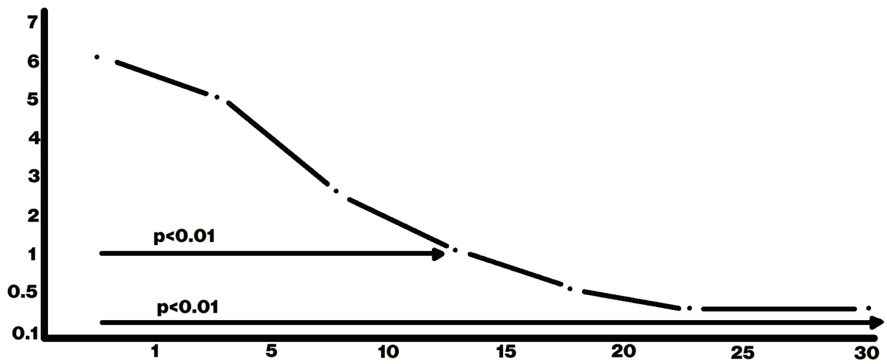
The subject may sporadically suffer from attention deficit, but focused attention is crucial. For the task, the subject is asked to relax completely, trying, as far as possible, to leave the mind blank. For the brain to perform the tasks, it is necessary to stimulate and reward it. This is done by setting goal thresholds that must be achieved. When you manage to cross the established thresholds, the system will provide you with a reward (a prize) in the form of a visual and/or auditory signal. Thus, it indicates to the brain that it has performed the exercise correctly.

Neurofeedback trains the brain to regulate its functioning, to rebalance the pace at which it works and achieving a more normal brain wave pattern. This results in a change for the better in the person. Standard Neurofeedback protocols are Alpha, Alpha/theta, Pico de Alpha, SMR, Beta, and Theta /Beta. All cases in the study followed the protocol sensorimotor rhythm 14Hz (SMR) training, which according to accumulated experience is linked to emotional processing. Each session is scheduled for 60 minutes, although the actual neurofeedback training will take between 30 and 45 minutes of that time.

Skin conductance responses (SCR), also known as galvanic skin response (GSR) or electrodermal activity (EDA), were measured throughout the experiment using two electrodes on the area of skin between the first and second phalanges of the second and third digits of the non-dominant hand. SCRs were calculated as the maximum response within a 0.5 - 4.5 s window following stimulus onset and controlling for a baseline period of 2 s. SCRs were square root transformed to normalize the distributions across participants, and the minimal response criterion was 0.02 μS (microsiemens). The signal spectrum is in the range of 0.045 - 0.15 Hz, although it can increase up to 0.37 Hz. For a variation in the signal to be considered as such, the amplitude must be at least 0.05 μS or 0.04 μS.

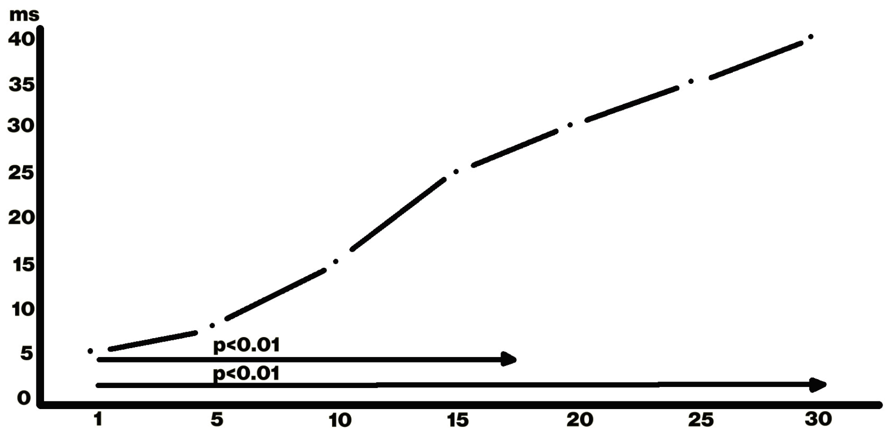
The suitability of SCR as a measure of emotional state is accepted. The evaluation methods used by the conductance are based on stress-induced sweating. The SCR is an indirect measure of sympathetic autonomic activity that is associated with both emotion and attention. In humans, the amplitude of SCRs is related to the level of arousal with either positive or negative emotional valence. The patient manages to reduce the signal, achieving greater control over his or her ability to relax. Reduction of fear has been associated with lower SCRs, trauma-exposed children showed higher SCRs,

