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Original article

BENEFITS OF HEART RATE VARIABILITY BIOFEEDBACK TRAINING ON MEDICAL STUDENTS' MENTAL HEALTH

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ABSTRACT

Background: Heart rate variability biofeedback (HRV-BF) has emerged as a promising non-pharmacological intervention for stress and emotional regulation. This study aimed to evaluate the longitudinal effects of HRV-BF on perceived stress, depression, and anxiety among international medical students over 12 weeks.

Methods: A total of 47 international medical students participated in the study, with psychological assessments conducted at two time points (February and May) over a 12-week period, using the Perceived Stress Scale (PSS), Beck Depression Inventory (BDI), Zung Self-Rating Anxiety Scale (SAS), and Beck Anxiety Inventory (BAI). Statistical analyses included the Wilcoxon Signed-Rank Test to assess changes over time within each group.

Results: The results revealed significant reductions in all measured psychological parameters within the biofeedback group, with stress ($p = 0.007$), depression ($p = 0.002$), and anxiety ($p < 0.001$) levels showing notable improvement over time. The control group exhibited minimal change over time, supporting the observed improvements within the biofeedback group.

Conclusions: These findings support the integration of HRV-BF training into medical education as a strategy for enhancing students' mental well-being. Future research should explore long-term effects and optimize intervention protocols to maximize benefits. HRV-BF may serve as a valuable tool in mitigating the psychological burden associated with rigorous academic environments.

Keywords: heart rate variability biofeedback, stress, medical students, anxiety, depression, mental health, non-pharmacological therapy,

INTRODUCTION

Heart Rate Variability Biofeedback (HRV-BF) has garnered significant attention as a non-pharmacological intervention aimed at mitigating psychological distress, particularly in high-stress populations [1]. HRV-BF involves training individuals to regulate their heart rate variability through controlled breathing and feedback mechanisms, thereby enhancing autonomic balance and emotional regulation [2]. This technique has been associated with reductions in stress, anxiety, and depression across various groups, including healthcare workers and students [3].

A number of studies, as well as our own, prove that medical students are notably susceptible to elevated levels of psychological distress due to rigorous academic demands and highstakes environments [4, 5, 6]. Studies have reported that the prevalence of depressive disorders among medical students exceeds 20%, a rate significantly higher than that observed in the general population [7]. Factors contributing to this heightened vulnerability include intense workloads, sleep deprivation, and the pressure to perform academically [8]. Consequently, there is a pressing need for effective interventions to support the mental health of this population [9].

Recent research has explored the efficacy of HRV-BF in reducing symptoms of psychological distress among students. For instance, a study assessing HRV-BF as an adjunct to college recovery programs found significant reductions in craving, perceived stress, anxiety, and depressive symptoms over a 12-week intervention period [10]. Similarly, another study demonstrated that a short-term HRV-BF intervention reduced stress and anxiety levels among university students, suggesting that even brief biofeedback training can have measurable psychological benefits [11].

These findings reinforce the potential of HRV-BF as an accessible and effective tool for improving mental well-being in student populations. Due to the consider-

able academic workload and psychological challenges faced by medical students, it is crucial to implement targeted interventions that enhance their mental resilience. Building upon this evidence, our study aims to evaluate the longitudinal effects of HRV-BF on perceived stress, depression, and anxiety among international medical students at Varna Medical University.

MATERIALS AND METHODS

The survey included 47 international medical students enrolled in the "Medicine" program at the Medical University of Varna, Bulgaria. Participation began following approval from the university's research ethics committee.

All participants completed 5 baseline questionnaires - sociodemographic questionnaire, Perceived Stress Scale (PSS), Beck Depression Inventory (BDI), Zung Self-Rating Anxiety Scale (SAS), and Beck Anxiety Inventory (BAI). These assessments were conducted at two time points: initially, immediately before the beginning of the investigation in February, and subsequently, at the end of the study in May.

