NeuroRegulation

Habit Formation and Automaticity: Psychoneurobiological Correlates of Gamma Activity

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Abstract

Within current mental healthcare practices, a reliable mechanism is needed for transitioning therapeutic interventions into long-term habit formation. While a sizeable body of literature on habit formation and automaticity looking at simple behaviors such as overall activity level and diet exists, few studies have investigated the complex behavior formation needed to instill new beneficial mental health habits. Additionally, limited research has looked at the neurophysiological or biological correlates of these mental processes and changes. Madhavan et al. (2015) proposed that, during active learning or recall, individuals exert more cognitive energy compared to information maintenance, resulting in heightened gamma activity. This new data demonstrates that gamma increases as learning is taking place then decreases once the behavior is learned (habituated), providing evidence of habit formation and automaticity and its nonlinear nature. The current pilot study seeks to contribute to the field's developing knowledge of habit formation and automaticity as something that can be deliberately and mindfully learned, through a planned and guided approach over a specified time frame, to empower individuals to achieve lasting improvements in mental health challenges. Our research contributes practical strategies to improve interventions and achieve sustainable outcomes for the public health emergency in mental health.

Keywords: automaticity; habits; mindfulness; complex behavior; gamma; telomeres; prolactin.

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Introduction

Mental health management is an emerging public health crisis (Kohn et al., 2004; Singh et al. 2022), and mental health services are insufficient (Patel et al., 2009), necessitating new effective, affordable, and accessible interventions that lead to sustainable change. To further research interventions to address this crisis, the current work examines the science of habit formation and automaticity as a possible way to create sustainable change and the improvement of mental health by building in practices leading to the discontinuation of detrimental behavior and the growth of practices that improve mental health. The present study used a unique psychoneurobiological approach, specifically looking at how habits and automaticity form using a whole person context in the hopes of contributing to how habit formation can be used in mental health interventions.

Interrelation Between Habit Formation, Automaticity, and Mental Health Intervention

The science of habit formation has been extensively researched across disciplines and has multiple definitions, mostly on a stimulus-response-reward continuum (Gardner et al., 2012; Trafimow, 2018;

Verplanken & Orbell, 2003; Wood, 2017; Wood & Neal, 2007; Wood & Rünger, 2016), but is largely defined as “mindless” learned cue-behavior of automated repeated sequences of lower-level actions requiring minimal cognitive effort and resistance to change (Harvey et al., 2022; Langer, 1989; Wood & Neal, 2009). Maddux (1997), on examining the definitions of habit formation and how theories of habit formation use habits, identified a logic error in that the “consensus definition of habit defines habit as a kind of behavior (automatic, unconscious) but our theories employ habit as a cause of behavior” (p.335). This is tautological reasoning, implying that a habit is both a “behavior and the cause of a behavior;” in essence, “a habit is caused by a habit” (Maddux, 1997, p. 335). Additionally, Maddux proposes that it would be more meaningful to look for the cause of a habit intentionally and deliberately in the context of an individual’s life experiences (Maddux & DuCharme, 1997). Furthermore, Gardner’s (2014) extensive review of 136 empirical studies and eight literature reviews of habit formation underscores the need for a more coherent definition of habit formation to make it more useful for the research and treatment of complex mental health and health behaviors. As most research on habit formation has been conducted using very simple behaviors, Gardener suggested an alternative way of seeing habits is as a “cognitive-motivational process, conceptually distinct from behavior” (Gardner, 2014, p. 289).

A further, important aspect of habit formation intervention involves the concept of automaticity, which is the “active ingredient” or “essence” (Gardner, 2012, p. 33) of a habit that transforms the pure meaningless repetition of a habit into a meaningful, mindful, and useful response that will override a trigger at any point in the future. It has, at its core, the characteristics of increasing self-regulation and therefore self-management and engagement (Gardner, 2012; Lally et al., 2010; Neal & Wood, 2009; Stone et al., 2023).

For habit formation and automaticity to happen, the process involves a pairing of sequential behavior with context in a repeated way to reinforce it, which motivates and strengthens the repetition in a cyclic way until stabilization occurs (Gardner & Lally, 2018). The repetition is growth-oriented in the sense that each “repetition” brings more insight into the reason they are forming a new habit. Therefore, the habit can be seen as the end product of the mindful process of automaticity (Maddux, 1997). Wood and Neal (2007) emphasized that habit formation involves controlled and deliberate higher-order cognitive capabilities. Automaticity is therefore the active process that strengthens the habit to the point where it is initiated and applied efficiently with less conscious control (Aarts & Dijksterhuis, 2000; Carden & Wood, 2018; Lally et al., 2010; Orbell & Verplanken, 2010). This suggests it takes more than just an intention to form a habit, but also deliberate effort, as intentions do not always translate into consistent action (Sheeran, 2001).

Furthermore, mindfulness and habit formation are often seen as opposites, with a habit defined as mindless behavior (Langer, 1989) and mindfulness as “paying attention in a particular way: on purpose, in the present moment, and nonjudgmentally” (Kabat-Zinn, 1994, p. 4). It is proposed in the literature that habit formation needs an expanded view that requires the mindfulness aspect in order to be better applied to the treatment of complex issues (Gardner, 2012; Harvey et al., 2022; Lally et al., 2011; Lally & Gardener, 2013; Robinson et al., 2022; Rothman et al., 2009). A comprehensive review of this literature across different disciplines shows that mindfulness involves deliberate and intentional focused reflection (Casey et al., 2022; Liu et al., 2021; Mitchell et al., 2021; Wong et al., 2022), which are elements that need to be incorporated into intervention that has the effective use of habit formation and automaticity (Ariyasinghe & Arachchige, 2020; Lewis et al., 2021). To establish habit formation and automaticity, it therefore requires mindful self-regulation and action planning, not just a mindless repetitive action (Fleig et al., 2013; Sniehotta, 2009; Sniehotta & Presseau, 2012). Mindful self-regulation thus becomes an elucidative requirement in forming new habits and their automatization, to change behavior leading to improved mental health outcomes (Frazier et al., 2021).

There is a consensus in the literature that including the science of habit formation and automaticity in the design and delivery of evidence-based therapies (EBT) for mental health challenges would appear to enhance their effectiveness (Fiorella, 2020; Harvey et al., 2022; Kazdin, 2018; Lally et al., 2011; Lally & Gardener, 2013; Robinson et al., 2022; Rothman et al., 2009). In patient care settings, the potential benefits of automating complex healthy habits are often overlooked due to the immediate effects of brief advice. Traditional methods of behavioral change tend to prioritize easily induced maintenance mechanisms rather than gradual habit stabilization (Gardner et al., 2012). While establishing long-term complex habits can be time-consuming and challenging, the effective development of automaticity in habit formation has demonstrated numerous advantages. These include an increased sense of autonomy (Gardner et al., 2012) and the ability of habits to act as a form of self-control and facilitate desired long-term behaviors, especially during periods of short-term motivational lapses (Gardner & Lally, 2018).

Habit formation and automaticity appear to involve phases: a conscious and deliberate process of formation of a habit, followed by the stabilization of the newly formed habit through learning in order to increase its strength (Gardner et al., 2012). The habit's strength is based on the intensity of these two stages and will determine how effectively an individual has a "ready response when distraction, time pressure, lowered willpower, and stress reduce the capacity to deliberate about action and tailor responses to current environments" (Wood & Rünger, 2016, p.307; Stojanovic et al., 2022; van der Weiden, 2020).

In understanding the process of habit formation and automaticity, it is also necessary to understand the timing of habit formation and automaticity in order for it to guide intervention that leads to sustainable change in mental health treatment. Despite the much-quoted myth that it takes 21 days to form a habit, which is based on anecdotal evidence from a plastic surgeon's recovering patients (Lally et al., 2010; Maltz, 1960), research on the timing of habit formation is still in its infancy, and it is known that habits do not form overnight and even over a few weeks. Most of the limited literature in this specific area of timing of habit formation and automaticity suggest it takes around 18–254 days, with peak automaticity plateauing around 59–66 days after the first daily implementation (Armitage, 2005; Gardner et al., 2012; Greeson et al., 2018; Keller et al., 2021; Lally et al., 2010; Raja-Khan et al., 2017; van der Weiden, 2020). The range of 66–254 days would appear to depend on the complexity and interrelated complicated networks of habits that may represent one or more issues being worked on (Carden & Wood, 2018; Gardner et al, 2012; Harvey et al., 2020; Hussam et al., 2017; Judah et al., 2013; Lally, et al., 2010).

Van der Weiden et al. (2020) demonstrated that a large increase in habit strength with complex behaviors such as improved relationships and health can occur over a period of 3 months (van der Weiden, 2020). Lewis et al. (2021) found a significant overall change in simple habit automaticity in the first 21 days, with it taking about 3 weeks to transform the mindfulness behavior of breathing into a habit (Lewis et al., 2021). Furthermore, consistency over that time period is important in habit formation and automaticity (Gardner & Lally, 2018; Lally et al., 2010).