Multiple scores during each session were recorded. Then, the average conductance in each session for each patient was recorded. All records met a low standard deviation, indicating that the data were spread out over a smaller range of values. Standard deviation is the measure of variability to show the extent to which the scores are arranged around the mean. Subsequently, the average conductance of each patient was obtained at the session intervals, that is, 0, 10, 15, 20, and 30 sessions (**Figure 1**).



Y-axis = conductance value in miscrosiemens (us) X-axis = number of sessions carried out. The statistical significance of the data was analyzed using paired sample t-test.

Figure 1. Graphical recording of skin conductance responses in successive sessions.



Y-axis = Root Mean Square of the Successive Differences between adjacent RR intervals in milliseconds (ms). X-axis = number of sessions carried out. The statistical significance of the data was analyzed using paired sample t-test.

Figure 2. Graphical recording of the HRV in successive sessions.

HRV stands for heart rate variability and measures the time interval between one heartbeat and the next and how constant it is over a period of time. It fluctuates slightly. A correlated variation between feelings and heart rate over time has been observed. The Root Mean Square of the Successive Differences between adjacent RR (ECG) intervals in milliseconds is the most reliable variable due to the lower coefficient of variation compared with other indices.

Multiple scores during each session were recorded. Then, the average HRV in each session for each patient was recorded. All records met a low standard deviation, indicating that the data are spread out over a smaller range of values. Standard deviation is the measure of variability to show the extent to which the scores were arranged around the mean. Subsequently, the average HRV of each patient was measured at baseline (session 1) and sessions 5, 10, 15, 20, 25, and 30 (**Figure 2**).

The training followed the SMR protocol in all cases. The protocol consists of increasing SMR (12 - 15 Hz) by placing the manual and individual threshold so that it has a success rate of 70%. The thresholds are set based on the success rate. The thresholds are automatic, and the program adjusts them based on the person's response. The reinforcement is soft and relaxing piano music. In addition, the Theta wave decrease (4 - 8 Hz) is simultaneously reinforced with a success rate of 80% and the High Beta decrease (21 - 35 Hz) with a success rate of 90%. It is manually controlled during the session and ensures that the overall success in the three bands is between 40% and 60% (less than 40% is too difficult for the brain, and more than 60% too easy). Thirty sessions is a standard number of sessions that is considered an average for an intervention to see positive changes (it can be less or more, but it is an accepted average). Therefore, we measured halfway, at 15 sessions, and at the end, at 30 sessions, to be able to measure the changes.

3. Results

The affective sweating occurs in response to emotions such as nervousness, anxiety, fear, stress, or pain, and reflects an increase in the activity of the sympathetic nervous system and decreased parasympathetic activity. This is associated with increased electrodermal activity and decreased heart rate variability. Instead, parasympathetic activity is associated with the opposite pattern, decreased electrodermal activity, and increased heart rate variability.

When the palmar and plantar sweat glands fill as a result of activation of the sympathetic system, skin resistance decreases (conductance increases), and when sweat is reabsorbed, the resistance of the skin increases. In the present study, marked changes in conductance were recorded during the application of Neurofeedback, illustrating the possible usefulness of conductance as an indicator of pain or discomfort. This study shows statistically significant differences in microsiemens between the baseline value and sessions 15 ($p = 0.01$) and 30 ($p = 0.01$) of neurofeedback (**Figure 1**). In the same way, increased heart rate variability was verified (**Figure 2**). This study shows statistically significant differences in Root

Mean Square of the Successive Differences between the baseline value and sessions 15 ($p = 0.01$) and 30 ($p = 0.01$) of Neurofeedback (**Figure 2**). It means the results are not attributable to random chance. It doesn't mean the results are robust.