The Perceived Stress Scale is a widely used psychological instrument for measuring the perception of stress. It assesses the degree to which respondents find their lives unpredictable, uncontrollable, and overloading. The overall scores can be evaluated as follows: 0-13 – low stress; 14-26 – moderate stress; 27-40 – high perceived stress [12].

The Beck Depression Inventory is a 21-item self-report inventory designed to measure characteristic attitudes and symptoms of depression. The total score is classified as follows: 17–20 indicates borderline clinical depression, 21–30 moderate depression, 31–40 severe depression, and scores above 40 suggest extreme depression [13].

The Self-Rating Anxiety Scale is a 20-item self-report scale that evaluates the severity of anxiety symptoms developed in the past several days. The raw score is converted into an index score, with values above 45 suggesting clinically significant anxiety [14].

The Beck Anxiety Inventory consists of 21 multiple-choice self-report inventory questions to measure characteristic attitudes and symptoms of anxiety. Scores between 0–21 indicate low anxiety, 22–35 moderate anxiety, and scores above 36 suggest potentially severe anxiety [15].

Group Formation

The selection of participants (n=47) for the biofeedback and control groups was based on the results of the psychological questionnaires administered at the beginning of the study. Students who exhibited elevated levels of stress, depression, and/or anxiety (n=24), as indicated by their scores on the PSS, BDI, SAS, and BAI, were included in the study. Those assigned to the biofeedback group underwent HRV-BF training, while those in the control group (n=23) did not receive any intervention and were observed to assess how they managed stress without external support. This approach ensured that the study targeted individuals with significant psychological distress, allowing for a clearer evaluation of the effects of HRV-BF on mental well-being.

Biofeedback Training Protocol

Participants in the biofeedback group underwent HRV-BF training using the emWave Pro Plus system. The training consisted of two sessions per week, each lasting 30 minutes. During these sessions, participants practiced slow-paced breathing techniques following a specific pattern aimed at increasing heart rate coherence. In addition to the in-lab training, participants were advised to apply the same breathing techniques at home after awakening, before sleeping, and before stressful events. This combination of structured sessions and self-guided practice was designed to enhance physiological self-regulation and stress resilience over time.

Statistical analysis

Differences in perceived stress, depression, and anxiety levels between the biofeedback and control groups were assessed using the Chi-Squared test for categorical variables. For continuous variables, the Mann-Whitney U test was performed due to violations of normality in the dataset. A p-value of <0.05 was considered statistically significant. To evaluate changes in psychological scores over time (February vs. May), the Wilcoxon Signed-Rank Test was used, as normality was not met for most variables, making non-parametric testing the appropriate choice. This test was applied to analyze changes in PSS, BDI, SAS, and BAI scores within each group over time.

The statistical analyses were performed using Jamovi v.2.6.24.

RESULTS

In this study, 47 international medical students were involved, with the majority being female - 85.1%, while males accounted for 14.9%. The sociodemographic characteristics of participants are shown in Table 1.

Table 1. Sociodemographic characteristics of the participants

Variable		Number (n=47)	Percent (%)
Gender	Male	7	14,9%
	Female	40	85,1%
Age	19-23	31	66,0%
	24-26	10	21,3%
	27-30	5	10,6%
	31-35	1	2,1%
Academic year	1	4	8,5%
	2	11	23,4%
	3	20	42,6%
	4	5	10,6%
	5	6	12,8%
	6	1	2,1%
Alcohol consumption/day	Don't drink	28	59,6%
	Light – one drink (glass, can) or less	18	38,3%
	Moderate – more than one drink (glass, can)	1	2,1%
Smoking	No	40	85,1%
	Less than one pack per day	6	12,8%
	One or more packs per day	1	2,1%

The psychological evaluation scores for perceived stress, depression, and anxiety among the participants are presented in Table 2, comparing the biofeedback and control groups at two time points: February and May.