Forming a habit involves learning because learning is "the process by which a relatively stable modification in stimulus–response relations is developed as a consequence of functional environmental interaction via the senses" (Lachman, 1997, p.477). An effective habit could then be defined as one that is learned successfully, or automatized, and will be accessible even without use for a period of time; thus, habits do not have to be enacted frequently to be useful (Gardner, 2012; Leaf et al., 1997). When a person is triggered, it will still lead to the automatized mentally healthy behavior being activated so that the person does not revert to the previous behavior. Essentially, habit formation and automaticity require an active learning phase (Leaf et al., 1977) to attain sustainable habits that improve mental health.

Gamma as a Delicate Balance Linked to Habit Formation, Automaticity, and Mental Health

Neuroscientific research has consistently demonstrated the involvement of gamma activity in cognitive functions such as learning, memory, and executive functioning (Barry et al., 2010; Jensen et al., 2007; Roh et al., 2016). Specifically, a correlation has been established between an increase in gamma activity and improved learning, memory formation, and recall (Jensen et al., 2007; Madhavan et al., 2015). A study by Madhavan and colleagues (2015) demonstrated that gamma increases in the temporal lobes during learning, and then decreases once the behavior is learned. They proposed that during active learning or recall, individuals exert more cognitive energy, resulting in heightened gamma activity, and then lessens after learning has taken place when the information is being maintained (Madhavan et al., 2015).

Similarly, greater cognitive resources are needed during the initial phases of habit formation (Lally et al., 2011); therefore, gamma activity should be higher. As the habit becomes more automatic, maintenance demands decrease (Gardner & Lally, 2018; Wood & Neal, 2007), which could potentially result in a corresponding decrease in gamma activity. According to Smith and Graybiel (2022), habitual behavior is a complex process and can be characterized by multiple neuronal changes across the same or different brain regions. These changes may be representative of gamma activity as well, since gamma is considered to be responsible for higher levels of cognition and awareness (Hima et al., 2020). While these concepts need to be explored further, this research sheds important insight into neurophysiological mechanisms that play a role in learning and habit formation.

Furthermore, in a recent review article exploring gamma activity (30–100 Hz) and memory, numerous studies revealed that increased gamma band synchronization was positively correlated with short-term and working memory maintenance (Howard et al., 2003; Jenson et al., 2007; Jokisch & Jensen, 2007; Mainy et al., 2007; Tallon-Baudry et al., 1998). The same review also found that both gamma activity and synchrony were implicated in long-term memory, which they explained to be due to increased gamma-modulated synaptic plasticity (Jensen et al., 2007; Wespatat et al., 2004). These findings demonstrate the potential of using gamma band activity as a marker for neurological and psychiatric disorders that affect memory and memory formation, which could be related to habit formation and automaticity.

Gamma activity has also been shown to be involved in healthy executive functioning (Barry et al., 2010; Lawson, 2013; Roh et al., 2016), which is important for higher level cognitive abilities including problem-solving, self-regulation, planning, and self-control (Diamond, 2013; Dovis et al., 2015; Henry & Bettenay, 2010). Barry et al. (2010) studied resting-state EEGs in 40 children with attention-deficit/hyperactivity disorder (ADHD) and 40 age-matched controls and found that children with ADHD had reduced relative and absolute global gamma (30–80 Hz) activity compared to controls. Additionally, they discovered a negative correlation between the inattention scores of the children with ADHD and gamma, demonstrating that decreased gamma activity could be linked to impaired executive functioning and increased inattention, which may be related to conditions like ADHD (Barry et al., 2010). Similarly, a study investigating the relationship between qEEG bands and inattention in major depressive disorder (MDD) also found that inattention scores and low gamma (30–50 Hz) activity in the frontal-central regions were negatively correlated (Roh et al., 2016), while another suggested that gamma band synchrony is decreased in people diagnosed with autism spectrum condition (ASC; Lawson, 2013). These findings further emphasize the involvement of gamma waves in healthy executive functioning paradigms. This idea could be related to an individual’s sense of autonomy, self-control (Diamond, 2013), and ability to effectively stop unhealthy habits, given that executive functioning is implicated in the cessation of habits like those found in individuals with obesity (Allom et al., 2018).

Studies have also shown an association between gamma band activity (30–80 Hz) and anxiety and depression (Li et al., 2016; Noda et al., 2017; Oathes et al., 2008), both of which can be a result of an unhealthy habit related to having negative thoughts about one’s self-image (Verplanken, 2006). In Noda et al. (2017), 31 patients diagnosed with MDD and a HAM-D score of greater than 10 were studied to evaluate the effects of repetitive transcranial magnetic stimulation (rTMS) on qEEG band patterns demonstrating a significant correlation between increased gamma activity at the F3 electrode and improved Hamilton Depression Rating Scale (HAM-D) scores. This has supported the conclusion that gamma power could be used as a biomarker for potential therapies for MDD, as gamma was shown to be connected to mood disorders (Noda et al., 2017). These findings are further supported by Hima et al. (2020), who proposed that an increase of gamma (40–100 Hz) is associated with states of happiness and compassion and Oathes et al. (2008) who found that there was a higher level of gamma activity in posterior electrode sites in patients with generalized anxiety disorder (GAD) during worry induction. Differences between these results could be related to the timing of when gamma activity is measured, under what conditions, and the brain region of the measurement.

The literature emphasizes the delicate balance required for gamma activity, as it represents a "goldilocks" frequency that is achieved through the excitation and inhibition of different neuronal circuits (Fitzgerald & Watson, 2018). It can be too low or too high, revealing the work of change, and its interpretation is based on the location of its source (Fitzgerald & Watson, 2018). Additionally, gamma can be seen as a representative of neighborhood communication between higher-level cortical sites (Hima et al., 2020; Jensen et al., 2007). Therefore, depending on which cortical areas you are talking about, the increase or decrease in gamma can be thought of as an index of overall arousal or activation in that cortical area as a result of work being done in the mind (Jensen et al., 2007).

Furthermore, gamma has been shown to be highly context-dependent and cannot be classified simply as good or bad purely based on an increase or decrease in activity (Fitzgerald & Watson, 2018). Interestingly, individuals with ASC exhibit excessive gamma activity (Lawson, 2013), which challenges the idea that increased gamma levels always correlate with normal brain function. As seen in the study conducted by Madhavan et al. (2015), gamma activity exhibits both an increase and decrease during different stages of a normal learning process. This suggests that gamma activity alone should not be used as a definitive diagnostic measure. In the current research examined the change in gamma in the control and treatment group were examined while they used the Neurocycle in a planned and guided way over time to intentionally form new habits that would lead to healthier lifestyles and mental well-being.

Biological Factors Impact in Habit Formation and Automaticity

Telomeres are a protective casing at the end of a DNA strand (Epel, 2009). Each time a cell divides, it loses some of its telomeres and an enzyme called telomerase can replenish it; however, chronic unmanaged stress and cortisol exposure decrease the supply of telomerase (Epel et al., 2004). When the telomere becomes too diminished, the cell often dies or becomes proinflammatory (Yegorov et al., 2020). Both chronic and perceived stress, or self-reported measures of unmanaged stress, have been linked to shorter telomeres (Cawthon et al., 2003; Lin & Epel, 2022; Rentscher et al., 2020). Existing research demonstrates that changing lifestyle behaviors and mindful meditation practices can influence telomere length (Epel, 2009).

The literature in this field has focused predominantly on changes in the telomerase activity because it was believed that changes in telomere length took months or even years to change, which is longer than the typical length of mindful meditation and lifestyle interventions for mental well-being (Conklin et al., 2018). However, more recent studies demonstrate that deliberate lifestyle changes such as exercise, diet, and mindful meditation can lead to an increase in telomere length over shorter periods of approximately 3 weeks to 4 months corresponding with the timing of habit formation and automaticity (Alda et al., 2016; Conklin et al., 2015; Epel, 2012; Shen et al., 2020; Wang et al., 2017). The research further suggests that the duration and intensity of a given intervention play an important role on the impact of telomere length (Carlson et al., 2015; Lengacher et al., 2014; Pines, 2013).

Carlson et al. (2015) and Conklin et al. (2015) found that telomere length declined in their control groups but stayed the same in the intervention groups, suggesting the potential protective effect of mindfulness practices, such as meditation and the intentional implementation of lifestyle habits, on telomere length. Therefore, attempting to expand on this research, our current study examined the change in telomere length in the control and treatment group while they used the Neurocycle in a mindful, planned, and guided way over time, specifically daily over 9 weeks, to intentionally form new habits that would lead to healthier lifestyles and mental well-being.