These data are associated with achieving a regulated state in the EEG and noncompliance with the clinical diagnostic criteria for enrollment in the sample in 90% of cases. Regulation means to control something, especially by making it work in a particular way. Therefore, regulation means restoring the electroencephalographic order considered normal. It is noteworthy that the results were maintained for three month and at a one-year follow-up. After two years, follow-up testing indicated a slight regression in ten patients.

4. Discussion

How does the device work? This study verifies that Neurofeedback exposure was associated with differences in SCRs [39] [40] and HRV, **Figure 1** and **Figure 2**. There was a significant main effect of time on SCRs during sessions. The authors observed cumulative effects that persisted over time (long-term potentiation effect), causing long-term behavioral changes resulting from the stimulation [41]. SCRs decreased over time and HRV did the opposite. This fact is supported by this available empirical evidence (**Figure 1** and **Figure 2**). In a previous study [42] [43], the administration of Neurofeedback showed its effectiveness in reversing (regulation) a state of rhythmic EEG dysfunction. This change was associated with a change from discomfort to sufficient well-being and that is what the conductance and heart variability conclude.

We have bibliographic information that SCR is related to the level of stress [44] and can provide information on the emotional regulation ability in situations of stress coping [45] [46]. Research on the relationship between the SCR and emotional states suggests that SCR is interpreted as an indicator of emotional reactivity [47] [48]. A high SCR may indicate severe difficulties in activating the parasympathetic nervous system to regulate the emotional state [44] [49]. On the other hand, low SCR is interpreted as an indicator of fearlessness and/or emotional well-being [46]. The behavior of both SCR and HRV after exposure to a stress factor has also been reported [50]. Stress (not serenity), more unconsciously than consciously, increases the amplitude of the waves and their frequency. When the brain relaxes the EEG regulates, showing patterns of normality or close to it [43]. Higher SCRs and activation of the anterior cingulate cortex and insula involved in pain processing have been demonstrated [25].

It is well known that we can change the rhythmicity of neurons by applying electromagnetic stimuli directly to the neurons from the outside [51] [52]. On the contrary, there are poorly understood therapies [53]. One wonders what makes the whole pattern of brain waves change without the mediation of a physical factor and acting on a wave in particular. It seems clear the repercussion of a wave in the rest. Is very important that the brain wave is an effect of neuronal activity and therefore is the consequence and not the cause of it. That is the question. In operant conditioning, the brain wave is considered as cause and not effect. That is, if we modify the wave, it will affect a change in neuronal activity and the manifestations derived from it.

We are far from understanding how certain mental tasks produce their effects. Several studies have shown that the act of imagining moving produces significant strength gains. For instance, there are several brain regions in which structural and functional changes have been found due to the use of video games [23]. Video game training is associated with neuronal changes in reward processing using functional magnetic resonance imaging [54]. Recent MRI work showed that commercial video games modified similar brain areas as these specialized training programs [55]. The findings are consistent with video gaming improving cognitive abilities that involve response inhibition and working memory and altering their underlying cortical pathways [56].

We are increasingly learning more about the behavior of brain waves, alpha, beta, gamma, delta, and theta. Basic mechanisms of cerebral rhythmic activities have been described [31] [57]. Reinitialization (reset) of the pacemaker cells, thus determining the resynchronization of the functional connectivity of the cerebral hemispheres, has been proposed [58]. The role of thalamocortical dysrhythmia is argued [34]. Shocking, nonoscillatory electrophysiological activity has been reported [59]. In a situation considered of rhythmic normality, the brain waves meet known conditions. States of stress and anxiety have been associated with a domain of gamma waves. For example, it has been possible to suppress gamma in healthy animals and the suppression induced depression-like behaviors in humans. Theta-gamma phase coupling is a prominent feature of the hippocampus [60]. So far, there are no known consistent patterns of brain waves in relation to emotional state. Extreme delta brush is a novel EEG finding seen in many patients with anti-NMDAR encephalitis [61].

