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Neuromeditation: The Science and Practice of Combining Neurofeedback and Meditation for Improved Mental Health

Jeff Tarrant

Abstract

Beginning meditators often complain that they do not know if they are “doing it right” or give up before realizing significant benefits. Advanced meditators often reach a plateau and struggle to reach “the next level” of their practice. Modern researchers and practitioners are finding a possible new solution to these challenges by using EEG biofeedback to increase awareness of subtle states of consciousness and speed the learning process. By tracking brainwave activity in specific regions of the brain, we can tell if someone is focused or relaxed. We can tell if the mind is wandering, if they are engaged in body-based emotions, or if they have entered a space of internal quiet. By monitoring this activity and connecting it directly to the intent of the meditation, it is possible to help meditators learn to quickly enter a desired state of consciousness and maintain this state for increasing periods of time. This chapter will describe the early research conducted in this area along with an original case study conducted by the author. In addition, the author will describe the way this technology is being used as a treatment intervention for ADHD, anxiety, depression, and PTSD.

Keywords: neuromeditation, neurofeedback, meditation, mindfulness, EEG biofeedback, neurotherapy

1. Introduction

There is abundant evidence that the practice of meditation can lead to improvements in an array of physical and mental health concerns [1]. Not surprisingly, this has led to increasing acceptance of these practices in Western societies. In fact, a recent survey found that three of the top four reasons for starting a meditation practice related to improved mental health or affect management [2]. Despite the increased interest in secular-based meditation programs designed to reduce stress or improve mental well-being (e.g., Mindfulness Based Stress Reduction, Mindfulness Based Cognitive Therapy), many people continue to find it difficult to begin or maintain a consistent practice, giving up before they realize any significant benefit.

Researchers, therapists, and meditation coaches are finding a possible new solution to these challenges by using EEG biofeedback to increase awareness of subtle states of consciousness and speed the meditation learning process [3–5].

2. Neurofeedback and meditation

2.1 Neurofeedback explained

Neurofeedback, sometimes referred to as EEG biofeedback, involves measuring brain wave activity through an electroencephalogram (EEG) and using that information to help the brain understand and modify its processes [6]. Because the raw EEG is a complex signal containing a wide range of frequencies, such data are typically filtered and organized into clusters, called bins. For example, alpha brainwaves are typically identified as the activity occurring between 8 and 12 Hz, while beta brainwaves can be identified as the activity between 15 and 25 Hz. The amount of activity recorded in each of these EEG clusters is measured in microvolts (mv). So, for each electrode used in a recording, it is possible to identify an average amount of power (mv) for each of the specified EEG bands (e.g., delta, theta, alpha, etc., see **Figure 1**).

Once the EEG signal has been quantified, it is connected to computer-based audio and visual signals (feedback) that change in response to the EEG patterns. In this way it is possible to create a pleasant signal that occurs when the brain moves in the desired direction and remove the signal when the brain moves in an undesired direction. With repeated exposure to this process the brain can learn to become more flexible and adaptive, shifting out of rigid states that may be connected to particular concerns, such as ADHD or epilepsy [7]. The neurofeedback provider is trained to understand EEG patterns in relation to specific concerns and is able to create individualized programs for each client based on their goals and needs.

2.2 EEG patterns and states of consciousness

EEG bands are clusters of frequencies, organized into groups based loosely on their shape and function. These bands vary in their definition depending on the specific researcher or clinician. Typical EEG band ranges and descriptions follow.

Delta waves (0–4 Hz) are the slowest brainwaves. When they are dominant, the person is most likely asleep. While we always produce delta activity, if it increases significantly in relation to the other EEG bands, it will be very difficult to maintain any sort of alert consciousness. Its function appears to be mostly related to rest and regeneration.

Theta waves (4–8 Hz) are also considered slow brainwaves, although a bit faster than Delta. This band tends to increase during memory retrieval, creative thinking,

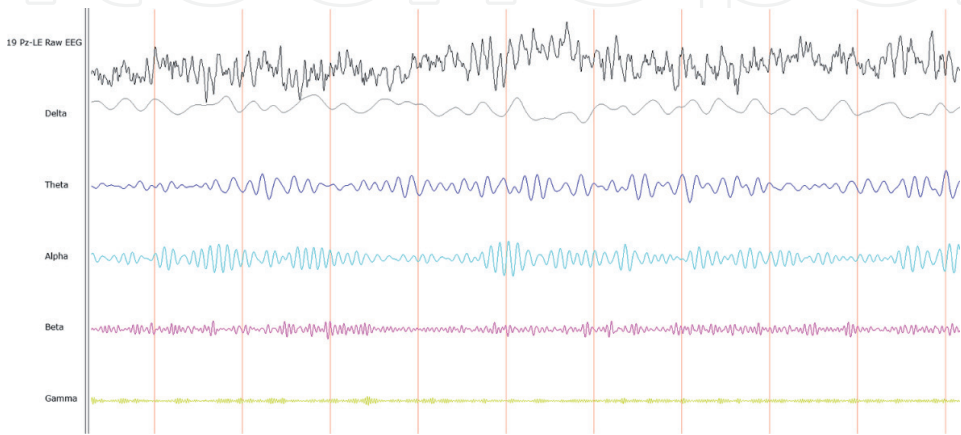


Figure 1.
Raw, delta, theta, alpha, beta, and gamma EEG bands.