Prolactin, a neuropeptide that promotes physiological responses related to reproduction, stress adaptation, neurogenesis, and neuroprotection, has been shown to play a role in the attenuation of the hypothalamic-pituitary-aderenal (HPA) axis, helping the brain and body to adapt to chronic stress (Lennartsson & Jonsdottir, 2011; Levine & Muneyyirci-Delale, 2018; Torner, 2016). Unmanaged stress leads to an imbalance in prolactin, which in turn can result in reduced neurogenesis and reduced stress modulation, impacting mental health (Elgellaie et al., 2021; Kumar, 2019; Torner, 2016). However, there is a scarcity of research showing that intervention changes prolactin levels, though there are a few studies in the meditation literature where mindful lifestyle changes like meditation have been shown to improve prolactin levels (Nagendra, 2022). Additionally, some research demonstrates that passive coping increases prolactin whereas active coping leads to lowering or unchanged prolactin levels (Theorell, 1992). Our current research examined the change in prolactin in the control and treatment group as they used the Neurocycle in a mindful, planned, and guided way over 9 weeks to intentionally form new habits that would lead to healthier lifestyles and mental well-being.

The Need for a Psychoneurobiological Approach in Automaticity and Habit Formation

With the current global mental health crisis (World Health Organization [WHO], 2022), clinicians, researchers, public health experts, and individuals alike have increasingly realized that effective, affordable, empowering, and sustainable mental health interventions are critically needed. Specifically, Gardner and Lally (2018), Lewis et al. (2021), and Harvey et al. (2020) have underscored the need for researchers to contribute to the investigation and improved effectiveness of mental health interventions by incorporating the science of habit formation and automaticity into their design. Research on how to use planned, guided, and mindful approaches to deconstruct a disruptive habit and mindfully reconstruct and reconceptualize a new useful habit as a lifestyle would clearly benefit an individual's mental health (Mantzios & Giannou, 2019).

This current pilot study seeks to contribute to the field's developing knowledge of habit formation and automaticity as something that can be deliberately and mindfully learned, through a planned and guided approach over a specified time frame, to facilitate lasting and impactful management of mental health challenges. Thus, this research contributes to the understanding of how to improve mental health intervention and achieve sustainable outcomes. Additionally, by using a psychoneurobiological approach within a longitudinal study, we are gaining insight into the amount of practice that is likely to be needed to form a habit that leads to improved and sustainable mental health changes. It is also important to acknowledge the complexity of these changes in the neurological and biological aspects of the human in response to the challenges of life (Vage et al., 2023), underscoring this need for a psychoneurobiological approach.

To achieve this, the study herein evaluated an evidence-based treatment protocol, the Neurocycle hosted on the Neurocycle app. With the ever-growing rise of technology influencing our everyday lives, it is not only convenient but essential to create accessible, technological interventions for mental health that promote well-being and sustainable changes (Figueroa & Aguilera, 2020; Hollis et al., 2015; Lattie et al., 2022; Philippe et al., 2022; Schueller et al., 2013). Furthermore, Singh and colleagues (2022) encourage the use of digital technology as an additional factor for improving mental health interventions in terms of ease of accessibility and use, thereby empowering an individual to manage their mental health. Answering this call, we implemented the Neurocycle app as a planned and guided process that models how to optimize the science of habit formation and automaticity in mental health interventions. The Neurocycle has been evaluated as an evidence-based intervention for mental health in clinical trials, using a psychoneurobiological approach, assessing participants' psychosocial reports of mental health wellness, energy patterns in the brain, and hematological measures (Leaf, Turner, Wasserman, et al., 2023).

The following hypotheses are being tested:

- H1: There will be positive change in the subjects' psychological well-being after their completion of the Neurocycle program, as measured by psychometric assessments of the Leaf Mind Management (LMM) Autonomy and Toxic Thoughts subscales and the Patient Health Questionnaire (PHQ-9) scale.
- H2: There will be a change in subjects' neurophysiological functioning as measured by gamma activity during and following the Neurocycle system.
- H3: There will be positive change in the subjects' biophysical anxiety symptoms after the completion of the Neurocycle program, as measured by blood serum for prolactin levels and telomeres length analysis.

Altogether, this psychoneurobiological approach will provide the more detailed neurophysiological data called for by Newson and Thiagarajan (2019) via mapping of the psychological, neurological, and biological identifiers of complex mental health behaviors as they become automatized into mindful habits and how this process relates to changes in the psychological aspects, gamma neural activity, and biological changes in telomeres and prolactin.

Materials and Methods

Based on the detailed methods previously described, we present a summary of the materials and methods herein (Leaf, Turner, Wasserman, et al., 2023).

Study Design

A double-blind randomized clinical trial (RCT) pilot study was selected, and the study design, instruments, and protocol were approved by the Sterling Institutional Review Board (approval ID no. 7281-RPTurner). A total of 14 participants were recruited based on the power analysis of convenience sampling; a priori power analysis was conducted, and the necessary sample size was verified as 12. An additional two participants were included for potential attrition during the study period. To ensure that participants met the recruitment criteria of preexisting anxiety and/or depression, the research team recruited a total initial pool of 30 recruits in a prescreening phase. To select the 14 participants from the initial 30 recruits, inclusion and exclusion criteria were applied. After the final 14 participants were selected, they were provided with an informed consent and randomly assigned to the treatment group (n = 7), the Neurocycle, or the control group (n = 7), which received no special attention beyond the standard of care of their physician. During the study, attrition occurred following baseline measurements in both groups (control: attrition of n = 1, for a final total of n = 6; treatment: attrition of n = 2, for a final total of n = 5). Attrition bias was avoided by removing their entire profiles from the final samples for analysis.

Materials

The intervention utilized the Neurocycle program hosted on the Neurocycle app. The Neurocycle (Leaf, 1997, 2021) is a 63-day mind-directed self-help mental health program, in which participants are directed by daily audio and video recordings through the five-step Neurocycle process of Gather Awareness, Reflect, Write, Recheck, and Active Reach; these steps provide a scientifically validated framework for participants to reconceptualize and take control of their mental health through mind-management, fostering development in the required skills to actualize the benefits of mindfulness: self-regulation, resilience, reconceptualization, and exposure (Shapiro et al., 2006).

Measurements, Instruments, and Data Collection

The psychological effects of the Neurocycle were measured by the LMM scale and validated with the Hospital Anxiety and Depression Scale, Anxiety and Depression subscales (HADS-A and HADS-D; Bjelland et al., 2022), as well as the BBC Subjective Well-Being Scale (BSC; Pontin et al., 2013). The neurophysiological effects of the Neurocycle were assessed using surface qEEG functional analysis. The psychological and neurophysiological effects were then verified in bloodwork analysis that measured the participants' prolactin levels, which are known to increase alongside stress, anxiety, and depression (Lennartsson & Jonsdottir, 2011; Levine & Muneyyirci-Delale, 2018; Torner, 2016). This tripartite approach addresses the lack of multimethod approaches in the field of electroencephalography (Newson & Thiagarajan, 2019) and is intended to help provide additional insight into resting-state gamma activity and how it is interpreted in the context of therapeutic intervention. The assessments were administered across six distinct time periods: preintervention (day 1), on days 7, 14, 21, and 42, and during postintervention on day 63. The schedule of assessment administration is provided in Table 1 below, and descriptions of each assessment phase are fully described in a previous article (Leaf, Turner, Wasserman, et al., 2023).

Table 1
Implementation Schedule for Measures of Interest to This Paper

Measure	Prescreen	Day 1	Day 7	Day 14	Day 21	Day 42	Day 63	3-Month Follow-Up
Clinical Anxiety (HAM-A)	X							
Clinical Depression (HAM-D)	X							
Psychological Effects (BBC-SWB)		X	X	X	X	X	X	X
Self-Report Anxiety & Depression (HADS-A & HADS-D)		X	X	X	X	X	X	X
Patient Health Questionnaire (PHQ-9)		X	X	X	X	X	X	X
Awareness, Autonomy, and Toxic Thoughts Subscales (LMM)		X	X	X	X	X	X	X
Neurophysiological Effects (qEEG)		X			X		X	
Bloodwork (Prolactin and Telomeres)		X			X		X	

Neurophysiological Assessment

Participants underwent three qEEG sessions for neuroimaging analysis on days 1, 21, and 63. Participants' qEEG was recorded for 10 min with their eyes open and another 10 min with their eyes closed. Only low gamma band (30–120 Hz) data are reported on in this paper.

Psychological Assessment

Self-assessment of psychometric indicators was taken by participants during all six key stages of the intervention's administration: days 1, 7, 14, 21, 42, and 63. The primary assessment tool implemented was the LMM scale. Improvements in stress and anxiety can be measured by increases in the Autonomy, Awareness, and Empowerment subscales alongside decreases in the Toxic Thoughts, Toxic Stress, and Barriers subscales. In this paper, data on the Awareness, Autonomy, and Toxic Thoughts subscales are reported. To triangulate and validate the LMM assessment in this study, traditional measures of anxiety, stress, and depression were also administered, including the PHQ-9, a depression module, which scores each of the nine DSM-IV criteria as “0” (*not at all*) to “3” (*nearly every day*).

