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ORIGINAL ARTICLE

The effects of auditory brainwave entrainment on the psychophysical health of healthcare programs students

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Abstract

Objective: *This pilot study aimed to explore the modulatory potential of auditory Brainwave Entrainment (aBWE) on the emotional and physical well-being of college students enrolled in healthcare programs.* **Methods:** *All enrolled participants from the Seminole State College received the same intervention of daily aBWE sessions over a 12-week period. Evaluations were conducted at the outset (1st week), midpoint (6th week), and conclusion (12th week), utilizing four distinct questionnaires: the Pittsburgh quality of sleep index (PQSI), the perceived stress scale (PSS), the generalized anxiety disorder 7 (GAD-7), and the profile of mood States (POMS).* **Results:** *Twenty-nine participants (mean age of 39.41) completed the study. In the PQSI, reductions were observed in Subjective Sleep Quality (p = 0.0039), Sleep Latency (p = 0.0454), and the Global Score (p = 0.0175). The PSS indicated significant reductions in stress after 6 weeks (p = 0.0402) and 12 weeks (p = 0.0006). The GAD-7 scale revealed a significant reduction in anxiety by the final evaluation (p < 0.0001). Similarly, the POMS questionnaire showed significant decreases in Tension at both midpoint (p = 0.0259) and final evaluations (p = 0.0001), along with reductions in Total Mood Disturbance (midpoint p = 0.0485, final p < 0.0001). In addition, significant improvements were noted in Depression (p = 0.0314), Anger (p = 0.0454), Vigor (p = 0.0297), Fatigue (p = 0.0002), and Confusion (p = 0.0019) by the final evaluation.* **Conclusions:** *We conclude that aBWE presents a promising intervention for enhancing sleep quality, mood states, and reducing stress and anxiety, without any reported adverse effects, indicating its safety.*

Keywords: *Brainwave entrainment. Neuromodulation. Anxiety. Mood. Sleep. Stress.*

Efectos de la inducción auditiva de ondas cerebrales en la salud psicofísica de los estudiantes de programas de atención sanitaria

Resumen

Objetivo: *Este estudio piloto tuvo como objetivo explorar el potencial modulador del arrastre de ondas cerebrales auditivas (aBWE) en el bienestar físico y emocional de estudiantes universitarios matriculados en programas de atención sanitaria.* **Métodos:** *Todos los participantes inscritos en el Seminole State College recibieron la misma intervención de sesiones diarias de aBWE durante un período de 12 semanas. Las evaluaciones se llevaron a cabo al inicio (1.ª semana), a la mitad*

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(6.ª semana) y al final (12.ª semana), utilizando cuatro cuestionarios distintos: el Índice de Calidad del Sueño de Pittsburgh (PQSI), la Escala de Estrés Percibido (PSS), la Escala de Ansiedad Generalizada (GAD-7) y el Perfil de Estados de Ánimo (POMS). **Resultados:** *Veintinueve participantes (edad media de 39,41 años) completaron el estudio. En el PQSI, se observaron reducciones en la Calidad Subjetiva del Sueño (p = 0,0039), la Latencia del Sueño (p = 0,0454) y la Puntuación Global (p = 0,0175). La PSS indicó reducciones significativas del estrés después de 6 semanas (p = 0,0402) y 12 semanas (p = 0,0006). La escala GAD-7 reveló una reducción significativa de la ansiedad en la evaluación final (p < 0,0001). El cuestionario POMS mostró disminuciones significativas en la Tensión tanto en la evaluación intermedia (p = 0,0259) como en la evaluación final (p = 0,0001), junto con reducciones en la Alteración Total del Estado de Ánimo (evaluación intermedia p = 0,0485, final p < 0,0001). Además, se observaron mejoras significativas en Depresión (p = 0,0314), Ira (p = 0,0454), Vigor (p = 0,0297), Fatiga (p = 0,0002) y Confusión (p = 0,0019) en la evaluación final.* **Conclusiones:** *Concluimos que aBWE presenta una intervención prometedora para mejorar la calidad del sueño, los estados de ánimo y reducir el estrés y la ansiedad, sin ningún efecto adverso reportado, lo que indica su seguridad.*

Palabras clave: *Arrastre de ondas cerebrales. Neuromodulación. Ansiedad. Estado de ánimo. Sueño. Estrés.*

Introduction

Mental disorders are on the rise globally, significantly affecting societal well-being. They stand as a leading cause of disability, leading to substantial functional impairments and diminished quality of life. The causes of mental disorders include both biological factors and social or psychological factors. Depression and anxiety, due to their high prevalence, contribute more to the overall disease burden than more severe mental illnesses, such as schizophrenia and bipolar disorder, as noted by researchers[1]. Despite a decrease in the age-standardized burden of mental disorders over the past three decades, Wu and colleagues[1] reported an increase in both the number of new cases and deaths attributed to mental disorders globally, a trend expected to continue. Notably, the incidence of mental disorders tends to be higher in women than in men[1].