In general, in a dangerous situation (stress), the cognitive cortical neurons that express alpha, beta, and gamma (predominant asynchronous activity) are required to work harder (more activity) at the request of subcortical risk-danger processor which expresses its functioning with slow waves (predominant synchronous activity), delta and theta. In the eyes-closed, awake normal condition, EEG oscillatory power in the alpha band (7 - 13 Hz) dominates human spectral activity. With eyes open, however, EEG alpha power substantially decreases. So far, very diverse wave patterns have been described under various conditions without conclusive results [61]-[64]. To conclude, whatever happens to the brain waves, it is a consequence but not a cause in Neurofeedback training.

How many sessions over time are required to obtain the desired effect is a matter of debate. Teaching methods still advocate an approach where longer practice equals better learning. For example, if you want to play the piano (procedural learning), you have to practice for many hours every day. The levels of commitment and motivation (emotional factor) linked to well-being and not only the amount of exposure to the task are factors that must be taken into account to maximize the effect. The medium and long-term effects (**Figure 1** and **Figure 2**) can be derived from the time of therapy, which is in line with what we know about long-term potentiation [41]. What is relevant is that the repetitive execution of the same mental task entails an alteration of the electrophysiological expression. Structural and functional neuroimaging studies have shown that functional and brain volume changes indicate brain plasticity, mediated by mental training over the long term [65]. According to the results of the SCR and HRV, it can be inferred that the therapeutic effect of Neurofeedback occurs when the sensitive emotional state changes from worse to better. This makes perfect sense, although its soundness may be questionable.

First of all, we claim that the power of focused attention and a change in personal beliefs acting on the brain's processing of emotional sensitivity (feeling) plays a determining role in the therapeutic effect of Neurofeedback. Human attentional capacity is quite limited, so our neurological processing is filtered to focus us on certain information. If you're going to be focused *in* on something, you have to be focused *out* of something as well. It is about interrupting the proliferation of mental events, which involve guilt, doubts, worries, and so on. This entails a decrease in rumination and a reduction in the negative symptoms, which in turn leads to well-being. All of this leads to a pleasant sensation with a state of relaxation. The mind just disconnects completely from all tension with a sense of clarity and relief, ease and peace. It is the cessation of inconvenient thoughts and feelings. This agrees with the SCR and HRV results of this study.

The client is progressively capable of changing the mental state in the brain, substituting waves of anxiety with waves linked to relaxation. It is known that changes in brain waves can occur due to changes in HRV [66]. To change the pattern of the EEG, the person has had to change his mental state. It is very likely that he has shifted from a state of mind of worry or rumination, to one of focusing on the task at hand, if only for a few moments. The first is a change in mental state, and then the wave change occurs. The brain learns to control and reproduce the desired mental states in each situation or moment of life when they are necessary. This will give the person peace of mind and well-being, as it will help them manage their emotions.

Second, but not least, is the role of beliefs, which turn out to be crucial [67]. A belief is associated with security or insecurity; that is, well-being or discomfort. The placebo (belief) has proven to be effective in sports and exercise training interventions [68] [69]. Neural correlates of placebo effects have been reported [70]. It has been recently reported [71] that placebo contributes significantly to pain reduction seen in cannabinoid clinical trials due to high expectation (belief). The placebo effect may be meaningful in sports and exercise training interventions [68]. The nocebo effect has to do also with beliefs [69] [72]. When we are psychologically healthy, the idea is that we strike a balance between our pre-existing expectations and new incoming information, updating our model of reality appropriately in the light of new evidence (Neurofeedback). Beliefs form in the minds of people with their individual history of particular experiences and ideas. What we need is a way of changing people's beliefs. Emotion malleability beliefs matter in emotion regulation [73]. Beliefs about how our bodies function directly influence physical health [67]. This last point is relevant to our purpose.