Biological Assessment

Participants were sampled for blood-measured prolactin levels and telomere length. Elevated prolactin levels and decreased telomere length are known to be associated with an individual’s elevated stress and anxiety levels and the direct neurotoxic effects (Aghayan et al., 2020; Chung et al., 2017; Epel, 2009; Epel et al., 2004; Mayer et al., 2023). During the preintervention on day 1, after the initial phase of the intervention on day 21, and postintervention on day 63, given that this sulphurated amino acid is responsible for mediating methylation, which is critical for nervous system balance and health (Kennedy, 2016), blood amino acid analysis for prolactin levels was then performed by a contracted lab and reported to the researchers as follows: normal range: 5–15 mcmol/L; moderately elevated range: 15–30 mcmol/L; intermediately elevated range: 30–100 mcmol/L; and severely elevated range: < 100 mcmol/L (Haldeman-Englert et al., 2022).

The qEEG study descriptions are presented in a previous article (Leaf, Turner, Wasserman, et al., 2023). Relative power was calculated for each frequency band relative to the total power in the 0.5–120 Hz range. Further, relative power was used for analysis to allow direct comparison from one subject to another, controlling for interpersonal differences in overall EEG amplitude. In this study, all-electrode-averaged eyes-open (EO) and eyes-closed (EC) global average gamma relative power (30–120 Hz), low gamma relative power (30–49.9 Hz), high gamma relative power (50–120 Hz), and EO frontal low gamma relative power (30–49.9 Hz; averaged over the three frontal electrode sites; F3, Fz, and F4) were analyzed.

Analysis

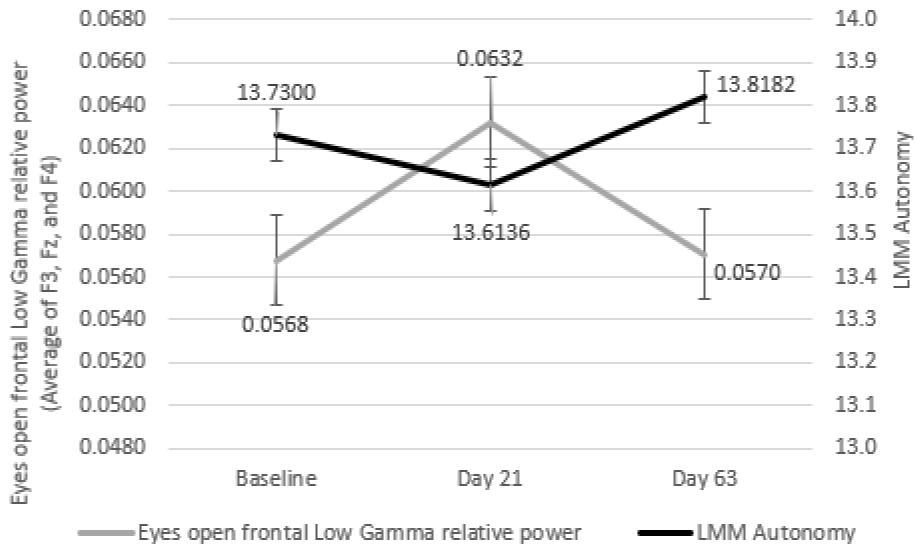
The data gathered from the qEEG, bloodwork, and psychometric assessments were analyzed altogether using IBM SPSS v27. The study analysis is presented in a previous article (Leaf, Turner, Wasserman, et al., 2023). In this study, we analyzed global average gamma (low = 30–49.9 Hz; high = 50–120 Hz) relative power and frontal low gamma (30–49.9 Hz; averaged over the three frontal electrode sites; F3, Fz, and F4) relative power in both the EO and EC conditions. To examine the specific hypotheses outlined in this paper, linear multiple regression models and simple regressions were conducted to examine the relationships among the specific variables as nonparametric correlations (ρ) to assess potential relationships. The alpha (α) level for this pilot study was set at 0.10.

Results

Overall Gamma Change and Psychological Relationship

EO frontal low gamma relative power (average of F3, Fz, and F4) increased from day 1 to day 21 (t = 1.35, p = .104) followed by a significant decrease from day 21 to 63, t = 1.75, p = .055 (Figure 1). The overall change in EO frontal low gamma relative power over the course of the entire study, from day 1 to 63, correlated significantly with change in the LMM Autonomy subscale, ρ = 0.575, p = .065.

Figure 1. *EO Frontal Low Gamma Relative Power and LMM Autonomy*.



Note. EO frontal low gamma relative power from baseline to day 21 all subject average, $t = 1.35$, $p = .104$, and day 21 to 63, $t = 1.75$, $p = .055$ and LMM Autonomy from days 1 to 63, $\rho = 0.575$, $p = .065$. Error bars are standard error.

A linear regression model showed that the stress (PHQ-9 scale) at baseline was a significant predictor and accounted for 34.5% of the variance of EO frontal low gamma relative power changes from day 1 to day 63, $F = 4.73$, $R^2 = .345$, beta coefficient (standardized) = .587, $p = .058$.

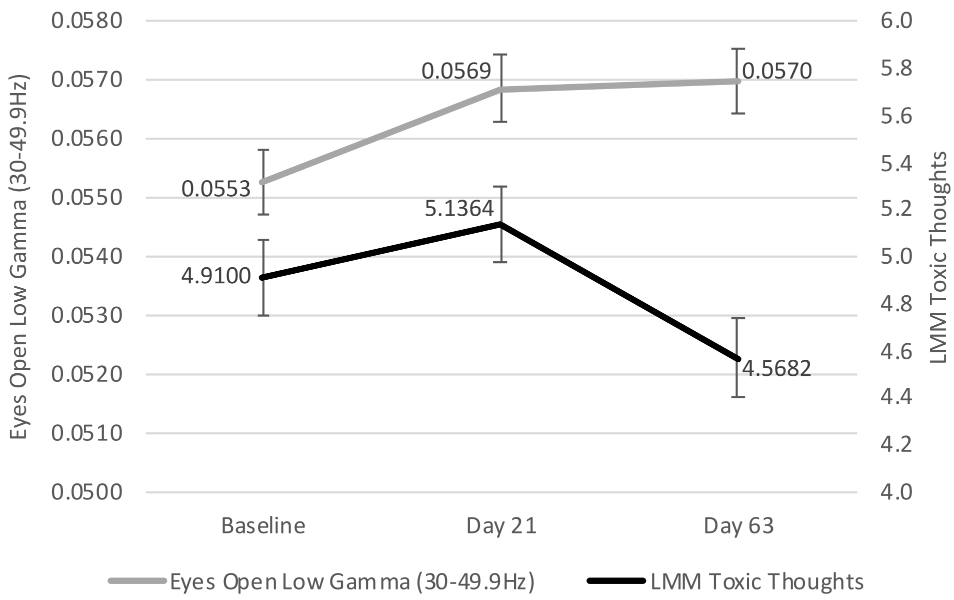
Stress levels, as measured by the PHQ-9 at baseline, were significantly correlated with the LMM Autonomy subscale ($\rho = -0.635$, $p = .036$) and the LMM Toxic Thoughts subscale ($\rho = 0.703$, $p = .016$). Scores on the LMM Autonomy subscales need to increase to show improvement; scores on the LMM Toxic Thoughts subscale needs to decrease to show improvement.

Similar to LMM scale validation results from another study (Leaf, Turner, Paulson, et al., in press), the LMM Autonomy subscale is significantly correlated to LMM Awareness ($\rho = 0.538$, $p = .088$) and LMM Toxic Thoughts ($\rho = -0.507$, $p = .097$). Scores on the LMM Autonomy and Awareness subscales need to increase to show improvement; scores on the LMM Toxic Thoughts subscale needs to decrease to show improvement.

Over the course of the study from day 1 to 63, EO global average low gamma (30–50 Hz) increased and scores on the LMM Toxic Thoughts subscale decreased, $\rho = -0.669$, $p = .024$ (Figure 2).

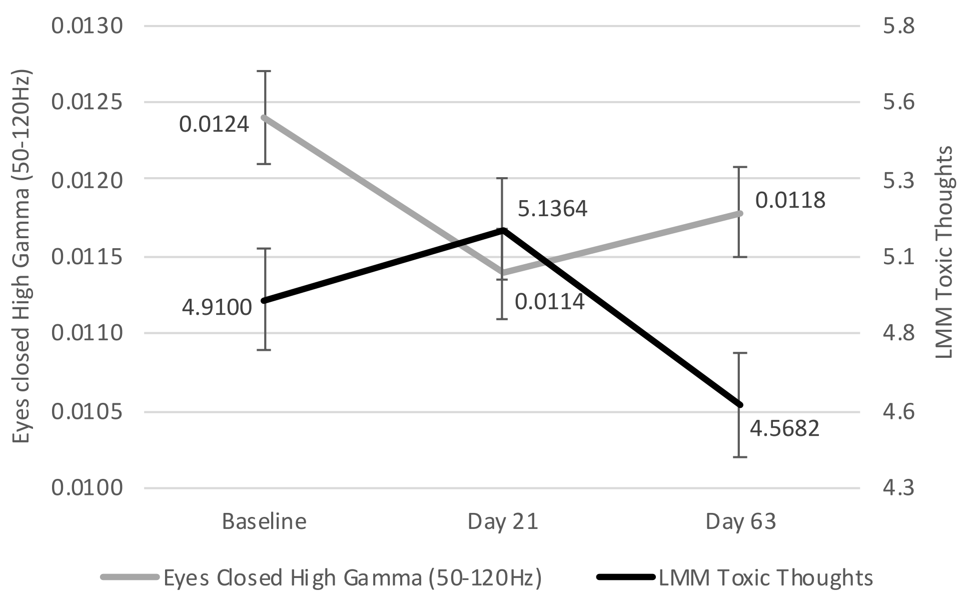
Over the course of the study, there was an inverse relationship between EC global average high gamma and the LMM Toxic Thoughts scores which was significant from baseline to day 63, $\rho = -0.758$, $p = .007$. We observed an inverse relationship between an increase of the Toxic Thought subscale from day 1 to day 21 and decreasing EC global average high gamma (50–120 Hz), both measures reverse trajectory at the 21-day inflection point (Figure 3).