Published studies with college health students have shown the prevalence of depression, anxiety, and stress among them, impairing their quality of life[2-4]. Hence, there's a pressing need to find simple interventions to improve such issues in this population. This is especially pertinent considering that health professionals already often face work overload and stressful conditions, frequently experiencing anxiety, depression, insomnia, and a lower quality of life[5-7].

One potential intervention is brainwave entrainment (BWE), which consists of the induction of specific physiological and psychological states through external auditory or visual stimuli at certain frequency bands[8]. Research exploring various frequencies has indicated improvements in anxiety across different contexts[9-11], stress reduction[12-14], sleep enhancement[15,16], and alleviation of depressive symptoms[17]. Moreover, BWE is recognized as a safe and cost-effective alternative[12,18,19]. Therefore, this pilot study was designed to explore the impact of BWE on the emotional and physical well-being of college students in healthcare programs.

Methods

Study design

This was a pilot study that involved college students from Seminole State College (Florida, USA) as participants. It was conducted in a continuous manner from July 2022 until December 2023. Students were informed about the study through e-mail and invited to participate. The inclusion criteria were individuals over 18 years old and enrolled in healthcare programs (Nursing, Respiratory Care, and other Related Disciplines). Participants with hearing disabilities, seizure disorders, epilepsy, or previous experience with BWE were excluded. This study was conducted following ethical standards and the principles from the Declaration of Helsinki. Furthermore, the Seminole State College Ethics Committee approved this study. Participation was entirely voluntary and carried out only after obtaining a signed Informed Consent Form.

Procedure

After enrollment, the study spanned 12 weeks. Participants began by completing a baseline evaluation of the questionnaires online. Subsequently, they participated in daily 20-min auditory BWE (aBWE) sessions (at home) throughout the study duration. Two additional evaluations were conducted online through Google Forms at the midpoint (6th week) and at the conclusion (12th week). Additional emails were frequently sent to increase adherence.