and the “twilight state” just before falling asleep. Theta waves are often associated with the mind being in a more receptive state, such as might occur during hypnosis.

Alpha waves (8–12 Hz) represent our “idle” speed, between the slow and fast waves. Alpha is generally associated with being relaxed and internally focused, hence its historical connection to meditation. Alpha activity tends to increase in the absence of stimulation and is frequently viewed as an inverse indication of activation.

Beta waves (12–30 Hz) are fast waves and associated with activation and arousal. When beta increases, it is likely that the person is engaged in thinking, planning, worrying, or some other active state.

Gamma waves (35–50 Hz) are associated with a very sharp focus and feelings of creativity and insight. Increases in this activity are often observed during high-level information processing or a more effortless, but complex form of understanding, such as occur in a flow state.

2.3 The meditating brain

Contrary to popular belief, there is no single EEG pattern associated with meditation. This is largely due to the fact that there are many different approaches to meditation with distinctly different ways of directing attention. In addition, each style of meditation impacts specific regions of the brain. For example many forms of a Focus or Concentration meditation practice result in activation of the frontal lobes while simultaneously showing a de-activation of regions in the back of the brain.

Based on reviews of the EEG meditation literature, most researchers agree that there are four basic styles of meditation defined by how attention is directed, the intention of the meditator, which brainwaves are involved, and in which brain regions [5, 8, 9]. These four styles can be described as follows:

Focus: Meditative practices with this emphasis involve sustaining attention on a single object, such as the breath or a mantra. When the mind wanders, the task is to recognize this and return to the original point of focus. Regardless of the specific target, practices in this category require sustaining attention and minimizing mind wandering. Consequently, neuromeditation approaches with this style in mind must monitor specific regions of the frontal lobe (sustaining attention) and the Default Mode Network (DMN; mind wandering). The goal is to keep the attention circuits activated without becoming caught in self-referencing narratives.

Mindfulness: While the term mindfulness has been popularized to refer to a range of practices, it is being used here to describe meditation styles that require the meditator to shift into an observer state of awareness, gently watching thoughts, feelings, and bodily sensations without attachment. It is a present moment awareness without attempts to control, analyze, or judge the experience. These practices also quiet down the Default Mode Network while simultaneously activating the Salience Network, which directs attention toward what is important in the moment.

Open heart: These practices involve activating a positive feeling state and directing those feelings toward self or others. Practices such as lovingkindness, compassion, gratitude, and forgiveness-based meditations fit in this category. These practices activate attention networks and brain regions associated with empathy and emotional processing.

Quiet mind: Practices in this category represent the stereotype of meditation. This is a state in which internal chatter has been reduced to a minimum. Sometimes it is described as a feeling of spaciousness or emptiness. This state is common in traditions like Zen or Transcendental Meditation (TM). Not surprisingly, the brain

patterns connected to these practices show a significant quieting of many regions of the brain, including the Default Mode Network and language centers.

3. Understanding Neuromeditation

Simply put, neuromeditation is the combination of meditation with neurofeedback. By monitoring brainwave activity in specific regions of the brain, it is possible to determine if someone is focused or relaxed, if the mind is wandering, if they are engaged in body-based emotions, or if they have entered a space of internal quietude. By tracking this activity in real-time and connecting it directly to the intent of the meditation, it is possible to help meditators learn to quickly enter a desired state of consciousness and maintain this state for increasing periods of time, increasing the impact and effectiveness.

3.1 History of Neuromeditation

The practice of combining neurofeedback with meditation is not new. In fact, many of the pioneers in the field of neurofeedback were motivated by the desire to enhance their meditation practice or explore states of consciousness. Based on the research of the time, meditation was primarily associated with increased Alpha brainwave activity, particularly in the Occipital and Parietal regions of the brain [10, 11]. As a result, rewarding increases in Alpha amplitude in these regions became the “go-to” approach to neuromeditation for many years [11]. Because increases in the Alpha band are generally related to an inhibition of mental activity [12], this approach was useful in achieving Quiet Mind meditative states, consistent with certain TM or Zen practices [4, 8]. It was also found that protocols designed to reward increases in Alpha amplitude frequently resulted in decreased anxiety, feelings of relaxation, and positive emotions, providing mental health benefits to those suffering from chronic stress or anxiety [13, 14].