Figure 2. *EO Global Average Low Gamma Relative Power and LMM Toxic Thoughts*.



Note. EO global average low gamma (30–49.9 Hz) and LMM Toxic Thoughts subscale scores. Total change from day 1 to 63 in EO global average low gamma were significantly correlated with LMM Toxic Thoughts subscale scores from day 1 to 63, $\rho = -0.669$, $p = .024$. Error bars are standard error.

Figure 3. *EO Global Average High Gamma Relative Power and LMM Toxic Thoughts*.



Note. EC global average high gamma (50–120 Hz) and LMM Toxic Thoughts subscale scores change from baseline to day 63, $\rho = -0.758$, $p = .007$. Error bars are standard error.

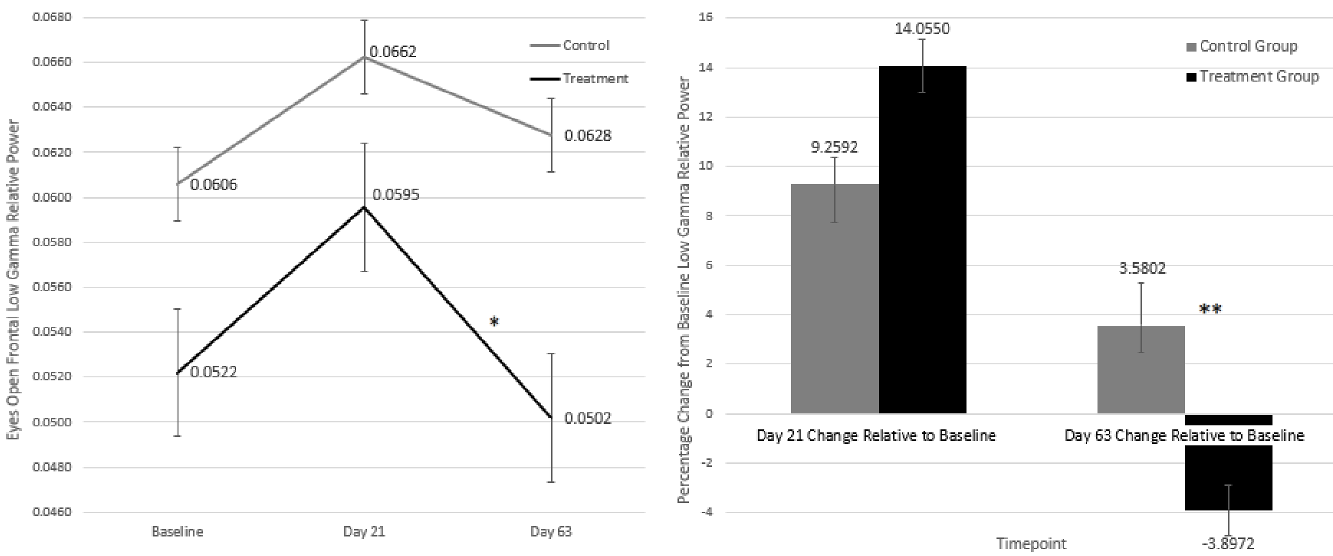
Overall Gamma Change and Biological Relationships

A linear regression model showed that the prolactin change from day 1 to 63 was a significant predictor and accounted for 65.2% of the variance of EO frontal low gamma relative power changes from day 1 to day 63, $F = 16.86$, $R^2 = .652$, beta coefficient (standardized) = .807, $p = .003$.

Group Differences and Psychological Relationships

Results revealed that while both the control and treatment group increased in EO frontal low gamma relative power change from baseline to day 21 and then decreased from day 21 to 63 EO frontal low gamma relative power change, the treatment group had significant change from day 21 to day 63, $t = 1.85$, $p = .069$ (Figure 4, left). Examination of the group differences on the percentage change relative to baseline revealed that the treatment group had decreased EO frontal low gamma relative power change relative to baseline while the control group had increased EO frontal low gamma relative power change relative to baseline (Figure 4, right), $t = 1.38$, $p = .097$.

Figure 4. *EO Frontal Low Gamma Relative Power and Percentage Change*.



Note. EO frontal low gamma relative power change from baseline to day 21 and day 63 for the treatment and control groups. EO frontal low gamma relative power percentage change from baseline to day 21 and baseline to day 63 for the treatment and control groups. Significant difference, (left) treatment group, day 21 to day 63, $t = 1.85$, $p = .069$; (right) control vs. treatment group day 63 to baseline, $t = 1.38$, $p = .097$. Error bars are standard error.

Results also revealed that the control group and treatment group had similar awareness scores at day 1, $t = .242$, $p = .407$; however, by day 63, the treatment group had significantly greater awareness scores than the control group, $t = 1.74$, $p = .058$ (Figure 5). Analysis showed that the awareness score of the treatment group significantly increased from day 1 to day 63, $t = 2.24$, $p = .045$, while the control group awareness score did not significantly change over the course of the study, $t = .045$, $p = .084$.

Looking towards the end of the 63-day program, for subjects in the treatment group who completed the 3-month follow-up LMM measures ($n = 5$), there was a significant correlation between EO frontal gamma relative power on day 63 of the study and their LMM Autonomy and LMM Awareness subscale scores at that same timepoint, $\rho = 0.894$, $p = .041$, which persisted through to the 3-month follow-up, $\rho = 0.894$, $p = .041$.

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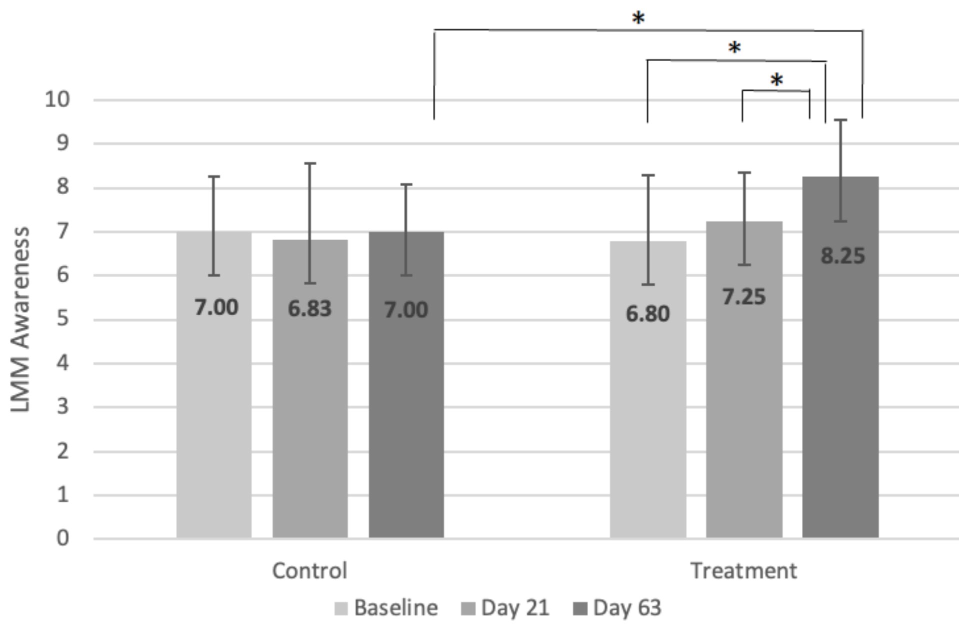
Figure 5. *Leaf Mind Manaement Awareness*.



Note. Leaf Mind Management Awareness subscale from baseline to day 63 for the treatment and control groups. *Significant difference, control vs. treatment group, t = 1.74, p = .058; treatment group: day 1 to day 63, t = 2.24, p = .045; treatment group: day 21 to day 63, t = 2.29, p = .042. Error bars are one standard deviation.