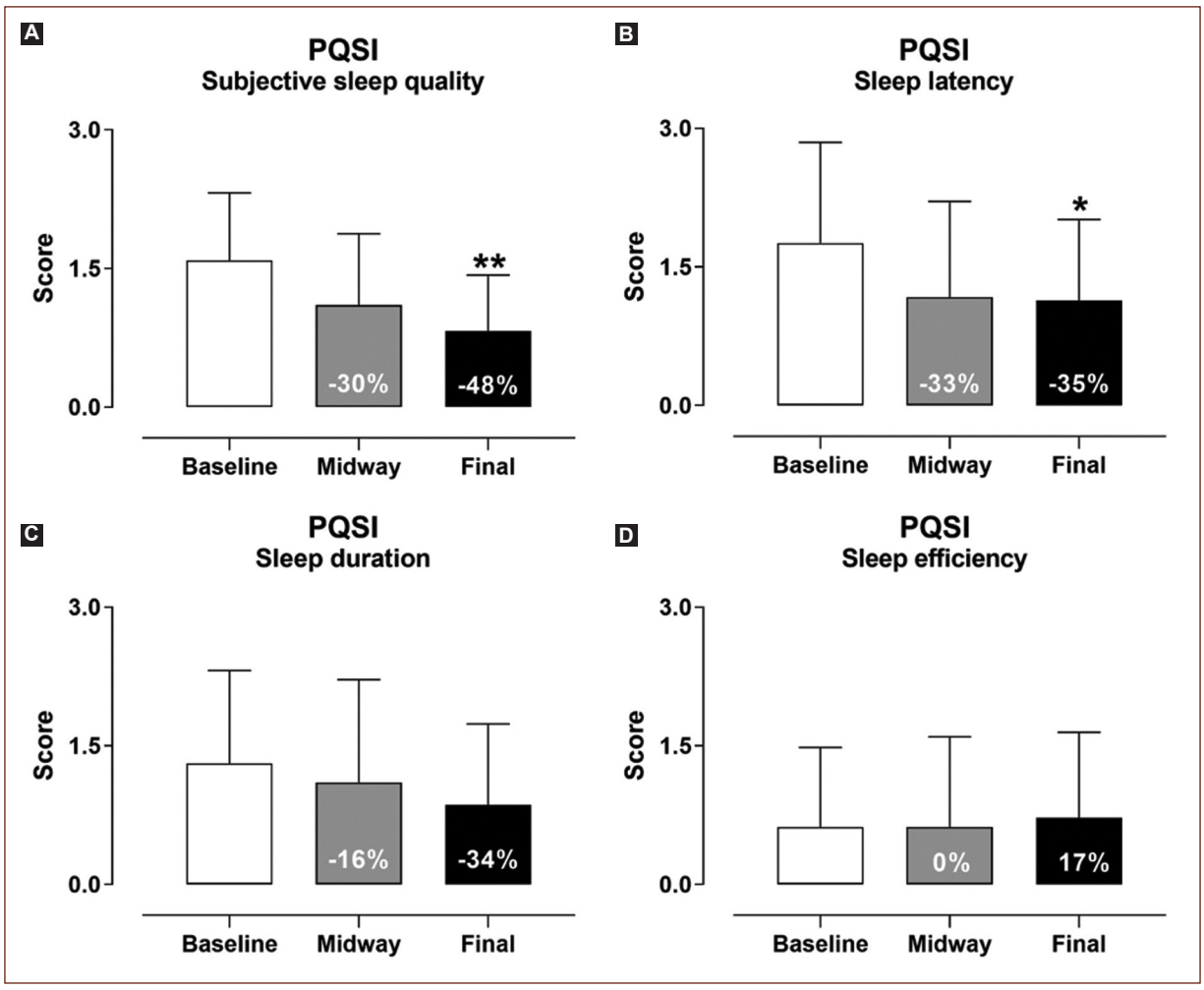

Figure 1. A-D: 12 weeks of Audio Brainwave Entrainment sessions significantly improved the Subjective sleep quality and Sleep latency components. Each point represents the mean of 29 participants and vertical lines show the mean with SD.
*Significant difference of $p < 0.05$ when compared baseline evaluations. The % value is in relation to the baseline. Statistical analysis was performed by Friedmans' test followed by Dunn's multiple comparison test. PQSI: Pittsburgh Quality of Sleep Index; SD: standard deviation.

Audio BWE

Participants engaged in daily 20-min aBWE sessions at home using the BrainTap APP (New Bern, NC, USA) for 12 weeks. The sessions incorporated Binaural Beats and Isochronic Tones designed to entrain brainwave frequencies in specific ranges: α (8-12 Hz) for relaxation and focus, θ (4-7 Hz) for deep relaxation and meditation, and Δ (0.5-3 Hz) for deep sleep and recovery. Binaural Beats were delivered by presenting slightly different frequencies to each ear, which the brain interprets as a single auditory tone, while Isochronic Tones used evenly spaced, sharp sound pulses to synchronize brainwave activity without requiring headphones. However, it was recommended that participants use stereo headphones to maximize the effectiveness of the Binaural Beats.

The sessions were pre-loaded in the app, allowing participants to simply select the session and press play, making it easy to follow the protocol without any additional setup. Participants did not report any issues or difficulties in accessing the app or selecting and playing the sessions, indicating a user-friendly experience throughout the intervention period.

Outcomes evaluation

To assess sleep quality, we chose the Pittsburgh Quality of Sleep Index (PQSI). This self-assessment tool evaluates seven areas (e.g., subjective sleep