It seems clear the role of beliefs about emotions [74] [75]. Beliefs reflecting on their value are acquired automatically and rejected only with effort. The way we experience the world is thought by some scientists to come from predictions we are making based on experience (beliefs)-called predictive processing. And this has to do with anticipatory unconscious processing when we decide. Activated beliefs are what dictates one's behavior [76] [77]. Our basic beliefs about reality can be impossible to prove, and yet we can feel a strong intuitive conviction about them. Feelings of insight are not epiphenomenal and should be investigated for their effects on beliefs. Humans rely on feelings of insight to appraise an idea's veracity [78].

In this regard, some recent bibliographic contributions are relevant. These are, for example, math-related emotions and beliefs [79], failure of hypnosis depended on a strong nocebo effect [80], the observed placebo analgesia has mechanistic and methodological implications [81], adolescent self-concept beliefs and internalizing problems, rather than academic skills per se, can predict emotional problems in young adulthood [82].

Given our reasoning above, focused attention is essential, and it is a primary characteristic of meditation, mindfulness, and hypnosis. Meditative practice is associated with changes in the anterior cingulate cortex, insula, and frontolimbic neural network, which are components involved in the emotional network [83]. Alteration of fecal microbiota balance is related to long-term deep meditation. These results suggest that meditation plays a positive role in psychosomatic conditions and well-being [84]. Effects were obtained for participants after a single meditation session [85] [86]. Neurologically, focus attention meditation can enhance the brain connection among and within emotional brain networks, especially the default mode network (brain resting-state) [87].

The mindfulness effect is proof of an activity not mediated by any physical element that achieves functional and structural changes in the brain. Mindfulness has proven its effectiveness in opioid misuse and chronic pain symptoms and reductions in opioid dosing, emotional distress, and opioid craving compared with supportive group psychotherapy [88]. It has been reported that the beneficial effect of mindfulness exercise on symptoms of depression and anxiety among individuals in a non-clinical population with emotional symptoms [89]. Mindfulness-based stress reduction produces reductions in pain and improvements in physical function, mood, and sleep disturbance in people with chronic pain conditions [90]. Strengths and limitations of mindfulness-based interventions have been reported [91].

There are many clinical applications of mindfulness [92]. It is well known the experience consists of short-term and long-term mindfulness training and pain modulation [93]. It should be noted that the effectiveness is demonstrated in clinical entities that have emotional dysfunction (discomfort) in common. Mindfulness is associated with lower pain and greater deactivation of the default mode network. Mindfulness meditation and placebo engage distinct neural pain signatures to reduce pain [94]. Mindfulness limits conscious processing of cognition and pain sensitivity [95] which synthesizes the basic mechanism of action of focused attention. It is about attention to a neutral focus. It does not leave the mind blank. The efficacy of mindful practice in improving diagnosis in healthcare was reported as a systematic review [96]. Mindfulness-based interventions for psychiatric disorders [97] and suicidal behavior [98] are well known. A brief mindfulness intervention holds promise for improving stress, anxiety, and resilience for patients with advanced heart failure awaiting transplant [99]. Strikingly, you don't have to be an expert meditator to experience these analgesic effects [100].

Evidence in neuroimaging suggests that mindfulness practice may exert its effects through structural and functional changes in brain regions and networks implicated in emotional processing. The anterior cingulate cortex, amygdala, and posterior cingulate cortex are examples. Remarkably, mindfulness reduces the activation of the amygdala and the default mode network, also linked to emotional processing [101]. Also, changes in intrinsic brain connectivity using functional connectivity MRI have been reported [102]. Likewise, it is associated with decreased synchronization between the thalamus (an area of the brain that transmits incoming sensory information to the rest of the brain) and parts of the default mode network. This is complemented by EEG findings. Two weeks of mindfulness meditation training produced a strong 4 - 8 Hz (theta) rhythm over the frontal cortex [103], which corresponds to mindfulness-based stress reduction. In the same sense, low-frequency amplitudes decreased after mindfulness meditation [104]. For greater redundancy, meditative and mindfulness practice is associated with changes in the neuroplasticity of the anterior cingulate cortex, insula, temporoparietal junction, frontolimbic neural network, and others, changes that can operate together establishing greater self-regulation [65] [87]-[91] [101] [102] [104]-[107].