3.2 Neuromeditation example

By placing an EEG electrode near the back of the head, it is possible to gain information about the state of the brain’s Default Mode Network (DMN). The DMN is a vast network with its primary hub located in the Posterior Cingulate Cortex (PCC) of the Parietal lobes (see **Figure 2**), just beneath electrode site PZ (see **Figure 3**). This area of the brain becomes active when a person is involved in self-referential thought [16]. Basically, any thought you have that relates back to your view of self or your connection to the world will involve the DMN. Not surprisingly, activity in the DMN (and PCC) is connected to mind wandering during a meditative practice [17]. Essentially, if you are not fully engaged in the intention of the meditation, you are likely thinking about yourself or something related to yourself. By quieting the DMN, represented by increases in Alpha amplitude or decreases in Beta or Gamma, it is possible to move beyond the typical “story-telling” tendencies of the mind and tap into an internalized, peaceful state of consciousness.

When the Alpha brainwave patterns increase in this region, it is likely that the internal state is more relaxed and the mental activity is inhibited. When Alpha is lower, there is likely to be more analyzing, judging, comparing, remembering, or planning. By establishing a threshold marker in the neurofeedback software, it is possible to identify when the Alpha is “high” or “low.”



Figure 2.
Sagittal MRI slice with highlighting indicating location of the posterior cingulate cortex [15].

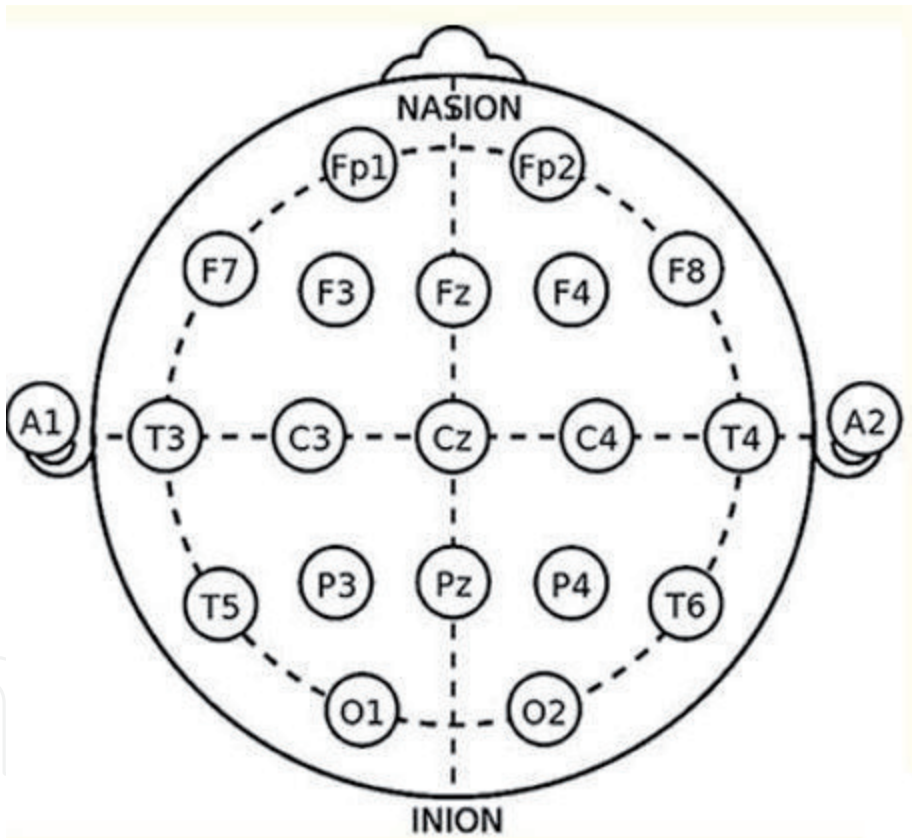


Figure 3.
International 10-20 EEG electrode map.

When the Alpha activity increases and moves above the threshold marker, the meditator receives some form of pre-determined feedback, letting them know they are on the right track. The feedback used for meditation is typically some form of audio signal or change in music volume designed to provide information without disrupting the meditative state. When the mind wanders, the Alpha drops, signaling a change in the audio signal (e.g., decrease in volume). This provides direct and nearly immediate feedback to the meditator, allowing them to refine their internal awareness.

It should be noted that the example provided above is an over-simplification of the process, but offered for the purposes of illustration.