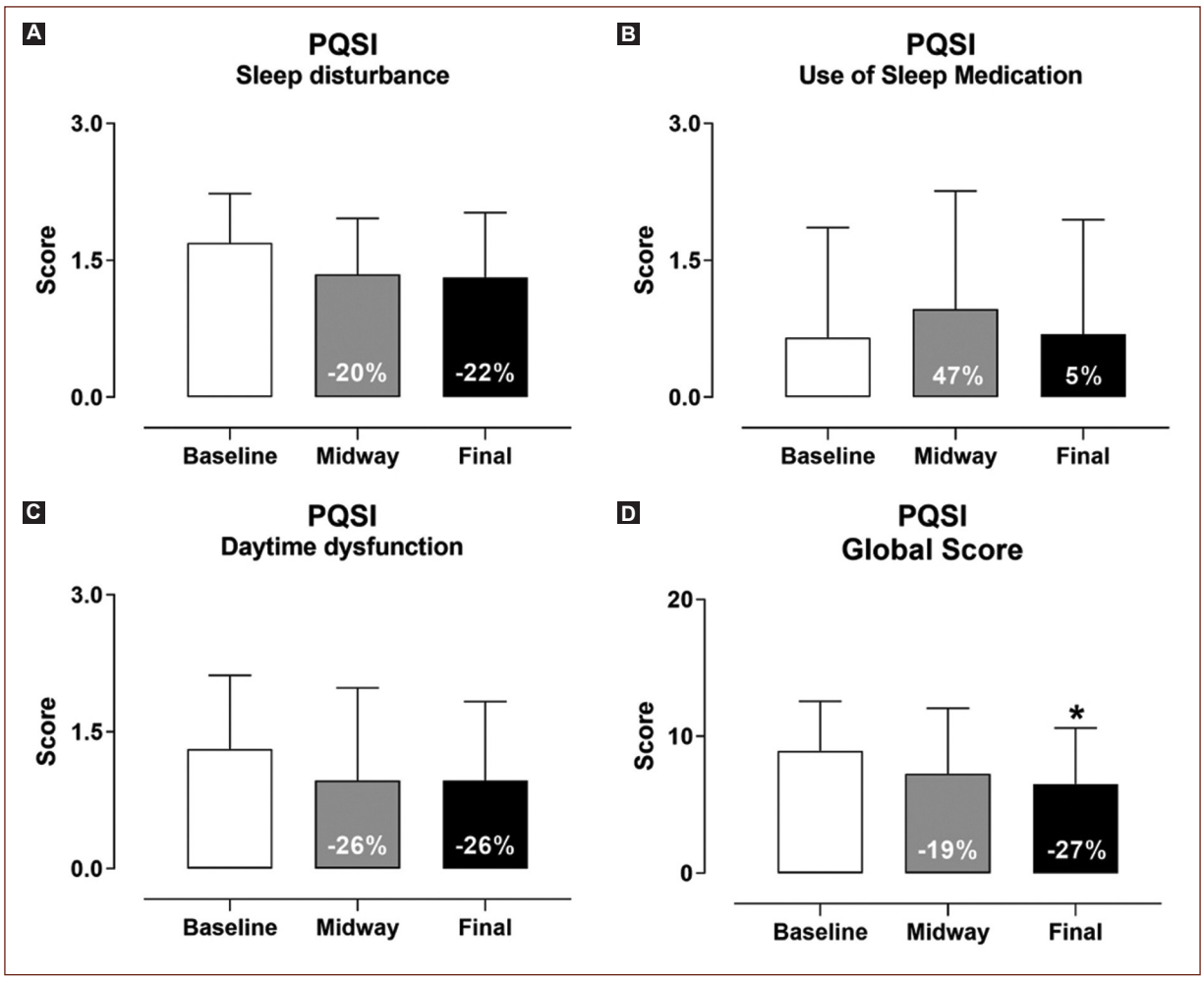

Figure 2. A-D: 12 weeks of Audio Brainwave Entrainment sessions significantly improved the PQSI Global Score. Each point represents the mean of 29 participants and vertical lines show the mean with SD.
*Significant difference of $p < 0.05$ when compared baseline evaluations. The % value is in relation to the baseline. Statistical analysis was performed by Friedmans' test followed by Dunn's multiple comparison test. PQSI: Pittsburgh Quality of Sleep Index; SD: standard deviation.

quality, sleep latency, and daytime dysfunction) over the past month, using a 0-3 scale, with higher scores indicating poorer sleep. The PSQI has shown strong internal consistency and reliability across diverse populations[20,21].

For stress measurement, we used the perceived stress scale (PSS), which assesses stress-related feelings and thoughts over the past month on a 5-point scale (0-4 question). Higher scores suggest increased stress. The PSS-10 has demonstrated good internal consistency (Cronbach's α: 0.71-0.91) and test-retest reliability (typically above 0.70)[22].

To evaluate anxiety levels, we chose the generalized anxiety disorder 7-item (GAD-7) scale. This tool scores 7 items on a 0-3 scale, with cut-off points of 5, 10, and 15 indicating mild, moderate, and severe anxiety. With a threshold of 10, the GAD-7 shows high sensitivity (89%) and specificity (82%) for diagnosing GAD and can also screen for other anxiety disorders[23].

The profile of mood states (POMS) questionnaire was used to assess specific mood states through 65 descriptors rated on a 5-point scale. The POMS has high internal consistency, with Cronbach's α ranging from 0.82 to 0.90 across its subscales[24].

Statistical analysis

We submitted the data to the Shapiro–Wilk test to assess normality. Results were displayed as the mean

plus standard deviation for each evaluation. For datasets failing the normality test, the Friedmans' test was conducted, succeeded by Dunn's multiple comparison test for detailed analysis. In cases where data met normality criteria, a one-way analysis of variance was performed, followed by Tukey's multiple comparison test to evaluate the differences between evaluations. A value of $p < 0.05$ was deemed to indicate statistical significance. Graph Pad Prism® (version 8.0) served as the analytical software for this process. In addition, percentage differences based on the means from the evaluations were calculated utilizing Microsoft Excel®.