We also observed a significant correlation between the overall decrease in EO global low gamma between days 21 and 63 and scores on the LMM Empowerment and Life Satisfaction subscale on day 63, ρ = −0.975, p = .005. This correlation also persisted through to the 3-month follow-up LMM scores, ρ = −0.975, p = .005. A similar pattern of inverse correlation was observed in the change in EC global average gamma from day 21 to 63 and LMM Autonomy and Awareness subscales on both day 63 and 3-month follow-up, ρ = −0.894, p = 0.041.

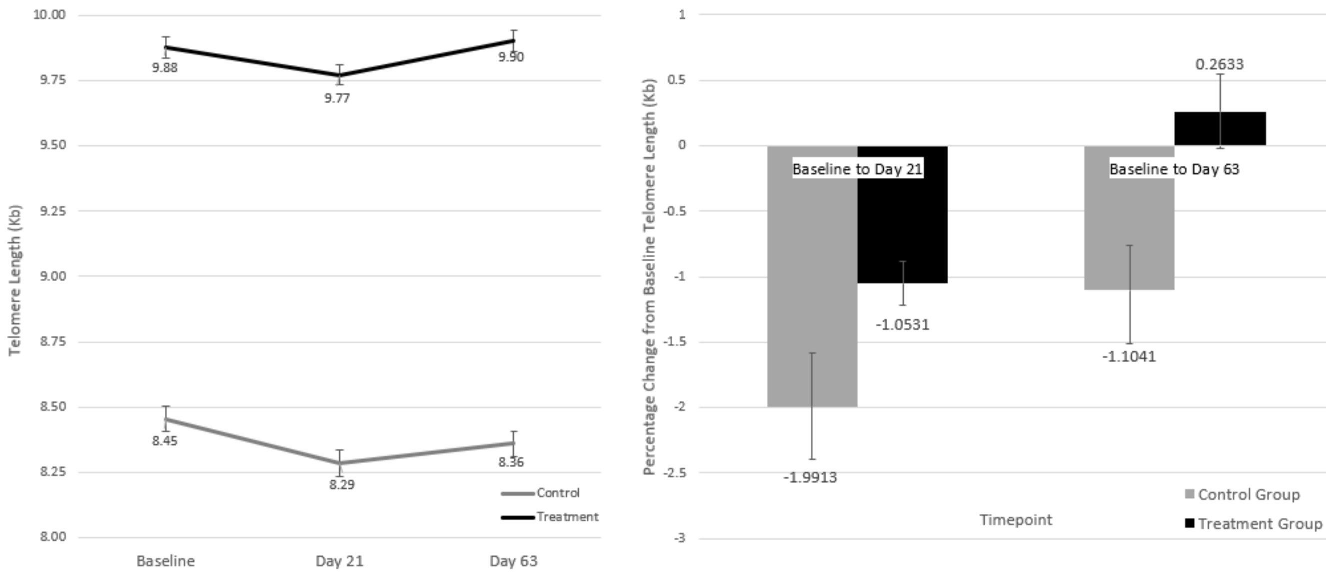
Group Differences and Biological Relationships

Telomere length decreased from day 1 to day 21 for both the treatment (−1.05%) and control (−1.99%) groups, although the decrease was less for the treatment group than the control group (Figure 6). Telomere length increased from day 21 to day 63 for both groups; however, the control group did not reach their baseline telomere length (−1.10%), while the treatment group exceeded their baseline telomere length (+0.26%), t = 1.62, p = .069.

Due to low sample sizes in the pilot study, multivariate correlational analyses by group were not possible; however, there are corresponding relationships of percent change of telomere length and improved LMM Toxic Thoughts scores from baseline to day 63 of telomere length and overall gamma relative power (30–120 Hz) during the EO condition, ρ = 0.670, p = .024, as well as percent change from baseline to day 63 of telomere length and improved LMM Toxic Thoughts scores, ρ = .560, p = .073 (see Figure 7).

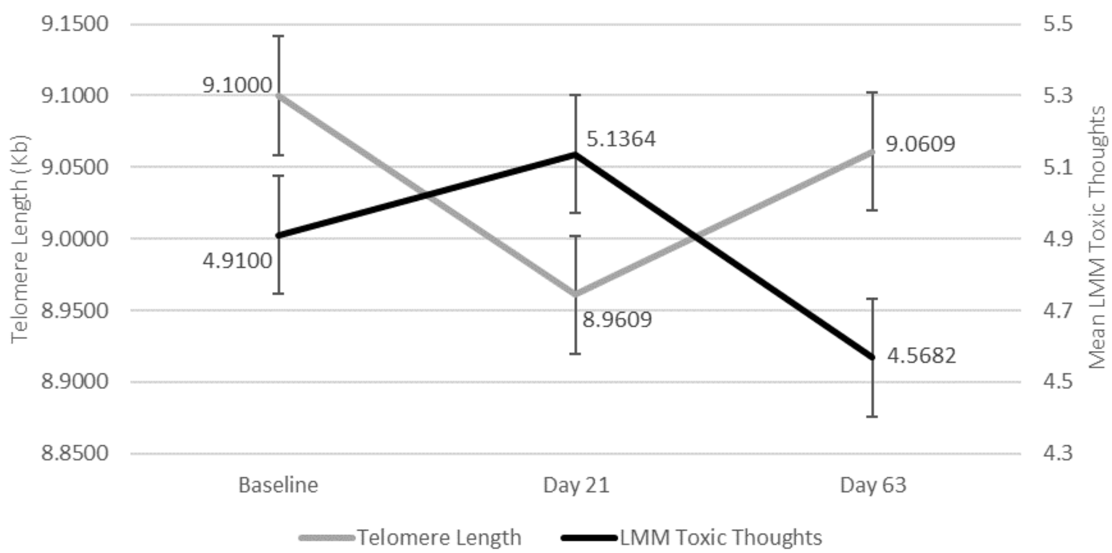
Percent change from baseline to day 21 telomere length was significantly correlated with percent change from baseline to day 21 for prolactin, ρ = 0.584, p = .059, indicating that greater change in telomere length was related to greater change in prolactin. In addition, percent change from baseline to day 63 in overall gamma (30–120 Hz) during the EO condition were significantly correlated with improved LMM Toxic Thoughts scores, ρ = .724, p = .012.

Figure 6. *Telomere Length and Percentage Change*.



Note. Telomere length; percentage change from baseline to day 21 and baseline to day 63 for the treatment (t = 1.62, p = .069) and control groups. Error bars are standard error.

Figure 7. *Telomere Length and LMM Toxic Thoughts*.



Note. Telomere Length (Kb) and LMM Toxic Thoughts subscale scores change from day 1 to 63, ρ = 0.560, p = .07. Error bars are standard error.

Discussion

Understanding the process of habit formation and automaticity is needed to contribute to creating interventions for mental health treatments that seek to create more sustainable change (Harvey et al., 2020). Even though a major focus of habit research has been on simple repetition of cue-response-reward sequences, the literature calls for a more mindful view, as well as the application of habit formation and automaticity into the design and implementation of evidence-based mental health intervention (Mergelsberg et al., 2021; Gardner et al., 2012). We have attempted to address this need through the current research by examining the effectiveness of a 9-week planned and guided intervention informed by the science of habit formation and automaticity using a psychoneurobiological approach. In the current study we used an app called the Neurocycle, a technology-based mental health intervention, as a tool for promoting habit formation and automaticity while working through mental health struggles (Leaf, Turner, Wasserman, et al., 2023). In a growing technological age, and after a global pandemic where there was so much isolation between people and fewer face-to-face interactions, technological interventions for mental health issues have vast potential to provide accessible and affordable mental health care. The present study further serves to study the effectiveness of said technology, as called for in current research (Aguilera, 2015; Jameel et al., 2022; Lattie et al., 2022; Naslund et al., 2017; Stawarz et al., 2015; Taylor et al., 2020).

We observed a pattern of change in the data over the course of the 9 weeks (63 days) time frame of the Neurocycle that integrates with the common consensus of how long it takes to build effective and useful habits that could have a positive impact on the mental health of an individual, whichh is around 8–12 weeks (Armitage, 2005; Gardner et al., 2012; Lally et al., 2010; van der Weiden, 2020). In this study, on a psychological level, we observed significantly improved increases in awareness and autonomy and decreased toxic thoughts. On a neurological level, we observed that this was reflected by frontal gamma following a pattern of increasing while active change and learning were taking place between days 1–21, and then decreasing between days 21–63. This potentially shows that habit formation is taking place and being wired into the brain, creating neural networks and demonstrating the learning process that leads to automaticity and habit formation. We also found correlated positive changes in the biological components (prolactin and telomeres). This psychoneurobiological approach helps to provide the more detailed neurophysiological data called for by Newson and Thiagarajan (2019) through a blending of the psychological, neurological, and biological identifiers of automaticity and habit formation.