3.3 The research evidence for Neuromeditation

While the real-world applications of neuromeditation have been explored in the neurofeedback community for many years, there have been only a few studies demonstrating the power of this approach in the lab. The first study to examine the feasibility of neurofeedback for meditation used real-time fMRI data to examine the subjective experience of meditators when the Posterior Cingulate Cortex (PCC) was active vs. quiet. Rather than measuring EEG activity, this study examined blood flow, which is an indication of activation [18].

The meditators in this study reported experiences of being “distracted,” “interpreting,” “controlling,” and “efforting,” when the PCC was active. In contrast, they reported experiences of “concentration,” “undistracted awareness,” “effortless doing,” and “observing sensory experience” when the PCC was deactivated. A follow-up study provided feedback to meditators about the activity level of the (PCC) during a Focus style of meditation [19]. Both meditators and non-meditators reported a significant relationship between activation of the PCC and mind wandering as well as deactivation of the PCC and focused attention.

The researchers also found that experienced meditators (but not novice meditators) were able to intentionally decrease activation of the PCC through the use of the feedback [18]. In another study using EEG neurofeedback, van Lutterveld, et al., found that both novice and experienced meditators were able to control the experience of effortless awareness in connection with a feedback signal indicating decreased PCC activation [20].

More recently, eight sessions of neurofeedback-enhanced meditation were compared to a control group that received sham neurofeedback [21]. Rather than focusing on the PCC, these researchers rewarded increases of frontal midline theta brainwaves (FM Theta). FM Theta are slow oscillations, between 4 and 7 Hz that are generated in the Anterior Cingulate Cortex (ACC; see **Figure 4**). Theta originating in the ACC often increases in power during a variety of cognitive processes

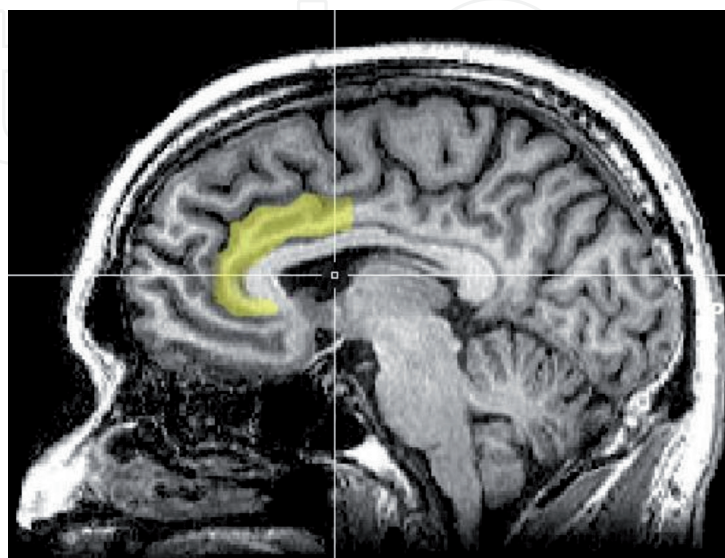


Figure 4.
Sagittal MRI slice with highlighting indicating location of the anterior cingulate cortex [15].

that require attention, focus, or emotional processing [22–25]. Several studies have found a correlation between increased FM Theta and focused attention meditation practices [26, 27]. Results showed that the experimental group was not only able to significantly increase FM Theta, but also improved performance on a working memory task [21].

Video 1 (<https://youtu.be/OxMdYj2Jq4Y>; [28]) provides a demonstration and explanation of a neuromeditation protocol that examines increases of FM Theta while simultaneously monitoring (de)activation of the DMN.

4. Neuromeditation for mental health

While most work in the field of neuromeditation has been devoted to enhancing or advancing the development of specific meditative states, clinicians and researchers are also beginning to explore this strategy as an intervention to improve mental health and cognitive functioning. Because both meditation and neurofeedback have independently been found to be effective in the treatment of a variety of mental health concerns, it is logical to combine them to target specific outcomes [3, 5]. For example, in the study cited above subjects receiving eight sessions of focus neuro-meditation significantly improved their performance on a working memory task, while the control group did not [21]. These outcomes make sense given that regions of the brain involved in working memory are exercised during Focus meditation practices. With this logic, it is possible to identify which styles of meditation might be best suited for particular outcomes.

Focus practices with an emphasis on sustaining attention on a single object, activate the frontal lobes, making it an ideal practice for improving functions related to attention, memory, or other executive functions [8, 29, 30]. Consequently, this might be the most beneficial practice for someone with ADHD, cognitive decline, or traumatic brain injury.

Mindfulness, which involves a much more relaxed, observing form of attention may be best suited for managing stress and anxiety [31]. A key component of mindfulness practices involves non-attachment and learning to let go [32], key elements involved in managing stress and anxiety. Not surprisingly, these practices have been shown to reduce activation of the Amygdala, a key brain region involved in the fight or flight response [33].