Results

Initially, 116 participants were enrolled in the study; however, only 29 completed all three evaluations and were included in the analysis. Of these, 28 were female (sex determined at birth), with an average age of 39.41 years. Some participants dropped out for personal reasons, but the majority was not included in the analysis due to not answering all evaluations in the appropriate time frame.

Quality of sleep

The PQSI revealed statistically significant improvements in sleep quality by the study's conclusion. Specifically, reductions in scores for Subjective Sleep Quality (Fig. 1) ($p = 0.0039$, Fig. 1A) and Sleep Latency ($p = 0.0454$, Fig. 1B) were noted when comparing final evaluation results to baseline values, as depicted in Fig. 1. In addition, as shown in figure 2, there was a significant decrease in the Global Score ($p = 0.0175$, Fig. 2D), indicating an overall improvement in sleep quality since a higher score on this scale is indicative of poorer sleep quality. However, it is possible to observe that there were no statistically significant changes in Sleep Disturbance (Fig. 2A), Use of Sleep Medication (Fig. 2B), or Daytime Dysfunction (Fig. 2C).

Stress

The PSS demonstrated that participants experienced statistically significant decreases in perceived stress following 6 weeks ($p = 0.0402$) and 12 weeks ($p = 0.0006$) of aBWE sessions, as illustrated in figure 3. On this scale, a higher score corresponds to increased perceived stress, indicating that the reductions in scores reflect an improvement in stress levels among the participants.

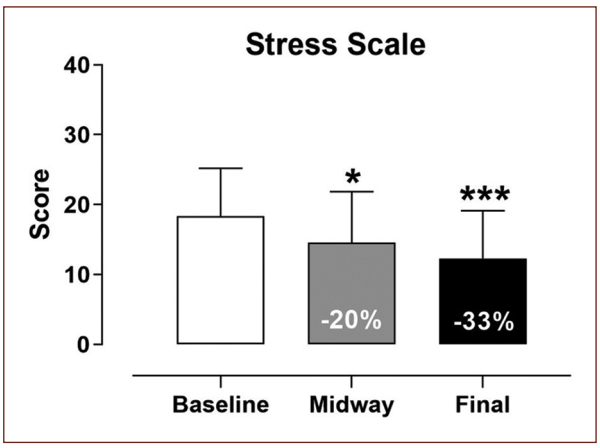

Figure 3. After 6 and 12 weeks of Audio Brainwave Entrainment sessions participants had lower perceived stress. Each point represents the mean of 29 participants and vertical lines show the mean with SD.
*Significant difference of $p < 0.05$ when compared baseline evaluations. The % value is in relation to the baseline. Statistical analysis was performed by RM one-way analysis of variance followed by Tukey's multiple comparison test. RM: repeated measures; SD: standard deviation.

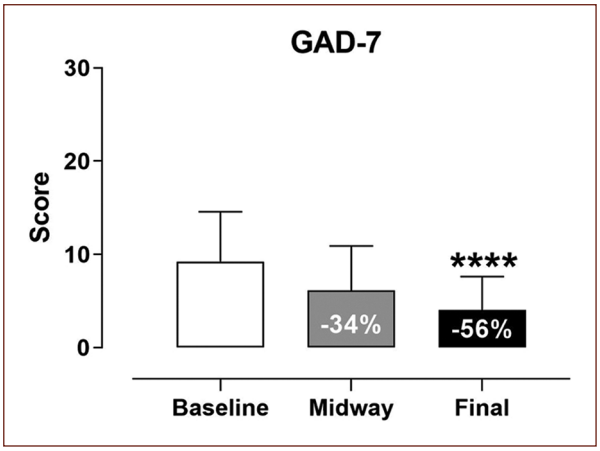

Figure 4. 12 weeks of Audio Brainwave Entrainment sessions significantly reduced participant's anxiety. Each point represents the mean of 29 participants and vertical lines show the mean with SD.
*Significant difference of $p < 0.05$ when compared baseline evaluations. The % value is in relation to the baseline. Statistical analysis was performed by Friedmans' test followed by Dunn's multiple comparison test. SD: standard deviation.