Other focused attention activities deserve mention. Non-pharmacological Tai Chi Chih may enhance default mode network connectivity changes associated with improved depressive symptoms and psychological resilience [108]. Yoga has shown efficacy as a monotherapy for the treatment of major depression [109]. Yoga and mindfulness-based interventions are recommended to reduce cancer-related fatigue [105].

Along the same line of reasoning, another paradigmatic example of focused attention is hypnosis [110]. Distraction (focused attention) using hypnotic immersive virtual reality may reduce pain and anxiety among children undergoing needle-related procedures [111]. Hypnosis is effective for functional neurological disorders [112]. Pediatric hypnosis practices are a valuable tool for enhancing emotional self-regulation and promoting resilience [113]. Hypnosis is a technique that has a multitude of scientific evidence in favor of its efficacy in the treatment of different disorders—medical or psychological nature—in children and adults [114]-[117]. It is well known the hypnotic analgesia [118]. Self-hypnosis, depending on how it is practiced, can more closely resemble mindfulness meditation. It is worth remembering that preserved critical ability and free will in deep hypnosis it is the rule and not the exception [119]. Besides, expectancy (future-oriented belief) plays a major role in hypnotic inductions and their effects [120].

The role of hypnosis in chronic pain is very significant [118] [121]. Also, study results suggest that single short-term hypnosis and mindfulness meditation sessions may be useful for acute pain self-management, with hypnosis being the slightly superior option [122]. Instead, no significant differences on chronic pain benefit between hypnosis and mindfulness were reported [123].

Neurobiological underpinnings induced by hypnosis remain unclear [124] [125]. Pain is the end product of many integrated networks that involve activity at multiple cortical and subcortical sites but again default networks appears as brain correlate of hypnosis [126]. It is consistent with our approach that inhibition of the left dorsolateral prefrontal cortex (cognitive processing) was associated with an increase in hypnotizability [127]. In terms of brain waves, increased delta connectivity, but decreased connectivity for alpha and beta have been demonstrated in hypnosis [128]. Desynchronization happens. Similar brain desynchronization has been observed when people are given anesthetic doses of propofol or ketamine, but not during sleep. Predictive processing does not work. The cessation could represent a breaking down of that process, and a resulting loss in conscious experience. What happens is deepening levels of concentration, profound concentration [129].

Previously [130] [131], the conceptualization of emotional processing has been reported according to the latest contributions from neuroscience. It is about understanding why humans think, feel, and behave the way they do. Put simply, emotional feeling explains what we think and what we do so that if we process bad feeling (danger) the thought is biased (cognitive bias) and the biased behavior is a defensive behavior that justifies but does not truly explain it. It is unconscious self-deception.

Although biological functions are often supported by multiple structures, it is a significant common denominator of functional neuroimaging studies that identify the same structures linked to emotional processing (sensitive-emotional processing). Among them, the anterior cingulate cortex [132], rostral anterior cingulate cortex [133], posterior cingulate cortex [134], and subcallosal cingulate [135] concerning the cingulate cortex. The orbitofrontal cortex [136] [137] on the other side and on the other the default mode network [65] [126] [138]-[143]. Sometimes, associated functional structures were identified. For instance, the left posterior cingulate cortex + left anterior cingulate + right medial amygdala [144], the anterior cingulate cortex + orbitofrontal cortex [137], the paraventricular thalamus-basolateral + amygdala circuit [145], the cingulate + amygdala + insula [146], the amygdala + amygdala-insula connectivity [147], the amygdala + medial prefrontal cortex [148], the amygdala + prefrontal [149], the insula + amygdala + nucleus accumbens + anterior cingulate + ventromedial prefrontal cortex [150], the orbitofrontal-ventromedial [151], the default network + anterior insula + dorsal anterior cingulate cortex [152]. These findings are consonant with the evidence indicating that shared brain networks across psychiatric disorders share emotional suffering [153]-[155]. It is consistent to think that these structures have to do with emotional decision-making centers in the brain. Let us recall that our study shows an association between improved well-being, EEG regulation, and a concordant response in both SCR and HRV.