Psychological Changes

Overall gamma changes and multiphasic pattern of habit formation and automaticity were found to be correlated with the psychological measures on the LMM scale. A change in EO frontal low gamma over the course of the entire study was related to a greater change in the Autonomy subscale of the LMM, with an inflection point occurring at day 21, followed by a change of direction from day 21 to day 63. These results indicate that a greater change in frontal low gamma relative power was related to a greater change in autonomy. This time course (day 21 to day 63) corresponds with the decrease in low gamma that Madhavan et al. (2015) recorded in frontal regions, suggesting that the mindful conscious part of the initiation and goal setting of the habit formation process may be frontally based.

Additionally, as EO global average low gamma increased over the course of the study from day 1 to day 63, scores on the LMM Toxic Thoughts subscale decreased, once again with an inflection point occurring at day 21, with the same change of direction from day 21 to day 63, which was also the pattern seen with the frontal low gamma. It is not surprising to see an increase in toxic thoughts while participants were prompted to become aware of the problem they had chosen to address because this involves active and deliberate learning and change as an individual becomes more aware and mindful of their issue, which is associated with the increase in low gamma globally (Leaf, Paulson, et al., 2023). Then at the inflection point of 21 days, toxic thoughts decrease along with the decrease in the slope of increase of low gamma.

These results may suggest that global low gamma relative power may be related to the initial awareness of facing and dealing with the toxic issue followed by stabilization after the inflection point. This may represent a measure of mindful cognitive effort working towards their goal. Both the treatment and control groups could be experiencing and benefiting from the “therapeutic alliance” (Alldredge et al., 2021), since they are both receiving the standard of care from the physician. Additionally, they were aware of being in a study to help manage mental health and were therefore motivated to initially face and deal with their issues (Benedetti, 2013; Munnangi et al., 2022), which could account for the increase in frontal low gamma.

Throughout the duration of the study, EC global average high gamma and the LMM Toxic Thoughts scores were inversely related (Figure 3). These results indicate that as one increases the other decreases and vice versa. These changes also occurred in a phasic pattern on a shorter timescale with a decrease in EC global average high gamma from day 1 to day 21 as the toxic thoughts increased, with an inflection point at day 21, and then from day 21 to day 63, where the global high gamma increased and the toxic thoughts decreased. This interpretation is supported by a similar trajectory of activation in EO relative beta power (Leaf, Turner, Wasserman, et al., 2023). These results suggest that as EC high gamma increased, over the second phase of the Neurocycle, toxic thoughts decreased. There is a delicate balance of resources in the brain, and the results demonstrated gamma modulating alongside correlation with changes in psychology among several different measures.

An overall gamma change was also found to be correlated with the psychological measures on the PHQ-9. The PHQ-9 stress scale at day 1 was a significant predictor of low gamma relative power changes from day 1 to day 63, if the study was a significant predictor of the patterns of change in frontal low gamma relative power. This is a foreseeable result of beginning to work on changing a toxic thought, which has implications for the initiation and consistency of working through the issue, pushing past the struggle. This could indicate an overall level of severity dictating how much of a change is yet to be made. Participants' stress levels at baseline, as measured by the PHQ-9, were also significantly correlated with LMM Autonomy and Toxic Thoughts subscales at baseline. These results indicate that at baseline, higher levels of stress, as measured by the PHQ-9, were related to lower scores on autonomy and higher scores on toxic thoughts on day 1. This potentially indicated that the worse a participant's starting point is, the more frontal engagement they still experience at day 63, which could be an indicator of the level of complexity of the issue that they are working on and suggests the potential benefit of another Neurocycle. Multiple sequential Neurocycles may prove beneficial for individuals dealing with complex mental health issues.

Group Differences in Psychological Measures

The LMM scale is uniquely situated to measure and help sustain the development of mindfulness awareness into a cognitive practice that involves self-regulation to form new habits and automatize them. This involves the initiation of the intervention to the learning and eventual stabilization of the new habits that have a consistent impact on well-being (Leaf, Turner, Paulson, et al., in press). The results of this automaticity are supported by the psychological component as part of the psychoneurobiological approach used in the study (Leaf, Turner, Wasserman, et al., 2023).

The current study revealed that the control group and treatment group had similar scores on the Awareness subscale of the LMM, from day 1 to 21; however, by day 63, the treatment group had significantly greater awareness scores than the control group (Figure 5). Analyses showed that the Awareness score of the treatment group significantly increased from day 1 to day 63, while the control group's awareness score did not significantly change over the course of the study. This reveals another important facet of automaticity and habit formation: that increased awareness leads to planned and guided practice, without which automaticity of a new effectual habits may not occur. Instead, the established destructive habit will persist, as was seen in the control group and prior literature (Fleig et al., 2013, Gardner, 2014).

Awareness is an essential component of self-regulation, and self-regulation is a significant skill for mental health given its profound impact on people's everyday struggles (Diamond, 2013; McCelland et al., 2015). Self-regulation is one of the mediating factors for well-being outcomes (Leaf, Turner, Paulson, et al., in press). Self-regulation is a critical factor in habit formation and automaticity that will change behavior irrespective of the context (Frazier et al., 2021). On a psychological level, this may represent the cognitive effort of identifying, disrupting, deconstructing, reconstructing, and reconceptualizing toxic thoughts involved in the process of doing the Neurocycle daily over the 63 days to improve mental health. The persisting LMM scores in the treatment group at 3-month follow-up indicate that the subjects maintained their psychological changes past the end of the program. Further investigations will include tracking of physiology past the end of the Neurocycle to investigate the long-term trajectories of how these measures interact with the psychology of Neurocyclists.

Neurophysiological Change

EO frontal low gamma increased from day 1 to day 21, peaked at day 21, followed by a significant decrease from day 21 to 63. EO global average low gamma (30–50 Hz) increased over the course of the study from day 1 to 63, but slowed down at day 21 after which the slope of the increase decreased. EC global high gamma (50–120 Hz) decreased from day 1 to day 21, then increased from day 21 to day 63. We observed a nonlinear trajectory of change in the qEEG gamma metrics. This supports the concept that the process of changing complex mental behaviors is not linear and requires a greater degree of investigation in the temporal domain in order to more fully describe the patterns and associations between the measured variables. The nonlinear nature of these changes supports the concept of gamma as a “goldilocks frequency” that has differing stable states of ideal activity depending on individual contextual factors and is interpreted differently depending on the source of gamma in the cortex.

Group Differences in Neurophysiological Measures

Results suggest that EO frontal low gamma increased from baseline to day 21 and decreased from day 21 to day 63 in both the treatment and control groups. However, the treatment group had a significant change from day 21 to day 63 (Figure 4), demonstrating the automaticity pattern with the peak at day 21 and the change of direction thereafter. Examination of percentage change from day 63 relative to baseline revealed that EO frontal low gamma relative power decreased in the treatment group and increased in the control group (Figure 4).

The decreased activity in frontal low gamma in the treatment group may represent that less deliberate intentional work is needed to manage the intrusive thought than was required in the initial 21 days, the first phase, where active deconstruction of the root cause and reconceptualization and reconstruction of the new thought was being carried out. The second phase, days 21 to 63, was a practice phase to stabilize and automatize the thought into a habit that will manifest as behavior change impacting mental health in a positive way. It is also possible that a modification in effective habit formation was happening at around the 21-day point and that this level of intense type focus was no longer needed as the person moved into a practice stage of stabilization of the new pattern. A simple comparison elucidating this is learning to ride a bicycle, drive a car, or play a musical instrument. Initially there is intensive deliberate intentional work to learn the “how to,” after which one is able to ride the bike, drive the car, or play the musical instrument automatically. In this study, improved self-regulation of an experience that was challenging the person’s mental health is the new habit that is forming. The automaticity component shows up in the decreased deliberate intentional conscious work needed and the shift to a stabilization of the new thought pattern.

In the control group, we observed a different pattern. They became aware of their problem thought through the interaction and interviews during the study but didn’t have a treatment plan to deal with this, which could be the reason why their frontal low gamma increased from baseline to day 63. The data support the concept that awareness alone is not sufficient for mental health change.

Biological Change

There is an overall correlation between the decrease in global gamma relative power (30–120 Hz) in the EO condition from day 1 to 63 and the change in telomere length over that same time period. It is critical, however, to analyze this finding in the context of whether or not the subjects were in the treatment or control conditions. Both groups saw decreases in telomere length from day 1 to 21 of the study (Figure 7); however, while the control group made a small rebound in telomere length from day 21 to 63 of the study, those in the treatment group had increased telomere length from day 21 to 63 and increased in average telomere length from the beginning to the end of the Neurocycle that approached statistical significance.