Anxiety

The GAD-7 scale results indicated a statistically significant decrease in generalized anxiety levels in the final evaluation compared to the baseline, with a

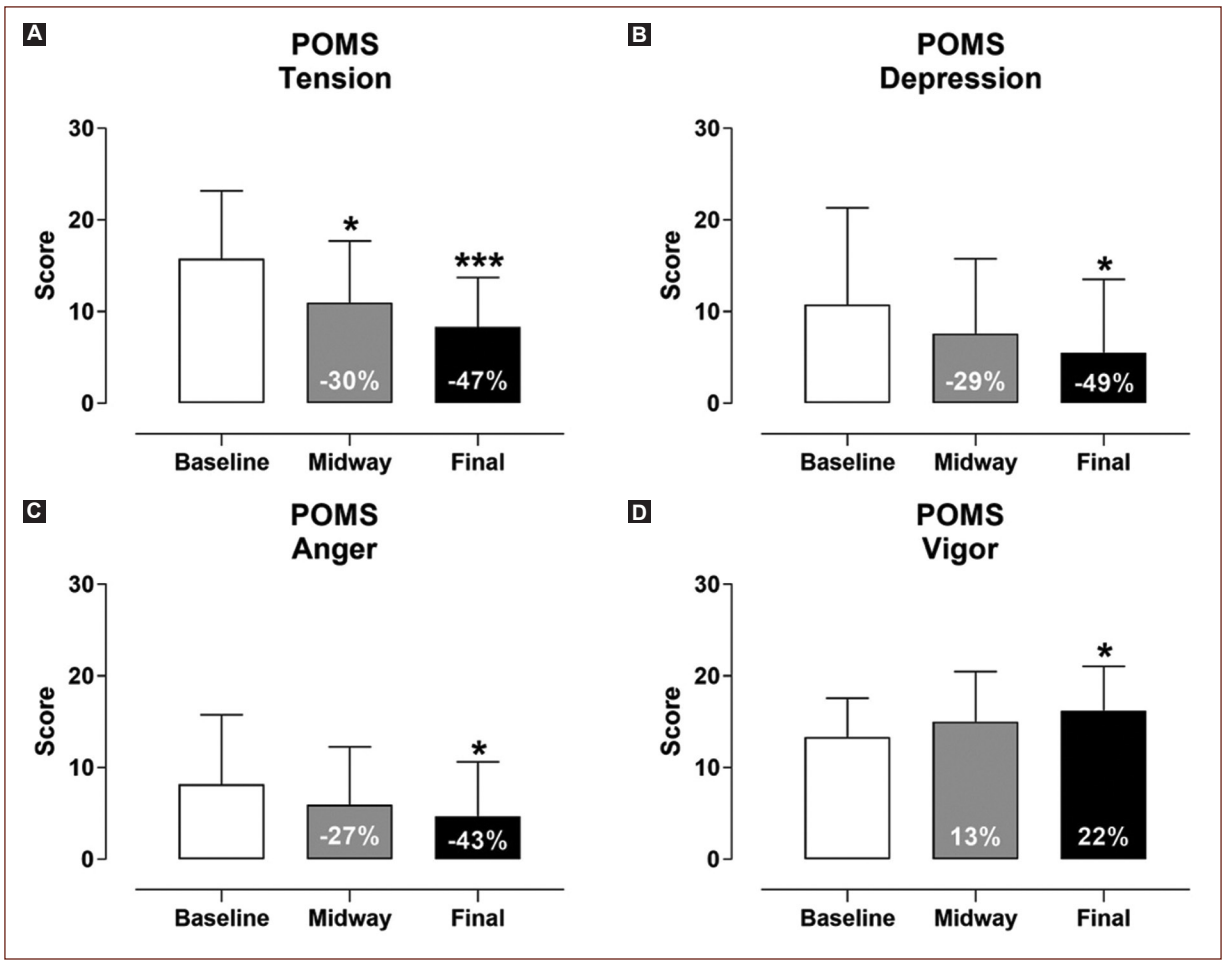

Figure 5. A-D: 6 and 12 weeks of Audio Brainwave Entrainment sessions significantly changes participants mood states. Each point represents the mean of 29 participants and vertical lines show the mean with SD.
*Significant difference of $p < 0.05$ when compared baseline evaluations. The % value is in relation to the baseline. Statistical analysis was performed by Friedmans' test followed by Dunn's multiple comparison test in sub-scales **A, B,** and **C**, and by RM one-way analysis of variance followed by Tukeys multiple comparison test in sub-scale **D.** POMS: Profile of Mood States; RM: repeated measures; SD: standard deviation.

$p < 0.0001$, as depicted in figure 4. This reduction signifies a notable improvement in anxiety symptoms among participants by the end of the study.

Mood states

The POMS questionnaire results revealed statistically significant improvements in mood states. Specifically, reductions in Tension were observed both at the midpoint (Fig. 5) ($p = 0.0259$, Fig. 5A) and in the final evaluations ($p = 0.0001$, Fig. 5A), alongside reductions in Total Mood Disturbance (midpoint $p = 0.0485$, final $p < 0.0001$, Fig. 6C). The final evaluation also showed significant improvements in several mood dimensions, including Depression ($p = 0.0314$, Fig. 5B), Anger ($p = 0.0454$, Fig. 5C), Vigor ($p = 0.0297$, Fig. 5D), Fatigue (Fig. 6) ($p = 0.0002$, Fig. 6A), and Confusion ($p = 0.0019$, Fig. 6B). These findings indicate that the aBWE sessions were effective in positively altering mood states among the participants.