Aging deteriorates the cognitive cortex sooner than the limbic system. The amygdala develops more than the hippocampus in the first three years of life. The fetus can feel pain as early as 12 to 18 weeks [156]. Cell type diversity was found to be remarkably high in the midbrain, hindbrain, and hypothalamus, circuits linked to the emotional brain [157]. This highlights the role of the sensitive brain linked to the defense mechanism over the cognitive brain (operant conditioning). Recently, it was reported that before death there was an increase in gamma wave activity, which was not reduced as the other rhythmic patterns after cardiac arrest. Coordination or coupling with other brain waves from different areas of the brain was observed. The human brain may possess the capability to generate coordinated activity during the near-death period [32]. These data demonstrate that the unconscious dying brain can still be active. In short, these are evidence of unconscious processing power [158] that we argue underlies the therapeutic effect of Neurofeedback.

When the brain relaxes, the SCR and HRV indicate it (**Figure 1** and **Figure 2**). The brain doesn't 'turn off' but moves on another "wavelength". The human brain is never really "at rest", but rather an orchestra of distinct functional networks in a dynamic concert. In Neurofeedback an individual is awake, and attention-demanding but not involved in a goal-directed task [159]. Research has identified a default-mode network of brain regions active in the resting brain and characterized by coherent low frequency neuronal oscillations (<0.1 Hz) [108] [138]. Low frequency waves are typical of subcortical processing that supports the processing of emotional feelings. This is particularly the case with the amygdala, the cingulate, and the most primitive frontal, namely the orbitofrontal and medioventral cortex. This network is made up of interconnected regions in the brain that work together during various emotional or feeling states (angry, happy, sad, and so on). Religious and spiritual experiences [160] activate the same emotional brain circuits as sex, gambling, music, or drugs. Consequently, all the emotions described have in common the processing of well-being-discomfort (pleasure-pain), which ultimately governs thought and behavior.

A common molecular basis of both physical and emotional human pain insensitivity has been reported, although functional magnetic resonance imaging has been studied for identifying objective measures of physical pain and differentiating from nonphysical ones [161]. A genetic mutation caused the person to not feel pain or experience situations of anxiety or fear [162]. These are arguments to deduce that pain and emotional pain share neurological mechanism. Both represent a defense mechanisms. Fears don't typically come in isolation; if you're scared of one thing, research suggests you're more likely to be scared of other things too [163]. There is a fear processing common to all fears (danger). A common basis means a common mechanism [162]. We know the neurotransmitters that underlie fear [164]. The stress neurotransmitter, known as epinephrine or norepinephrine, facilitates fear processing in the brain changing the oscillation frequency of brain waves in the amygdala from a resting state to an excited state that promotes fear processing and memorization [165]. Cognitive and emotional forgotten memories may remain intact in the brain forever [166], which allows us to think that they are part of our unconscious processing forever. The past actions influence the present [167].

Assessment of emotion is crucial [168]. Emotion is relevant for well-being [169]. High-stress levels hinder performance on all kinds of tasks [170]. Knowledge is not only the product of rational and logical processes, but there are also affective factors. Emotional abilities are a major attribute contributing to positive outcomes of intelligence, creativity, and wisdom [171]. Up to 20 types of emotions have been described [172] or 1,083 Chinese emotion words exist [89], but there is a processing of fear (danger) that is common to all negative emotions.