Table 2. Chi-Square Test of Group Comparisons in Mental Health Scores

Measure	Scale	February Biofeedback (n=24)	February Control (n=23)	May Biofeedback (n=24)	May Control (n=23)	χ^2	df	*p*-value
PSS	0–13	1 (4%)	13 (57%)	8 (33%)	10 (43%)	10.2	2	0.006
	14–26	7 (29%)	9 (39%)	16 (67%)	10 (43%)			
	27–40	16 (67%)	1 (4%)	0 (0%)	3 (13%)			
BDI	1–10	3 (13%)	20 (87%)	12 (50%)	17 (74%)	15.8	3	0.001
	11–16	2 (8%)	1 (4%)	7 (29%)	2 (9%)			
	17–20	2 (8%)	1 (4%)	1 (4%)	1 (4%)			
	21–30	11 (46%)	0 (0%)	2 (8%)	2 (9%)			
	31–40	6 (25%)	1 (4%)	2 (8%)	1 (4%)			
	Over 41	0 (0%)	0 (0%)	0 (0%)	0 (0%)			
SAS	< 45	10 (42%)	21 (91%)	19 (79%)	20 (87%)	9.03	2	0.011
	45–59	11 (46%)	1 (4%)	5 (21%)	3 (13%)			
	60–74	3 (13%)	1 (4%)	0 (0%)	0 (0%)			
	75–80	0 (0%)	0 (0%)	0 (0%)	0 (0%)			
BAI	0–21	8 (33%)	20 (87%)	20 (83%)	20 (87%)	10.2	2	0.006
	22–35	11 (46%)	1 (4%)	3 (13%)	2 (9%)			
	Over 36	5 (21%)	2 (9%)	1 (4%)	1 (4%)			

The PSS results indicate a notable difference in stress levels between the two groups. In February, 67% of the biofeedback group exhibited high perceived stress (scores 27–40), whereas only 16% of the control group fell into this category. By May, there was a substantial improvement in the biofeedback group, with no participants remaining in the high-stress category, while the control group still had 13% experiencing high stress.

Regarding depressive symptoms, as measured by the BDI, there was a significant shift in the biofeedback group over time. In February, 46% of biofeedback participants scored in the moderate depression range (scores 21–30), while 25% had severe depression (scores 31–40). By May, these numbers had significantly declined, with 50% of the biofeedback group falling within the minimal depression category (scores 1–10) and only 8% remaining in the moderate range. In contrast, the control group exhibited a much slower reduction in depressive symptoms, with a higher proportion of participants still scoring in the mild and moderate depression ranges.

The SAS further supports these trends. In February, 46% of the biofeedback group had mild anxiety (scores 45–59), and 13% had moderate anxiety (scores 60–74). By May, there was a reduction in anxiety severity, with 79% of biofeedback participants falling below the clinical anxiety threshold. Meanwhile, the control group remained relatively stable, with a significant proportion still experiencing mild or moderate anxiety.

The BAI results further reinforce these findings. In February, 46% of the biofeedback group had mild anxiety (scores 22–35), while 21% experienced severe anxiety (scores above 36). By May, there was a noticeable shift, with 83% of participants who underwent biofeedback training falling into the minimal anxiety category (scores 0–21), and only 4% remaining in the severe anxiety range. In contrast, the control group showed little change over time, with 87% consistently classified in the minimal anxiety category and a small but stable percentage still experiencing moderate to severe anxiety. These results indicate that the biofeedback group experienced a substantial reduction in anxiety levels, while the control group displayed minimal improvement.

Changes in Psychological Variables over Time in Biofeedback and Control Groups

Analysis of the distribution of stress, depression, and anxiety levels at two time points (February and May) revealed notable trends within the biofeedback and control groups. The biofeedback group exhibited a significant reduction in perceived stress levels, as shown by the decreased proportion of individuals classified in the moderate and high stress categories by May. In contrast, the control group showed relatively minor shifts in stress distribution, with a greater proportion of individuals maintaining moderate stress levels throughout the study period. The chi-square test confirmed that changes over time were statistically significant within the biofeedback group ($\chi^2 = 10.2$, $p = 0.006$), suggesting a measurable improvement in stress management.