Discussion

Our study hypothesized that aBWE could positively affect sleep and mood while reducing anxiety and stress among college students in healthcare programs (Nursing, Respiratory Care, and other Related Disciplines). This hypothesis was confirmed through significant improvements observed in all measured outcomes after 12 weeks of training. The students improved their

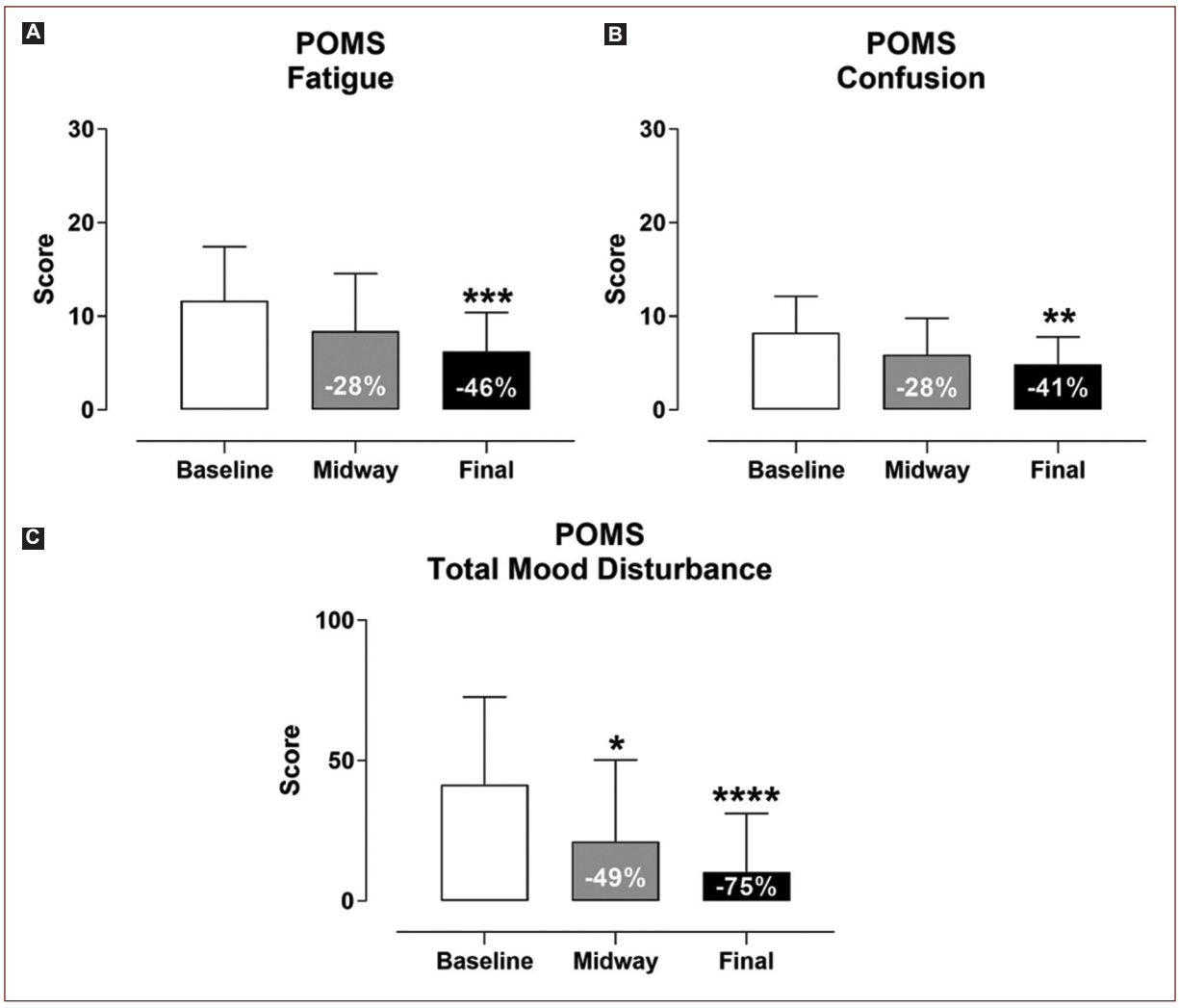

Figure 6. A-D: 6 and 12 weeks of Audio Brainwave Entrainment sessions significantly changes participants' mood states. Each point represents the mean of 29 participants and vertical lines show the mean with SD.
*Significant difference of $p < 0.05$ when compared baseline evaluations. The % value is in relation to the baseline. Statistical analysis was performed by Friedmans' test followed by Dunn's multiple comparison test. POMS: Profile of Mood States; RM: repeated measures; SD: standard deviation.

mood, quality of sleep, while also reducing anxiety and stress.

