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NSSEC-24

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National Social Sciences & Education Conference

06-07 July 2024

Virtual conference organized by CLM Publishing

e-IPH
e-International Publishing House Ltd., United Kingdom

Effects of Biofeedback Training on HRV, Mood State and Shooting Performance of Shooters

Huang Donghai, Muhammad Nubli Abdul Wahab*

**Corresponding Author*

Center for Human Science,
University Malaysia Pahang Al-Sultan Abdullah,26600, Pahang, Malaysia

henanhuangdonghai@aliyun.com; nubli@umpsa.edu.my
Tel: *+60 129683117*

Abstract

This study investigates the effects of biofeedback training on the HRV, emotional state, and shooting performance of athletes. Results indicate significant improvement in athletes' HRV frequency domain indices ($p < 0.05$), reduced negative emotions like tension and anger ($p < 0.05$), increased vitality and positivity, though changes in fatigue and self-emotional state weren't statistically significant ($p > 0.05$). Shooting performance significantly improved post-training ($p < 0.01$). This suggests that biofeedback training positively impacts autonomic nervous system function, emotional stability, and shooting skills. Biofeedback training significantly enhances shooting performance by improving HRV, optimizing emotional state, and strengthening emotional regulation abilities.

Keywords: biofeedback training; heart rate variability; mood state; shooting performance.

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DOI: https://doi.org/10.21834/e-bpj.v9iSI20.6100

1.0 Introduction

Psychological skills training is an essential component of modern sports training systems, significantly influencing elite athletes' daily routines and performances in major tournaments (Dagnall et al., 2021). To excel in fierce competitions, athletes need not only robust physicality, agile adaptability, and sharp competitive awareness but also strong mental fortitude (Schinke et al., 2024). Consequently, athletes, coaches, and training teams increasingly prioritize psychological adjustment abilities, recognizing them as vital for elevating competitive standards. Achieving excellence requires a balanced emphasis on both psychological and physical conditioning (Horvath et al., 2022). Based on, this study aims to explore the effects of a 12-week heart rate variability biofeedback training (HRV-BF) program on shooting athletes, focusing on its impact on performance, mood states, and HRV indicators.

2.0 Literature Review

2.1 The Role of Heart Rate Variability in Psychological Resilience and Athletic Performance.

Heart Rate Variability (HRV), encompassing heart rate reactivity or heart period variability, quantifies fluctuations in the time intervals between successive heartbeats (R-R intervals). These variations originate from electrical impulses generated by the sinoatrial node,

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which are directly influenced by the synergistic action of the sympathetic and parasympathetic divisions of the autonomic nervous system, thus serving as a critical indicator of their activity intensity (Cerritelli et al., 2021). Research demonstrates that HRV dynamically reflects an individual's state of fatigue, emotional fluctuations, and psychological adaptability under stress, acting as a crucial marker of physiological resilience and behavioral adaptability (Crameri et al., 2021). Through targeted intervention strategies aimed at modulating HRV, it is possible to effectively promote balance within the autonomic nervous system, achieving harmony between physiological and psychological states. This harmonization leads to enhanced psychological control, improved emotional stability, and superior athletic performance (Lehrer et al., 2018).

2.2 The Impact of Biofeedback Training on Heart Rate Variability, Stress Management, and Psychological Resilience

Biofeedback Training (BFT), recognized as an innovative psychological training method, empowers athletes with real-time physiological information through scientific instruments, thereby enabling self-regulation of physiological functions (Ju, F et al., 2023).Heart Rate Variability (HRV), a central monitoring metric in BFT, provides athletes with instant insights into their heart rate status, emotional stability, and concentration levels, significantly enhancing the efficacy and engagement of psychological training (Lehrer et al., 2018). In recent years, BFT has emerged as a potent complement to traditional sports psychological interventions, such as imagery training, in the athletic domain (Crameri et al., 2021). Unlike conventional approaches focusing primarily on the psychological response to stress, BFT facilitates the training of the sympathetic and parasympathetic nervous systems to achieve a balanced state, effectively addressing imbalances within the body's nervous system and enhancing psychological resilience and stress management capabilities (Cerritelli et al., 2021). Numerous studies have substantiated those athletes undergoing BFT exhibit substantial reductions in anxiety, stress, and arousal symptoms, alongside increases in HRV, low-frequency (LF) components, decreases in high-frequency (HF) components, and improvements in athletic performance, accompanied by notable enhancements in self-efficacy (Lehrer et al., 2020; Gronwaldl et al., 2020). Collectively, BFT assists athletes in regulating physiological functions, boosting HRV, alleviating stress and anxiety, reinforcing psychological stability, and comprehensively optimizing athletic performance, positioning itself as a powerful tool for augmenting the holistic capabilities of athletes.