Similarly, depression scores demonstrated different patterns over time within the two groups. In the biofeedback group, a substantial number of participants shifted from moderate and severe depression categories toward minimal or borderline depression levels by May. Conversely, the control group maintained a higher proportion of participants in the mild-to-moderate depression range. Chi-square analysis indicated a significant shift over time within the biofeedback group ($\chi^2 = 15.8$, $p = 0.001$), highlighting the potential benefit of the intervention on depressive symptoms.

For anxiety measures, both the SAS and BAI scores indicated pronounced changes in the biofeedback group. Participants initially exhibiting moderate to severe anxiety showed a marked movement toward minimal anxiety levels by the end of the study. In contrast, the control group displayed minimal changes, with a stable distribution of anxiety levels. Chi-square tests confirmed significant shifts in the distribution of anxiety symptoms in the biofeedback group for both SAS ($\chi^2 = 9.03$, $p = 0.011$) and BAI ($\div^2 = 10.2$, $p = 0.006$).

Within-Group Comparisons over Time (February vs. May)

The descriptive analysis provides an overview of the psychological measures (PSS, BDI, SAS, and BAI) assessed separately within the biofeedback and control groups over time (February to May). Table 3 summarizes the changes in mean scores from February to May. Among participants in the biofeedback group, a consistent decrease in stress, depression, and anxiety levels was observed across all psychological measures. In contrast, the control group exhibited relatively minor changes, suggesting the absence of substantial spontaneous improvement without intervention. These trends were further evaluated through non-parametric statistical testing.

Table 3. Descriptive statistics and Wilcoxon Signed-Rank Test Results

Measure	Group	February Mean ± SD	May Mean ± SD	Wilcoxon W	*p*-value
PSS	Biofeedback	19.2 ± 8.11	15.6 ± 7.02	274.5	< 0.001
	Control	19.2 ± 7.25	15.6 ± 6.93	98.5	0.819
BDI	Biofeedback	14.9 ± 11.8	9.96 ± 9.01	297.0	< 0.000001
	Control	20.4 ± 12.2	17.2 ± 11.5	79.5	0.895
SAS	Biofeedback	39.7 ± 12.2	33.4 ± 9.20	298.5	< 0.000001
	Control	41.0 ± 13.5	35.2 ± 10.3	108.5	0.721
BAI	Biofeedback	18.7 ± 13.2	12.2 ± 10.2	300.0	< 0.000001
	Control	20.5 ± 13.6	16.8 ± 11.8	100.5	0.801

To determine whether the data met the assumptions of normality, a Shapiro-Wilk test was conducted for all psychological variables. The results indicated that most measures, including BDI scores at both time points, SAS scores in May, and BAI scores in February and May, significantly deviated from a normal distribution ($p < 0.05$). Only PSS scores in May and SAS scores in February demonstrated normality ($p > 0.05$). Given the overall violation of the normality assumption across key variables, non-parametric statistical methods such as the Wilcoxon Signed-Rank test were employed in the subsequent analyses (Table 3).

The results indicate a significant reduction in perceived stress, depression, and anxiety levels in the biofeedback group between February and May. The Wilcoxon Signed-Rank Test confirmed that these changes were statistically significant across all psychological measures. The decrease in stress levels, measured by the PSS, was notable, reflecting an overall improvement in participants' ability to manage stressors. Given that chronic stress is a major concern among medical students, the observed decline suggests that HRV-BF may be an effective tool for enhancing stress resilience and emotional stability over time.