Our findings align with existing literature, such as Dabiri and colleagues[25] that demonstrated improvements in sleep parameters and mood with 90 min of exposure to Delta Binaural beats[25]. However, their study only observed improvements in anxiety and anger, while in ours there were also changes in other mood parameters such as tension and depression. Maybe these differences could be attributed to the fact that their treatment period was 1 week, while ours was 12 weeks, suggesting that more improvements are obtained with long-term exposure. Abeln and colleagues[26] showed in elite soccer players enhancements in sleep quality, wakefulness, and motivation by 6 weeks of α, Theta, and Delta binaural beats during sleep[26].

Further studies have also corroborated the efficacy of Audio Stimulation in reducing anxiety and improving mood across various frequency bands, with combinations of α-Theta-Gamma[27] or Theta alone[28]; also under different conditions, such as surgical procedures[10-13,29-31].

A meta-analysis by Garcia-Argibay et al.[31] concluded that Binaural-beat stimulation could impact cognition, anxiety, and pain perception without needing prior training, indicating a positive correlation between exposure time and effect sizes without leading to habituation. Despite

the heterogeneity and sometimes unclear frequency parameters in these studies, there is growing evidence supporting binaural beats' influence on psychophysiological states[31]. Aparecido-Kanzler et al.[32] explained that brainwave activity results from the bioelectric interactions among neuronal networks, suggesting that BWE can modulate mind states[32].

Another important observation of our study was that there were no adverse events reported by the participants during the entire study period. This shows that aBWE is not only a non-invasive intervention but also safe and feasible to perform for a longer period. Especially, because many improvements were achieved and it required only 20 min of practice, which is easy to integrate into an individual's routine, which is very important when it comes to students and health professionals who tend to have busy daily routines. As previously mentioned, poor sleep quality, anxiety, stress, and fatigue impose a high burden in health professionals and can negatively impact not only their quality of life but also their work performances, posing risks to patients[6]. Therefore, integrating 20 min of aBWE in work settings or in professionals' routines could be a great aid in mitigating these outcomes, since we also observed in our study a reduction in parameters such as fatigue, confusion, and an increase in vigor. Even though there could be a bias of these scales being self-reported, it is important to consider how the individual perceives itself.

Notably, our study predominantly involved female participants with an average age of approximately 39.41 years. This is a limitation because it restricts the generalizability of research findings and their applicability to clinical practice. However, it is also relevant because hormonal changes can increase the risk of sleep disturbances and disorders, with studies showing a decline in nocturnal melatonin secretion with age, accompanied by an increase in primary sleep disorders among post-menopausal women[33]. The observed improvements in sleep and mood among this demographic underscore the potential of aBWE as a therapeutic tool for enhancing women's health and quality of life across different life stages.

Our study faced several limitations, including a small sample size and the absence of a control or placebo group to definitively attribute the observed improvements to aBWE. Another issue was the high percentage of sample loss (75%, n = 87), which could be attributed to participants forgetting to complete the questionnaires on the indicated dates as they were answered online, which suggests the need for closer monitoring by researchers and more frequent individual reminders to prevent this from happening. In addition, the inability to verify the daily completion of sessions and the influence of sleep or mood medications taken by some participants, pose challenges to the study's conclusions. A randomized controlled trial, with a larger sample size and control of medications taken by participants, would be ideal to confirm the findings from our study.

Conclusion

Despite limitations presented in our study, the significant improvements noted –coupled with the lack of adverse events reported– suggest that daily sessions of aBWE represent a promising, non-invasive intervention for improving sleep, mood states, and reducing stress and anxiety among healthcare students. To solidify these findings, further research involving larger randomized controlled trials with placebo and control groups is recommended.

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The authors declare that this work was carried out with the authors' own resources.

Conflicts of interest

The authors declare that they have no conflicts of interest.

Ethical considerations

Protection of humans and animals. The authors declare that the procedures followed complied with the ethical standards of the responsible human experimentation committee and adhered to the World Medical Association and the Declaration of Helsinki. The procedures were approved by the institutional Ethics Committee.

Confidentiality, informed consent, and ethical approval. The authors have followed their institution's confidentiality protocols, obtained informed consent from patients, and received approval from the Ethics

Committee. The SAGER guidelines were followed according to the nature of the study.

Declaration on the use of artificial intelligence. The authors declare that no generative artificial intelligence was used in the writing of this manuscript.

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