2.3 The Role of Heart Rate Variability and Biofeedback Training in Reducing Anxiety and Improving Accuracy

In the field of shooting, Heart Rate Variability (HRV) has become an important biological marker for assessing athletes' performance (Argilés et al., 2022). Gronwaldl and colleagues' study revealed that in tactical pistol competitions, individuals with greater heart rate decreases not only completed the competition faster but also performed better, a phenomenon significantly correlated with sympathetic nervous response (Gronwald et al., 2020). Furthermore, Ortega and colleagues' research on Heart Rate Variability biofeedback training found that the experimental group outperformed the control group in LF, HF, and shooting accuracy, indicating that biofeedback training can effectively enhance Heart Rate Variability and shooting accuracy while reducing anxiety and increasing self-confidence (Ortega et al., 2018). Englert ' study pointed out that high-level shooting athletes possess stronger psychological self-control abilities, maintaining attention even when mentally fatigued (Englert et al., 2021). Park and colleagues analyzed the psychological anxiety and cortisol changes in 72 shooting athletes before the competition, finding that the severely anxious group had significantly increased cortisol secretion, indicating that psychological stress leads to physiological stress, affecting performance (Park et al., 2020).

2.4 The Impact of Exercise and Psychological Training on Emotional Well-being and Performance

Mood, an enduring emotional state influenced by external stimuli, falls into two main categories: positive and negative. Positive moods entail energy and happiness, while negative moods encompass depression, fatigue, anxiety, anger, and tension (Wei et al., 2014). Once established, mood persists and affects attitudes, behaviors, and well-being. The Profile of Mood States (POMS) measures mood, with a lower Total Mood Disturbance (TMD) score indicating a more positive state. Research by Ayar, M (2023) shows pre-competition aerobics enhances athletes' mood balance. Ramchandani, R (2024) found high-altitude training increases tension and fatigue but reduces energy. Kostrna, J (2022) discovered goal setting improves mood and basketball skills. Nien (2023) concluded muscle relaxation training benefits sprinters' moods. In essence, physical exercise and psychological training can uplift mood, enhance performance, and bolster mental health.

3.0 Methodology

3.1 Participates

The sample size for this study will be determined using priori power analysis, aiming for a power of at least 0.80 and a significance level of 0.05（Reito et al,2020）.Fifteen shooting athletes (mean age 19.13 ± 2.82 years) from the Henan Province Shooting Athlete Management Centre, comprising 10 males and 5 females with 5 ± 1.5 years of experience, were recruited. Inclusion criteria included passing a baseline POMS test, no history of psychological intervention or medical diagnoses, and informed consent. Participants completed the POMS questionnaire during the initial visit, followed by HRV biofeedback training and baseline HRV tests at the Psychological Training Laboratory. All experiments were conducted at the shooting range and psychological training laboratory.

3.2 Study Design

A total of 15 shooting athletes were given a 12-week HRV biofeedback relaxation training. The training was divided into three stages (1 stage/4 weeks) with increasing difficulty. During this period, each athlete underwent biofeedback training twice a week (on Wednesdays and Fridays). At the end of each stage, the athletes completed the POMS brief mood questionnaire. Before the formal experiment, the athletes were given two group briefings (experimental introduction, POMS questionnaire, and standard shooting performance test). After the experiment, the shooting athletes took the standard shooting performance test again. After the experiment, each athlete had a total of 24 sets of HRV feedback data, 4 sets of POMS questionnaire data, and 2 sets of standard shooting task scores. The specific steps are shown in Figure 1:

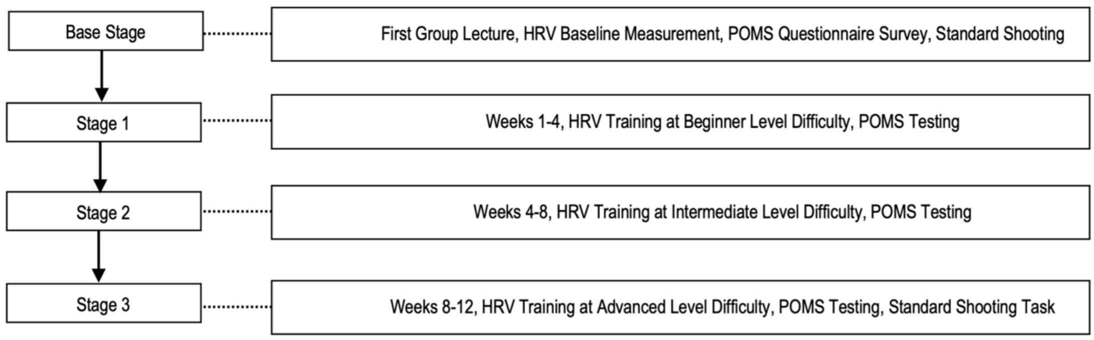

Fig. 1. experimental Procedure

3.3 HRV Biofeedback Training Protocol

The HRV biofeedback training protocol is based on Huang Donghai's patented method for 10m air rifle shooting (Malaysia Patent No.: CRLY2024C02212). In a psychological training lab, researchers use the emWave Pro software to conduct the training. Fifteen athletes create profiles and fill in their personal information. Subjects are briefed on the experimental procedures and fitted with earlobe sensors. Following Lehrer's program, athletes perform breathing exercises at various frequencies (6.5, 6, 5.5, 5, 4.5 breaths/min) for 3 minutes each, inhaling through the nose and exhaling through the mouth with extended exhalation times (Lehrer et al., 2020). Post-training, the optimal resonant breathing frequency is determined, followed by 5 minutes of breathing exercises. Athletes engage in 15-minute training games and receive printed feedback on their coordination, HRV values, and spectral data. The data is analyzed to help athletes understand and improve their physiological and psychological states (Figure 2 shows the entire training process).

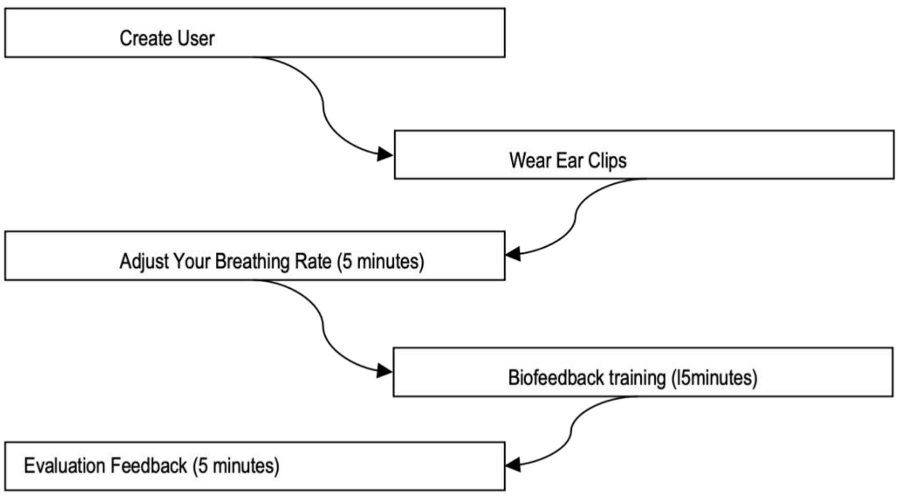

Fig.2 HRV Biofeedback Training Process

3.4 Measurement

The study was divided into three stages, with data collected four times using the POMS short-form questionnaire (Baker et al.,2002): at baseline and after each stage. Athletes performed HRV biofeedback training using the emWave Pro device, measuring TP, VLF, LF/HF, LFnorm, and HFnorm indicators. In each stage, 24 valid measurements per athlete were collected and analyzed. Additionally, 15 athletes were tested for shooting performance at baseline and post-experiment using a 10-meter air rifle task, firing 60 rounds in 75 minutes, following Olympic competition rules (International Shooting Sport Federation, 2022).

3.5 Statistical Analyses

SPSS version 22.0 (Copyright © SPSS Inc.) was utilized for data analysis. Independent samples t-tests compared baseline and experimental stages (Stages 1, 2, 3). Pearson correlation analysis examined mood states, Heart Rate Variability (HRV), and shooting performance correlations. Statistical significance was set at $p < 0.05$ for differences and $p < 0.01$ for significant differences. Linear analysis, including frequency-domain analysis (TP, VLF, LF/HF, LFnorm, HFnorm), was chosen to accurately assess athletes' psychological and physiological indicators across stages.