DISCUSSION

The present study aimed to evaluate the effectiveness of HRV-BF as an intervention to enhance the mental health of medical students. We observed notable improvements in stress, depression, and anxiety symptoms over time within the biofeedback group, whereas the control group exhibited relatively stable patterns without meaningful change. The findings provide compelling evidence that HRV-BF training is associated with significant improvements in psychological well-being, particularly among students who participated in the biofeedback sessions. The perceived stress levels (PSS), depression (BDI), and anxiety (SAS, BAI) scores significantly decreased in the biofeedback group, whereas the control group exhibited relatively stable psychological distress levels. The reduction in distress was statistically significant, as confirmed by the Wilcoxon Signed-Rank test, reinforcing the effectiveness of HRV-BF in modulating autonomic regulation and promoting emotional resilience.

Reduction in Perceived Stress

One of the most notable findings of our study was the significant reduction in perceived stress (PSS) among participants who underwent biofeedback training. In February, 67% of students in the biofeedback group exhibited high perceived stress, but by May, none remained in this category. This suggests that HRV-BF played a critical role in reducing psychological distress, possibly through its effects on autonomic balance, as previously proposed by other studies [1]. HRV-BF has been shown to enhance parasympathetic nervous system activity, which counteracts stress-induced physiological responses [2]. Our findings align with previous studies, which indicate that biofeedback training can significantly lower stress levels in high-pressure academic settings [11].

Given that medical students face chronic academic stress, which increases their risk of burnout, emotional exhaustion, and cognitive overload, the observed reduction in PSS scores highlights HRV-BF's potential as a preventative mental health strategy. Future research should investigate whether long-term HRV-BF interventions can further sustain these stress-reducing effects beyond the 12-week training period.

Depression Symptoms

Our study found a significant reduction in depressive symptoms among participants who received HRV-BF training. In February, nearly half (46%) of students with biofeedback training scored within the moderate depression range, and 25% exhibited severe depressive symp-

toms. By May, the majority of them (50%) had shifted to the minimal depression category, and only a small percentage (8%) remained in the moderate range.

This reduction in BDI scores is consistent with prior research suggesting that HRV-BF enhances emotional self-regulation by stabilizing the central autonomic network [3]. The ability of HRV-BF to increase vagal tone and promote a relaxation response may explain why participants experienced improved mood regulation and reduced depressive symptoms after the biofeedback training. Moreover, previous studies have demonstrated that biofeedback-based interventions can be particularly beneficial for populations with high baseline stress levels, as seen in a cohort of medical students [10].

Expectedly, the control group did not exhibit the same magnitude of improvement, with a notable percentage still scoring in the mild-to-moderate depression range by May. This suggests that, in the absence of an active intervention, students may experience persistent depressive symptoms despite the natural course of the academic semester. The decline in depressive symptoms suggests that HRV-BF training may have contributed to improved emotional regulation and mood stability. Considering the high prevalence of depression among medical students, these findings reinforce the potential of HRV-BF as a non-pharmacological intervention for mental health support. Given the strong association between depression and academic performance, integrating HRV-BF training into medical curricula as a standardized mental health support tool could be a valuable strategy.

Anxiety Reduction

Anxiety levels also declined significantly among the biofeedback group at the end of the training, as indicated by SAS and BAI scores. The proportion of students experiencing moderate anxiety, evaluated by the SAS inventory, decreased from 46% to 21%, with no participants experiencing severe anxiety in May. A similar trend was observed in BAI scores, where severe anxiety cases dropped from 21% to 4%, and the majority of participants (83%) fell within the minimal anxiety range. The sharp reduction in anxiety symptoms suggests that HRV-BF training may have helped participants gain better control over physiological responses associated with anxiety, such as heightened autonomic arousal. The substantial decrease in BAI scores, in particular, points to HRV-BF's effectiveness in addressing both cognitive and somatic aspects of anxiety.

Our results confirm existing literature evidence indicating that HRV-BF improves emotional regulation by enhancing interoceptive awareness and promoting a state of physiological calmness [1]. The intervention likely increased participants' ability to control anxiety-related physiological responses, such as heart rate fluctuations, respiratory rate, and muscle tension, which are critical in reducing stress-induced hyperarousal [2].