Brain mechanisms of conscious awareness [173] turn out to be such that our conscious experience is a series of predictions that we're incessantly and subconsciously fine-tuning – a world we build from the inside out, rather than the outside in. Verbally and consciously reported beliefs do not have to be those unconsciously memorized as authentically responsible for self-reporting [130] [131]. Almost all of the work goes on entirely unconsciously, inaccessible to our conscious minds. The brain's main mission is to ensure the survival of the organism, and to achieve this it is constantly making predictions using information memorized from previous experiences (anticipatory unconscious processing). This allows it to be faster when processing information and making decisions. Predictions based on previous experience (beliefs) predominate over novel or strange perceptions even when constructing memories in the very short term. Our mind deceives us [174]. Anticipatory unconscious processing is a proven reality in unsuspected processing. Shocking, interspersed with the areas responsible for movement (homunculus) of the hands, feet, or face, other areas that do not seem to be directly involved in motor functions, even though they are located at the heart of the motor area of the brain. They are activated when one thinks about moving, before executing it (anticipatory unconscious processing) [175].

Much recent neuroscience has found that human rationality is weaker than is commonly presumed, and emotions make it possible to make decisions. Our rationality serves our emotions, and we have less control over our emotions than is commonly presumed. So "gut instinct" is a type of subconscious, automatic think-ing-feeling that relies on the accumulation of past experiences as you make judgments and decisions in new situations. In general, the therapy works through reductions in worry which it entails the strongest beneficial influence on the other symptoms [176] like suppression of unwanted thoughts [177].

Exposure therapy seeks to help decrease the intensity of the stress responses you might have to situations, thoughts, or memories that provoke anxiety or fear [178]. When, through empathetic interpersonal communication, the therapist makes the client aware that the reasons given and the behaviors carried out are a consequence of unconscious discomfort, exposure therapy is taking place. Finally, the therapeutic relationship between a therapist and client is therefore decisive in the application of Neurofeedback. We will remember that the role of the treatment relationship in hypnosis has been emphasized [179] as well as hypnotist-client rapport (88%) and client emotional motivation (75%) as very or extremely important factors for successful hypnotherapy [180].

We know that hippocampal-prefrontal neuronal synchrony during sleep enhances memory consolidation in humans [181]. It is known that effective communication between brain regions requires that groups of neurons synchronize their activity patterns. It has been possible to verify very low-frequency neuronal oscillations providing temporal synchrony between functionally specific and diverse brain regions [182]. We now know that interpersonal synchrony expresses an interpersonal emotional state. For instance, parent-adolescents have brain-to-brain synchrony when experiencing different emotions together [183]. Also, brain responses change in tandem during social interaction [184]. Inter-brain coupling is behind the fact that patient-clinician encounters can influence pain. These findings support that empathy and supportive care can reduce pain intensity [185]. This is the importance of the therapeutic relationship [186] and eye contact and emotional stability [187] during live interactions [188]. Much of the improvement is related to the improvement of the affective state. As a corollary, we affirm the irreplaceable role of the therapist who applies Neurofeedback.

5. Conclusion

The main conclusion of this study is that the application of Neurofeedback leads to a better change in the emotional state and that this change could explain the change in brain waves and behavior. This is not to suggest that this is the only logical feature involved in Neurofeedback, but this is arguably the most important of the salient ones.

Limitations

The study has its limitations. The lack of a control group is a limitation. The lack of previous studies with the same design, which on the other hand, is an invitation to studies that replicate these results. One other issue that arises here is that Neurofeedback must be replicated in a population different from ours, considering culture, ethnicity, socioeconomics, and other influences. One further point follows from this, longer-term clinical studies to find out if effects persist beyond 2 years. Also, more research can help to personalize Neurofeedback protocols. Because different protocols target different brain activity frequencies and different locations, studies' results are difficult to pool. It is something we leave open.

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Author contributions

All authors contributed toward data analysis, drafting, and critically revising the paper and agree to be accountable for all aspects of the work. They all approved the final version of the manuscript for submission and agreed to be accountable for all aspects of the work.

Ethics Statement

The survey instrument was carefully designed to protect the anonymity and confidentiality of participants, and no personally identifiable information was collected. Participants were made aware that their involvement was voluntary, and consent was secured from every respondent. The study adhered to all ethical guidelines.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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