4.0 Findings and Discussion

4.1 Changes in HRV indicators

Table 1 shows the impact of biofeedback training on heart rate variability (HRV) in shooting athletes. Paired sample t-tests reveal significant improvements in cardiac autonomic regulation over the training stages. Notably, TP values significantly differed between stages, with stage 3 showing the most positive effect (P<0.05). Differences between stages 1 and 2 were also significant (P<0.01), indicating mid-term training benefits. However, no significant difference was found between stages 2 and 3 (P>0.05), suggesting continued training may be necessary for sustained improvements. Initial stages did not yield significant changes compared to baseline (P>0.05), highlighting the time required for training effects to emerge. Overall, these findings align with Pizzoli and Pravettoni (2021), supporting the notion that biofeedback training enhances HRV indicators (Pizzoli et al., 2021).

Biofeedback training's impact on heart rate variability (HRV), particularly the very low frequency band (VLF), in shooting athletes reveals an increasing trend in mean VLF during training, likely linked to long-term autonomic regulation responses to heart stress. While no significant VLF difference was noted between baseline and stage 1 (P > 0.05), differences emerged between stage 1 and 2 (P < 0.05), indicating potential stress reduction benefits. Despite no significant differences between subsequent stages (P > 0.05), the increase in mean VLF suggests biofeedback training's potential in mitigating long-term stress. These findings echo Rydzik and Kopa's results, underscoring biofeedback training's ability to reduce athletes' long-term stress levels (Rydzik et al., 2023). This study reinforces biofeedback training's potential in enhancing athletes' autonomic nervous system function and psychological stability, with its positive effects becoming more apparent with continued training.

The LF/HF ratio, crucial for assessing autonomic nervous system balance and emotional regulation, decreases as biofeedback training progresses. This decline in mean value suggests enhanced emotional stability and psychological recovery for athletes. While no significant difference is observed between stage 1 and 2 (MD = -2.89, P > 0.05), differences emerge between baseline and subsequent stages, confirming improved stability and recovery abilities. This aligns with Talbert and Larson's findings, supporting biofeedback training's potential in enhancing athletes' autonomic nervous system balance and emotional regulation capabilities.

LFnorm and HFnorm, crucial in HRV analysis, represent sympathetic and parasympathetic nervous system activity, respectively. In Table 1, the MD value of LFnorm decreases gradually, indicating reduced sympathetic nervous system sensitivity during training. Significant differences exist between baseline and Stage 2 (P < 0.05), Stage 3 (P < 0.01), Stage 1 and Stage 2, Stage 2 and Stage 3 (P < 0.05), and Stage 1 and Stage 3 (P < 0.01), showing biofeedback training's effectiveness in reducing sympathetic nervous system sensitivity. Conversely, the MD value of HFnorm increases gradually, with significant differences between baseline and Stage 1 (P < 0.05), Stage 3 (P < 0.01), Stage 1 and Stage 2 (P < 0.05), and Stage 2 and Stage 3 (P < 0.05), indicating enhanced parasympathetic nervous system activity during training. These changes signify athletes' progress in parasympathetic nervous system regulation capacity, supporting biofeedback training's potential in balancing the autonomic nervous system, consistent with Wang's findings (Wang et al., 2024).

Table 1. The Differences of Training Results of the Three Stages of HRV Indicators

Frequency Domain Indicators	TP		VLF		LF/HF		LFnorm		HFnorm	
Stage Comparison	MD	P	MD	P	MD	P	MD	P	MD	P
Baseline VS Stage 1	-1944.08	0.081	113.47	0.59	-0.56	0.594	0.35	0.21	-1.35	0.54
Baseline VS Stage 2	11327.85	0.53	-287.15	0.040*	-3.45	0.045*	5.47	0.036*	-3.27	0.022*
Baseline VS Stage 3	8456.31	0.031*	-536.23	0.001**	-5.33	0.000**	11.63	0.001**	-5.33	0.001**
Stage 1 VS Stage 2	13271.93	0.005**	-400.62	0.638	-2.89	0.074	5.12	0.018*	-1.92	0.048*
Stage 1 VS Stage 3	- 6512.23	0.043*	-649.7	0.375	-4.77	0.000**	11.28	0.001**	-3.98	0.000**
Stage 2 VS Stage 3	-2871.54	0.427	-249.08	0.096	-1.88	0.000**	6.16	0.011*	-2.06	0.009**