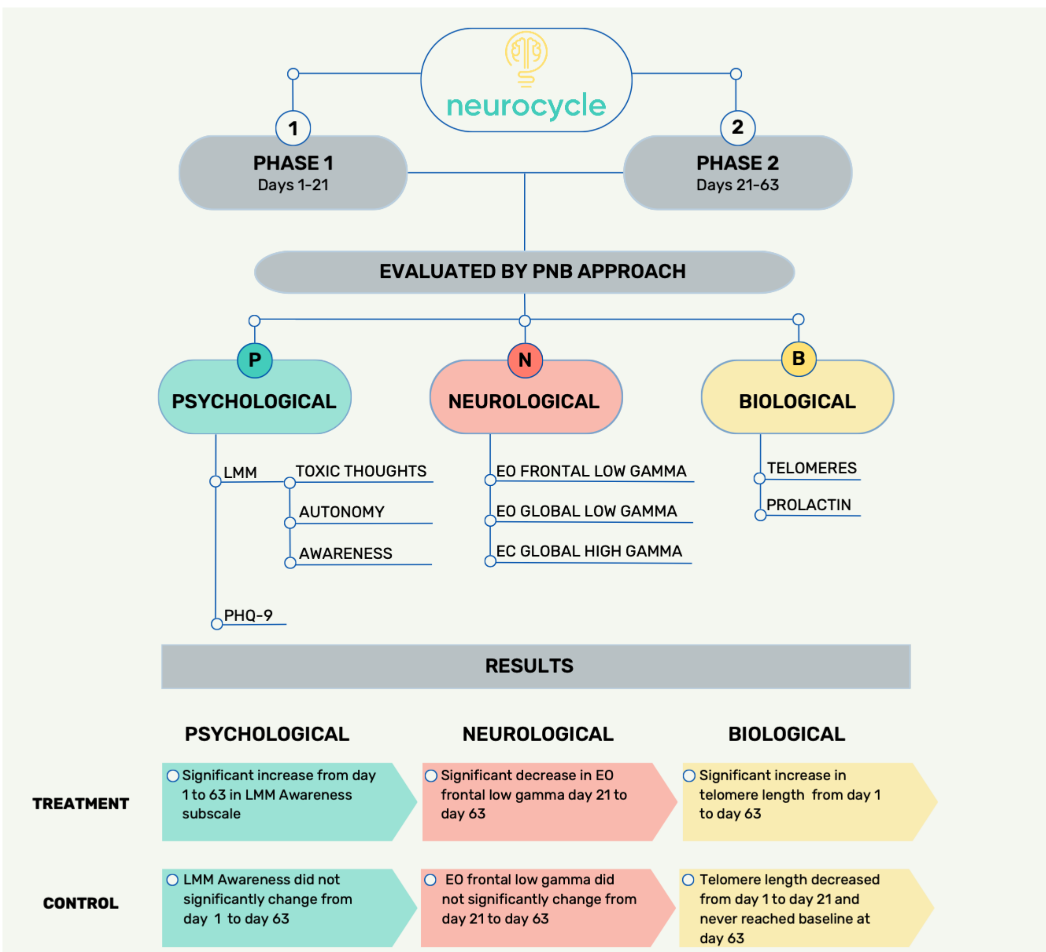
The hard work being done over the first 21 days is mentally challenging and can increase stress in the process of gaining insight into the cause of the mental health issues being worked on. This is supported by the telomeres shortening in both groups, which can be likened to having surgery where you must be cut first to then be healed. The improved telomere length in the treatment group aligns with the improved mental health management reported in the second phase from days 21–63 of the intervention where automaticity of the new reconceptualized behavior is in the process of developing.

Likewise, the change in prolactin from day 1 to day 63 was a significant predictor of frontal low gamma relative power changes over the same time span. Prolactin is a versatile hormone that has been associated with adaptation to stress and neurogenesis, and it has been shown to help alter neural circuits to help the individual cope with stress (Torner, 2016). It would be improper, however, to interpret the associated increase in gamma as also being therefore beneficial by association. Instead, we propose that gamma is likely representative of an overall arousal level, or index of local cortical activity, and needs to be interpreted based on context. As discussed in the introduction, gamma activity, like most other brain activity, can be maladaptive in either a hyper- or hypoactive manner (Barry et al., 2010; Lawson, 2013; Roh et al., 2016). The ideal level of activity is a constantly moving target range dependent on a myriad of individual factors and contexts.

Group Differences in Biological Measures

Group differences revealed a smaller decrease in telomere length from day 1 to day 21 in the treatment group. The treatment group was working within a deliberate and guided treatment protocol to reconstruct the new patterns of behaviors and emotions and perspectives, versus the control group which had no specific guidance; therefore, the stressors experienced by both groups were experienced differently, either as the eustress of planning to address challenges or merely bringing up stressors without providing a plan to address them. From day 21 to day 63, both groups exhibited an increase in telomere length; however, the control group never recovered to their baseline length, while the treatment group surpassed their baseline telomere length. We recorded in this biological measure, the pattern of the peak at day 21, followed by changes from day 21 to day 63. Furthermore, within the treatment group, our results showed a correlation between the percent change from baseline to day 63 in overall gamma relative power (30–120 Hz) and telomere length during the EO condition. Similarly, the percentage change from baseline to day 63 in telomere length and improved LMM Toxic Thought scores were also related (Figure 8).

Figure 8. *The Psycho-Neuro-Biological (PNB) Impact of the Neurocycle*.



Note. Gamma, prolactin, telomeres, and psychosocial measurements.

These results suggest a positive correlation between a greater change in telomere length, greater overall gamma change, and improved LMM Toxic Thoughts scores in the same automaticity pattern. From baseline to day 21, percent change in telomere length was also significantly correlated with the percent change in prolactin, indicating that greater change in telomere length was related to greater change in prolactin, with both following the automaticity pattern. Additionally, during the EO condition, the percentage change from day 1 to day 63 in overall gamma (30–120 Hz) was significantly correlated with improved LMM Toxic Thoughts. These results suggest a positive correlation between improved LMM Toxic Thoughts and a greater change in overall gamma activity. It would therefore appear that chronic stress management using the Neurocycle was also reflected in the biological results, which is supported by the literature (Epel, 2009, 2012; Epel et al., 2004) Further research is needed to confirm these results.

Conclusion

Integrating the Psycho-Neuro-Biological to Inform Automaticity and Habit Formation

The brain has evolved to process and encode sensory information and cognitive processes in a manner that utilizes a minimal amount of effort and energy, both biologically and cognitively speaking. Unfortunately, the most effective and energy-efficient way of solving problems is often not the most psychologically healthy solution. It is possible that for some situations, the most energy-efficient solution is not just a nonideal one but could be maladaptive in the long run. An individual can alleviate the exposure to a stressor by suppressing or simply removing oneself from the situation, but this is often unrealistic. Therefore, a more effortful process of discovering why the stressor initiated that strong response and going through a process of self-discovery and reconceptualization are needed to move past that stressor. This requires a great deal more cognitive, emotional, and biological energy to complete; however, it has the potential to provide a more healthy, long-term, solution to that stressor. The present pilot study was conducted to assess the efficacy of the Neurocycle as providing such a planned and guided system to foster effective and sustainable habit formation and the automaticity of complex mental health issues of participants as measured using a psychoneurobiological approach.

Neurophysiological changes were observed as an indicator of improved complex mental health wellness through improved psychosocial state as indicated by decreased LMM Toxic Thoughts, increased autonomy scores, and decreased PHQ-9 stress scores. Neurological and mental health improvement were validated with the measurement of changed gamma levels as correlated with improved self-regulation on the LMM, decreased prolactin blood levels, and increased telomere length from day 21 to day 63, coinciding with decreased self-reporting of symptoms of stress and anxiety. The correlation of these results provides novel support for the connection between gamma as a goldilocks frequency and automaticity and habit formation. Gamma can be too low or too high and is interpreted based on source location (gamma is representative of communication between higher level cortices). Thus, depending on which cortical areas you are talking about, the increase or decrease in gamma can be thought of as an index of overall arousal or activation in that cortical area, expending effort. Furthermore, the automatization effect of habit formation appears to involve frontal low gamma increasing from days 1–21 and then pivoting and decreasing to day 63 to a greater extent for the treatment versus the control group. This potentially shows the hard work being done in days 1–21 as the person is embracing, deconstructing, and reconstructing the issue resulting in low gamma increasing frontally, then calming down as the individual starts to practice using the new habit to stabilize it. The global low gamma is potentially showing that, as the new habit is developing from day 1 to day 21, and then stabilizing from day 21 to day 63, the whole brain gets involved in this complex organic growth-oriented process of the new habit being practiced. Additionally, this could possibly be evidence of complex activity in the nonconscious mind that needs to happen outside of conscious awareness in order to stabilize an effective habit that will be helpful and useful to the individual. The therapeutic alliance effect was evidenced in the significant improvement in awareness and empowerment in the control group over the course of the 63 days.

As this was a pilot study done on a small, nondiverse population, it has limitations. Future research should confirm these relationships with larger data sets and longitudinal studies to understand how to incorporate the science of habit formation and automaticity in improving mental health intervention.

Author Declarations

As an owner of Switch on Your Brain and the Neurocycle, Dr. Caroline Leaf receives financial benefits from royalties for the intellectual property

that is subject to evaluation or improvement through the research presented here. Concerns over financial interest were addressed by the double-blind research design and involvement of an independent third-party research consulting firm. There are no conflicts of interest or grant support to disclose.

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