Open Heart practices, such as lovingkindness-compassion, and gratitude engage positive feeling states, increasing empathy, perspective-taking, and the experience of joy and appreciation [8, 30]. These practices can be helpful for those dealing with resentment, unresolved grief, anger management, or depression.

Practices in the Quiet Mind category result in a reduction of self-talk, leading to the experience of spaciousness or emptiness [8, 34]. Because these practices essentially involve interrupting the “normal” process of “selfing,” they can be helpful for concerns connected to a distorted or inaccurate perception of self, which includes most mental health concerns.

While the four styles can certainly serve as a guide for matching a person to the ideal meditation practice, there are often levels of nuance that require assessment and direction from a trained mental health professional. This is particularly true for clients engaging in neuromeditation with unresolved trauma. In addition, we have found that EEG guided meditation is most effective when it is individualized and includes meditation coaching. The case study below will demonstrate this approach.

4.1 Case study

4.1.1 Background

B.A. is a 39-year-old, Caucasian woman with a mental health history of anxiety, eating disordered behaviors, and post-traumatic stress disorder (PTSD). The PTSD relates to a car accident and childhood sexual trauma.*.

B.A. began working with yogic practices in her 20s. She noted that she would frequently experience strong emotions such as grief and anger while holding certain poses which led to some resistance to these practices. She began practicing Transcendental Meditation during her late 20s, but never felt confident in this practice. She described mostly engaging in brief practices and struggles with judging herself.

She identified three concerns she hoped to address through her neuromeditation practice; these included: a tendency to be hyper-critical of self and others, feeling overwhelmed and sensitive to sound, and a desire to feel more grounded-to slow down. These were all rated as moderate concerns. In elaboration of item 3, B.A. noted that she is “very much in her head” and often feels disconnected from her body.

Known barriers to expanding her current meditation practice include time, internal resistance, the critical mind, and a tendency to “leave her body” when she begins to relax.

*Identifying information related to this client has been altered to protect their identity. In addition, the client has given permission for their case to be shared in this format.

4.1.2 Assessment results

Results of the neuromeditation Styles Inventory [35] indicated that her concerns most closely matched the Quiet Mind style of meditation. Elevated scores on the New Mind Cognitive Emotional Checklist (CEC) Symptom Checklist [36] indicated concerns with memory, sensitivity to light and sound, feeling “spacey” or “out of my body,” and thinking obsessively. In addition to the above, a Quantitative EEG assessment provided a comparison of her baseline EEG activity to a clinical database. Using a Laplacian reference for the eyes closed data set and analyzing it through qEEG Pro [37], the most striking feature was increased absolute power across all EEG bands in similar brain regions (see Figure 5).

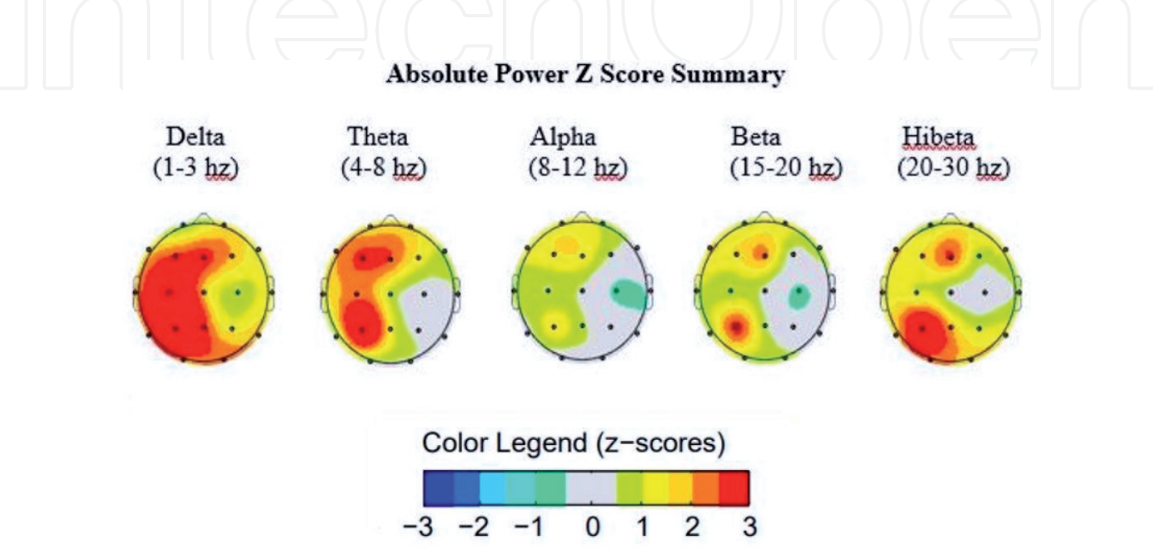


Figure 5.
Absolute power across EEG bands compared to qEEG Pro clinical database.