^{NS} not significant p > 0.05 * Significant at p<0.05 ** Significant at p<0.001

Table 3 presents changes in various indicators of the Profile of Mood States (POMS) for shooting athletes before and after the experiment. Through paired-sample t-tests analysis, several significant changes were observed. Firstly, significant reductions in tension, anger, and confusion emotional states (p < 0.01) at Stage 2 suggest that biofeedback training effectively reduces athletes' anxiety levels, potentially enhancing performance. Additionally, improvements in depression and vigor values (p < 0.05) indicate positive effects on mental health and vitality. Although fatigue and self-related emotional states show no significant differences (p > 0.05), the decrease in perceived fatigue and increase in self-related emotional scores imply beneficial effects on athletes' well-being. These findings align with existing research, such as Ayar, M and Nien, supporting biofeedback training's efficacy in enhancing mood states and mental health among athletes (Nien et al., 2023). Moreover, the observed improvements in self-perception and self-efficacy resonate with studies (Ferguson et al., 2020), highlighting the potential comprehensive benefits of biofeedback training in optimizing athletes' psychological states for better performance.

Table 3. Changes of POMS Indicators Before and After the Experiment

Emotional states	Baseline（M±SD）	Stage 3（M±SD）
Tension	35.37 ± 4.56	29.89 ± 5.34**
Anger	45.21 ± 9.76	37.46 ± 3.98**
Fatigue	43.65 ± 7.67	39.42 ± 6.34
Depression	47.87 ± 10.15	39.23 ± 5.97*
Energy	45.44 ± 9.45	61.34 ± 7.82*
Panic	42.56 ± 9.33	35.75 ± 8.81**
Self-related Emotions	41.23 ± 10.78	43.45 ± 8.91

NS not significant $p > 0.05$ * Significant at $p<0.05$ ** Significant at $p<0.001$

4.2 Shooting performance analysis

Table 4 analyzed the changes in shooting scores of shooting athletes before and after the experiment using paired-sample t-tests. The results indicate a significant difference in shooting scores before and after the experiment ($p < 0.01$). This finding clearly demonstrates the significant effect of biofeedback training on improving athletes' shooting performance. It suggests that through biofeedback training, athletes have experienced a significant improvement in psychological regulation, which translates into actual shooting performance, thus confirming the effectiveness of biofeedback training as an auxiliary training method. Through this training, athletes can maintain a more stable mindset during competitions, reduce the interference of negative emotions, and thereby improve shooting accuracy and overall performance. These results underscore the substantial impact of biofeedback training on shooting performance, illustrating its potential to enhance athletes' competitive capabilities. The significant improvements in shooting scores suggest that biofeedback training facilitates better psychological regulation, leading to increased accuracy and consistency. Similarly, Sut Txi et al. (2020) found that biofeedback significantly improved archers' performance by enhancing focus and emotional control. Conversely, Pizzoli and Pravettoni (2021) reported no significant improvements, attributing this to the insufficient training duration and individual differences in response to biofeedback.

Table 4. Changes in Shooting Performance Before and After Biofeedback Training

	M±SD	T value	P value
Baseline Shooting Performance	578.490±27.385	6.082	0.008**
Shooting Performance After the Experiment	588.392±25.302		

NS not significant $p > 0.05$ * Significant at $p<0.05$ ** Significant at $p<0.001$