Notably, the control group exhibited minimal change in anxiety scores, suggesting that the benefits of HRV-BF extend beyond natural semester-based fluctuations in stress levels. This finding is particularly relevant given that medical students have a disproportionately high risk of anxiety disorders, which can impair both cognitive performance and long-term career satisfaction [8].

Comparison with Existing Research and Theoretical Implications

The findings of our study align with reports demonstrating that HRV-BF is a promising intervention for reducing stress-related psychopathology in high-stress environments [11]. Moreover, the research extends existing knowledge by providing longitudinal evidence that HRV-BF's benefits persist over 12 weeks of training, suggesting that the effects are not transient but sustained.

A potential explanation for these results is that HRV-BF trains individuals to develop greater control over their autonomic nervous system, leading to more effective stress responses and enhanced cognitive flexibility [1]. This aligns with polyvagal theory, which posits that increased vagal tone enhances emotional resilience and reduces maladaptive stress responses [16].

However, it is important to acknowledge that not all participants experienced equal benefits. Some individuals may have required more time or personalized feedback to integrate biofeedback techniques into their daily routines. Future studies should explore whether customized HRV-BF training protocols (e.g., tailored breathing patterns or neurofeedback components) could enhance treatment efficacy.

Limitations and Future Directions

While our study provides valuable insights, several limitations should be considered. First, the sample size was relatively small (N = 47), which may limit the generalizability of our findings. Future research should aim to replicate these results with larger, more diverse cohorts of medical students to confirm the robustness of our conclusions.

Second, while we observed significant reductions in stress, depression, and anxiety levels, we did not assess whether these changes were associated with academic performance, sleep quality, or neurocognitive outcomes.

Given that previous studies have suggested a link between HRV-BF and improved executive functioning, future research could explore whether biofeedback training enhances learning efficiency and memory consolidation in medical students.

Third, the nature of semester-based education imposes certain limitations on the duration and consistency of biofeedback training. The academic schedule, characterized by intensive coursework, exams, and clinical practice, restricts the time available for structured HRV-BF sessions. Future studies should consider implementing training programs that align with students' academic calendars, ensuring sustained engagement and optimal benefits from the intervention.

Additionally, this study relied on self-report questionnaires to measure psychological outcomes, which may be subject to response bias or social desirability effects. Future studies should consider incorporating objective physiological measures (e.g., heart rate variability indices, salivary cortisol levels) to provide a comprehensive assessment of HRV-BF's impact on autonomic regulation.

Our findings highlight the effectiveness of HRV-BF in promoting psychological well-being and reducing distress levels over time. The significant reductions across all measured variables suggest that HRV-BF training led to meaningful and lasting improvements in mental health. Future research should explore whether these effects are maintained beyond the 12-week training period and investigate potential moderating factors such as individual differences in baseline stress levels or engagement with the intervention.

CONCLUSIONS

This study evaluated the effects of HRV-BF on perceived stress, depression, and anxiety among medical students. The findings demonstrate that HRV-BF is an effective, non-pharmacological tool for improving psychological well-being, with significant reductions in stress, depressive symptoms, and anxiety levels in the biofeedback group. The students who underwent HRV-BF training demonstrated notable improvements over time, whereas the control group exhibited relatively stable patterns. Over a period of 12 weeks, none of the participants with biofeedback training remained in the high perceived stress category, while many in the control group continued to report moderate to high stress. Depression and anxiety levels also declined more significantly in the biofeedback group, reinforcing HRV-BF's role in enhancing emotional regulation and autonomic balance. Given the chronic stress medical students face, integrating HRV-BF into academic support programs may serve as a preventative measure against psychological distress.

In conclusion, HRV-BF is a promising and accessible strategy for improving mental health in medical students. Its integration into university settings could support better stress management and overall well-being, fostering a healthier academic environment.

Abbreviations

HRV-BF - heart rate variability biofeedback
PSS - Perceived Stress Scale
BDI - Beck Depression Inventory
SAS - Zung Self-Rating Anxiety Scale
BAI - Beck Anxiety Inventory

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