The EEG analysis indicates that Delta (1–3 Hz) and Theta (4–8) activity were elevated in left frontal and parietal regions. These same regions also demonstrated elevated Beta (15–20 Hz) and Hibeta (20–30 Hz) which appeared more localized at FZ and P3. Alpha activity was largely within normal limits.

The combination of excessive slow and fast activity in similar regions with average alpha activity suggests that this pattern may be related to the PTSD concerns noted in the interview. Specifically, the increased slow activity may be connected to the tendency to dissociate. This pattern could also be related to some of the memory, attention, and impulsivity concerns noted in the CEC. The elevated fast activity may be related to tendencies toward anxiety as well as sensory sensitivity.

4.1.3 Individualized approach

Based on the information gathered, a Mindfulness meditation protocol was identified as the best match for her concerns and background. Specifically, this protocol would reward increased activation of the right Insula and deactivation of the PCC. Activity in the Right Insula is a common finding in Mindfulness practices and relates to interoception, emotional self-awareness [38], and metacognitive awareness [39]. The right Insula was highlighted as it tends to be more connected to a felt sense of the body and may be helpful in feeling more grounded (one of B.A.'s goals). The reduction of activity in the PCC will require a limit on cognitive processing such as analysis, comparison, or creating a narrative about the experience. This aspect of the protocol addresses concerns around “thinking obsessively.”

4.1.4 Session results

4.1.4.1 Session 1

B.A. was initially instructed to simply observe whatever she notices in her body as sensation without any interpretation or internal dialog about these observations. Near the 11-min mark of the meditation, B.A. came out of her meditation and commented that she was having trouble feeling into her body and tends to “disappear,” feeling nothing. The therapist provided grounding skills training including rubbing her fingers together, or tapping her fingers to her thumb to create a tactile sensation. B.A. attempted this for approximately 6 min and stopped the session again. She noted that she was struggling with this practice. After additional discussion, B.A. agreed to try focusing on the heart by imagining breathing into and out of the heart, attending to any sensations in that area. After the session, she noted that this seemed to work better for her and was assigned as homework. **Figure 6** below shows an analysis of the session in the neuromeditation Report Writer. Each of the time segments described above were identified in the EEG record for comparison. The scores indicate the percent of time that she was able to keep the identified EEG activity in the desired direction. It is clear from examining the right Insula, PCC, and the combined success, that B.A. was much more skilled at reducing activity in the PCC than in increasing activity in the right Insula. This is consistent with her report that she “felt nothing” and tended to “disappear.” This was also consistent with her history of practicing TM meditation, which falls into the Quiet Mind category.

4.1.4.2 Session 2

The session began with a discussion of her home practice during the past week (without neurofeedback assistance). We explored her tendency to try too hard, become impatient with herself and judge “success.” B.A. was encouraged to relax



Figure 6. Analysis of session 1 in the NeuroMeditation report writer. Scores reflect the percent of time that EEG criterion was met for specified meditation segments.

her goals and expectations for the practice, allowing time to find the meditative space. B.A. was able to connect to sensations in her throat during the session. The time periods of the session where this occurred were easily identified with increased gamma activity in the *R. insula*. While this approach appeared successful, B.A. reported feeling somewhat “panicky” near the end of the session. B.A. indicated that focusing on the throat was causing some trauma related feelings and memories connected to a history of sexual abuse. We discussed her reaction briefly, inviting her to change the focus of her meditation, engage with eyes open, use a variety of grounding tools, or titrating the experience to maintain a feeling of safety.

4.1.4.3 Session 3

B.A. noted that the tendency to dissociate is so strong that it requires a lot of energy and effort to stay present. To encourage present focused awareness, B.A. began coaching herself internally, reminding herself that she is safe, noting her process and experience. While this strategy helped B.A. to stay in her body without dissociating, the internal narrative caused the activity in the PCC to increase. Consequently, the EEG analysis for this session showed increased success with the *R. insula*, but decreased success with the PCC.

4.1.4.4 Session 4

B.A. noted more spontaneous experiences of mindfulness outside of session and fewer dissociative moments. During the session we altered the instructions and