4.3 Correlation analysis between shooting performance and heart rate variability index and mood state index

Pearson correlation analysis was conducted between shooting scores and heart rate variability (HRV) indices (TP, LFnorm, and HFnorm), as well as mood states (table 5.). The correlation between HRV indices and shooting scores revealed that TP (Total Power) is positively correlated with shooting scores ($r = 0.79$, $p < 0.05$), indicating that an increase in TP is associated with improved shooting scores. LFnorm is negatively correlated with shooting scores ($r = -0.68$, $p < 0.05$), suggesting that an increase in LFnorm may be associated with a decrease in shooting scores. HFnorm is also positively correlated with shooting scores ($r = 0.77$, $p < 0.05$), reflecting a potential relationship between increased HFnorm and improved shooting scores. Regarding mood states and shooting scores, tension is negatively correlated with shooting scores ($r = -0.74$) but did not reach statistical significance. Anger is negatively correlated with shooting scores ($r = -0.49$, $p < 0.05$), indicating that increased anger may have a negative impact on shooting scores. Depression is positively correlated with shooting scores ($r = 0.38$) but did not reach statistical significance. The correlation between mood states revealed a positive correlation between anger and tension ($r = 0.52$, $p < 0.05$), suggesting that these two emotional states may jointly influence athletes' performance. Energy is negatively correlated with depression ($r = -0.80$, $p < 0.01$), indicating that an increase in energy may be associated with a reduction in depressive mood. The Pearson correlation analysis highlights the intricate relationships between HRV indices, mood states, and shooting performance. The positive correlations between TP and HFnorm with shooting scores ($r = 0.79$ and $r = 0.77$) suggest that enhanced autonomic balance is associated with better performance, while the negative correlation of LFnorm ($r = -0.68$) points to the detrimental effect of sympathetic dominance. Similarly, Tok et al. (2020) found that higher HRV indices were linked to improved precision in archery. Conversely, Spangler et al. (2020) did not find a significant correlation between HRV and shooting performance, attributing their results to variations in training intensity and individual stress responses. Additionally, mood states such as anger and tension show significant negative correlations with shooting scores ($r = -0.49$ and $r = -0.74$), emphasizing the critical role of emotional regulation in optimizing athletic performance.

Table 5. Correlation analysis results between variable growth rates

variable	TP	LFnorm	HFnorm	Shooting Performance	Tension	Anger	Fatigue	Depression	Energy	Panic	Self-related emotions

TP	1										
LFnorm	0.08	1									
HFnorm	0.65*	-0.37	1								
Shooting Performance	0.79*	-0.68*	0.77*	1							
Tension	-0.08	0.71*	-0.63	-0.74	1						
Anger	0.17*	0.85**	-0.39	-0.49	0.52	1					
Fatigue	0.018	0.053	0.11	-0.12	-0.01	0.04	1				
Depression	-0.22	-0.37	0.70	0.38	0.07	0.01	0.42	1			
Energy	0.02	0.09	0.21	0.69	0.45	0.09	-0.80	-0.26	1		
Panic	-0.19	0.83*	-0.29	-0.75	0.34	0.59	0.52	0.07	0.36	1	
Self-related Emotions	-0.27	0.01	0.01	0.72	0.58	0.11	0.05	0.52	0.55	0.51	1

NS not significant $p > 0.05$ * Significant at $p<0.05$ ** Significant at $p<0.001$

5.0 Conclusion& Recommendations

The study demonstrates that biofeedback training (BFT) significantly enhances heart rate variability (HRV), mood states, and shooting performance among shooting athletes. BFT positively influences HRV indicators, including Total Power (TP), Very Low Frequency (VLF), LF/HF ratio, LFnorm, and HFnorm, indicating improved autonomic nervous system balance and emotional regulation. Moreover, BFT leads to reductions in negative emotions and increases in positive mood states, as evidenced by decreased Total Mood Disturbance (TMD) scores and improvements in various emotional states. Additionally, shooting performance significantly improves following BFT, highlighting its efficacy in translating psychological regulation into tangible performance gains. Correlation analysis further elucidates the relationships between HRV indices, mood states, and shooting performance, underscoring the potential of BFT in optimizing athletes' psychological and physiological well-being. However, the experimental design still has some limitations. For example, the experimental period was only 12 weeks, and no follow-up study was conducted. Whether the HRV level of athletes can still be maintained after 12 weeks needs further study; The athletes' mentality was measured using only a single scale, and the rationality needs to be further proved; The experiment was conducted on only 15 subjects, which is a relatively small number of subjects. Whether the test results are representative needs further confirmation. It is hoped that in future studies, comparisons of different populations will be added, such as whether there are differences between Asians, Europeans and Africans; and whether adding some sound and light stimulation to the experiment will be more conducive to improving the mental stability of athletes. Based on the test results, the following suggestions are given managers of shooting events should add corresponding mental training equipment to facilitate shooting athletes to observe their psychological changes at any time; coaches should add HRV biofeedback training in daily training; athletes should always pay attention to changes in their HRV indicators to adjust their mentality in order to improve shooting accuracy.

Acknowledgement

The authors would like to express their gratitude to Dr. Muhammad Nubli Abdul Wahab for their guidance and assistance in the preparation of this thesis project.

Paper Contribution to Related Field of Study

This study investigates the potential of enhancing shooting performance and alleviating psychological stress through a personalized biofeedback training program. The findings suggest broader applicability to other sports, such as diving and skiing, offering a valuable stress management tool. The results serve as a reference for coaches and sports science policies, promoting advancements in athletic training programs.

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