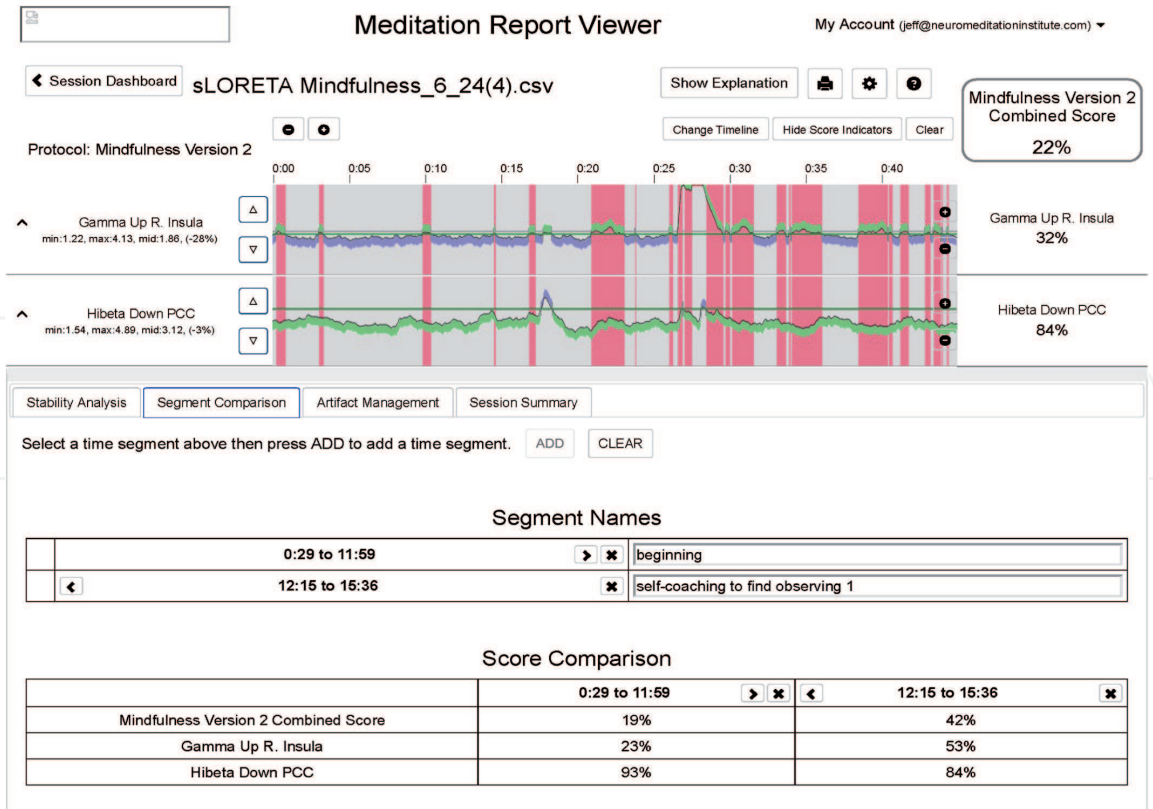


Figure 7.
Analysis of session 4 in the NeuroMeditation report writer. Scores reflect the percent of time that EEG criterion was met for specified meditation segments.

the EEG expectations such that she could use self-talk to help notice her present-moment experiences. This resulted in the most significant positive results to date. In fact, B.A. ended the session claiming that she felt “amazing.” She described the meditative state as “feeling without trying to feel.” She described it as an effort-less awareness of her body in the present moment. **Figure 7** shows a comparison between the beginning of the session vs. the period of self-coaching. When this shift occurred in session, B.A.’s percent of combined success went from 19 to 42%.

4.1.4.5 Sessions 5–8

Once B.A. was able to experience the desired state and learn to do so in a way that felt safe without dissociating, she mastered it very quickly. During the next three sessions, she continued to demonstrate the ability to quickly find the desired meditative state and maintain it for increasing lengths of time. She also noted experiencing similar meditative moments through the day. B.A. reported feeling that she is fully “in her skin” and enjoying it. **Table 1** below is a comparison of sessions, 2, 4, 6, and 8. By examining the percent of success across each session, her progress is clear.

Score Comparison				
	Session 2	Session 4	Session 6	Session 8
Mindfulness Combined Score	7%	22%	44%	75%
Gamma Up R. insula	15%	32%	45%	83%
High Beta Down PCC	61%	84%	100%	86%

Table 1.
Comparison of sessions 2, 4, 6, and 8 in NeuroMeditation report writer.

4.1.5 Pre-post symptom changes

At the conclusion of each neuromeditation session, B.A. completed the Toronto Mindfulness Scale [40]. This is a 13-item self-report scale designed to assess state mindfulness with respect to meditation practice. Six items are summed to produce a total Curiosity score ($\alpha = 0.88$), reflecting an attitude of wanting to learn more about one’s experiences (e.g., “I was curious to see what my mind was up to from moment to moment”), and seven items are summed to produce summed to produce a Decentering score ($\alpha = 0.82$), reflecting a shift from identifying personally with thoughts and feelings to relating to one’s experience within a wider field of awareness (e.g., “I was aware of my thoughts and feelings without overidentifying with them”). **Figure 8** shows her scores for each session.

These results show a consistent increase in Decentering, which is the scale most relevant to decreasing stress and anxiety.

B.A. also completed a symptom questionnaire around sessions 4 and 8. **Figure 9** below demonstrates the change in symptoms from Pre-post.

The gray areas at the top of each bar represent the scores during the initial assessment, the colored areas represent the most recent scores. Clearly, there was a perceived decrease in symptoms, which were most notable in “easily distracted,” “filtering,” “hypervigilance,” “reading comprehension,” and “worry.” Most of these improvements appear directly related to the goals and concerns identified in the intake process. It is unclear why there would be such improvements in reading comprehension. It is possible that improvements in attention resulted in improved reading comprehension. It is also possible that any brain changes

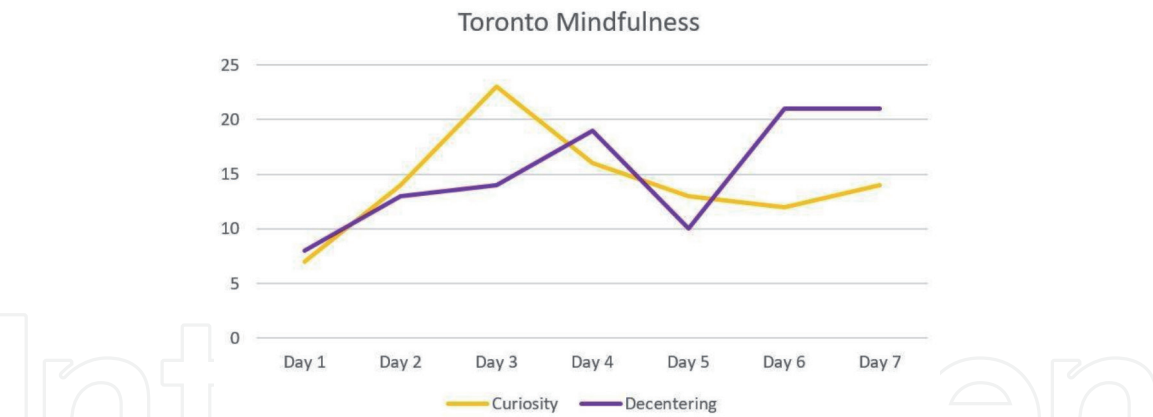


Figure 8. Toronto Mindfulness Scale scores (curiosity, decentering) for client B.A. across sessions 1–7.

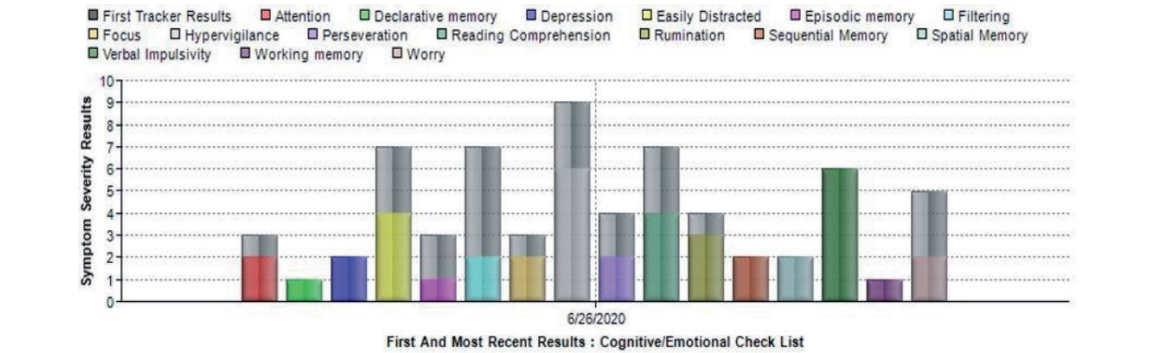


Figure 9. Session 4 vs. session 8 symptom questionnaire scores for client B.A.

occurring as a result of the training had a more generalized impact on brain health and functioning, influencing concerns not directly related to the training itself.

5. Conclusions

While combining neurofeedback with meditation is not new, advances in our understanding of the neurological mechanisms of meditation have led to a more refined approach. Clinicians and researchers are now able to identify different meditation styles based not only on the way attention and intention are directed, but on brainwave patterns and brain regions involved. This has led to the ability to personalize the process, helping meditators choose a meditation style that is most likely to address their goals and needs. Indeed, researchers are now beginning to show that specific neuromeditation approaches can be used to improve cognitive functioning [41], and psychological concerns including anxiety, depression, and PTSD [5]. When this process is used in conjunction with meditation coaching, it is possible to use neuromeditation as a treatment modality that is individualized, and trauma informed. As such, neuromeditation promises to help define and refine meditation for the 21st century.

Conflict of interest

The author is the Director of the neuromeditation Institute.

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