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Sensorimotor Rhythm (SMR) Neurofeedback Training on Anxiety: A Case Study on Archers

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Abstract

While According to some studies, the putative calming effect of EEG neurofeedback training could be useful as a therapeutic tool for anxiety. To investigate this possibility, we conducted a study to test the efficacy of eight neurofeedback training (NFB) sessions in improving anxiety symptoms and sports mental toughness in two archery athletes. The aim of the NFB training was to enhance the Sensorimotor Rhythm (SMR) wave (12 to 15 Hz), while simultaneously inhibiting theta wave (4-8 Hz) and high beta wave (22-36 Hz) at C4 over the right motor area. The reference electrode was placed on A2, and the ground electrode was placed on A1. Our study focused on two archers, Participant F and Participant V, with the goal of reducing anxiety symptoms and improving sports mental toughness. We employed a pre-post design, with the following dependent variables: (i) psychometric measures of anxiety, including the State-Trait Anxiety Inventory (STAI), Sport Anxiety Scale-2, and General Anxiety Disorder-7; and (ii) Sport Performance and Sports Mental Toughness. After completing the eight neurofeedback training sessions, both participants exhibited noticeable improvements in sports mental toughness, including enhanced confidence, constancy, and control. Additionally, symptoms related to sports anxiety, such as somatic manifestations, worry, and disruptions in confidence, as well as state-trait anxiety and generalized anxiety disorder symptoms, showed significant reductions. These findings support the effectiveness of neurofeedback training in reducing anxiety symptoms and improving sports mental toughness. However, it is essential to note that this study was a case study, and the results cannot be generalized. While the study offers valuable insights into the potential benefits of neurofeedback training for anxiety management and sports performance, further research with larger and more diverse samples is necessary to establish the broader applicability of these findings.

Keywords: Neurofeedback training, archery, human and health, sports mental toughness, anxiety.

1. Introduction

The sport of archery is a rigorous mental endeavor requiring unwavering concentration, exceptional shot consistency, and a robust capacity to navigate a variety of challenges (Li et al., 2021). The margins for error are minute; a moment's lack of focus or careless slip in technique can drastically alter the trajectory of an arrow, resulting in a missed target (Prasetyo, 2018). In the highly pressured environment of elite archery competitions, where every shot counts, archers often find themselves holding their breaths in anticipation as they release their final arrow, hoping it will strike the mark (Nuradila, 2022). The harsh reality is that a single missed shot can spell the difference between victory and defeat. Hence, the significance of mental preparedness and composure cannot be understated for archers striving for long-term success (Rahmatika, 2022). The development of mental resilience and mastery over anxiety are foundational components that warrant priority attention in the preparation of archery athletes, fortifying their performance against a myriad of factors that could potentially compromise their overall achievement (Indahwati & Ristanto, 2016; Mukhtar & Rubiono, 2020).

Emerging from the forefront of modern interventions designed to optimize performance in various spheres such as organizations and sports is neurofeedback training. Neurofeedback therapy is backed by substantial research demonstrating its efficacy in managing a wide array of mental disorders, ranging from anxiety and depression (Cheon et al., 2016) to attention deficit disorder (Arns et al., 2009), sleep disorders (Moore, 2022), and conditions that trigger headaches and migraines (Connelly et al., 2023), among other emotional disturbances (Herwig et al.,

2019). Moreover, the therapy has been found beneficial in treating individuals diagnosed with organic brain disorders, such as autism, cerebral palsy, and seizures (Grohol, 2015). Neurofeedback is chiefly concerned with modifying the brain's electrical activity, which forms the basis of emotional and behavioral functions in the human body (Heinrich et al., 2007). This approach capitalizes on the functionalities of the electroencephalogram (EEG), advances in computer technology, and the principles of operant conditioning (Swingle, 2010). Through neurofeedback, the brain is endowed with self-recognition and can change or self-regulate its electrical activity in accordance with specific treatment protocols that either reward (enhance) or inhibit (diminish) particular brainwave patterns (Coben et al., 2010). The therapy is designed to empower clients with the ability to disrupt dysfunctional neurological patterns (Belkacem et al., 2023) and cultivate more harmonious brainwave patterns (Case, 2015).

While neurofeedback has been established as a valuable tool for manipulating brain activity, the scope of influence these changes can have on behavior remains a subject of ongoing exploration. Vernon (2003) has pointed out that previous research suggests the applicability of neurofeedback in managing conditions such as attention deficit hyperactivity disorder, epilepsy, and alcoholism through the targeted training of brain activity. Nonetheless, research explicitly connecting the use of neurofeedback with enhancements in sports performance is scarce, particularly in Malaysia. Thus, there is a pressing need for more extensive investigations to ascertain the potential benefits of this training in positively influencing sports performance. The current study is designed to fill this gap, aiming to evaluate the effectiveness of neurofeedback training in enhancing the mental resilience of two sports participants and assisting them in anxiety self-regulation, with the objective of ultimately augmenting their self-confidence in sports performance.

The technique of neurofeedback (NF), or EEG biofeedback, encompasses a specific paradigm of operant conditioning in which individuals are trained to influence their brain's electrical activity, including frequency, amplitude, or synchronization (Jordanova, 2009). In this process, the brain's electrical activity is relayed to a computer, with no electrical current being introduced into the brain. This training focuses on imparting skills through the rewarding experience of inducing EEG changes that are manifested in a perceptible signal, such as light (Gong et al., 2021). This breakthrough approach facilitates the reconditioning and retraining of the brain. Neurofeedback has shown immense promise, particularly in relation to conditions marked by dysfunctional regulation of cortical arousals, such as epilepsy and attention deficit hyperactivity disorder. Other research has highlighted the potential of neurofeedback in promoting optimal performance among high-level musicians (Egner & Gruzelier, 2003) and dance performers (Raymond, Sajid, Parkinson, & Gruzelier, 2005).

2. Case Presentation

A pre-post design was applied, featuring the following dependent variables: (i) psychometric measures of anxiety via the State-Trait Anxiety Inventory (STAI), Sport Anxiety Scale-2, and General Anxiety Disorder-7; (ii) Sport Performance and Sports Mental Toughness. Prior to NFB training, a set of questionnaires consisting of the aforementioned instruments was administered to 17 archery athletes aged 12 years and older from the Kota Kinabalu District Archery Association. Based on the pre-test results, five participants were identified as scoring high in anxiety and sports performance anxiety inventory, and low in sports mental toughness. However, due to the participants' commitment to school activities, only two participants were able to complete the eight sessions of NFB training.

Consequently, this case study focuses on two volunteer archers aged 16 and 18 who have experienced sports performance anxiety and scored high in the anxiety inventory, impeding their athletic potential and overall psychological functioning, and who have completed the eight sessions of NFB training. Neurofeedback training, a non-invasive technique, is proposed as a potential intervention to address these challenges. Neither of them had previous knowledge or experience with NFB training. The parents of the participants signed the informed consent, and this study was conducted in accordance with the ethics approval from the Medical Research Ethics Committee, Universiti Malaysia Sabah (Code: JKEtika 1/21 (39)). The profile of the participants is shown in Table 1.

Table 1

Demographic Information of the Participants

Variable	Participant F	Participant V
Gender	Female	Female
Age	16	18
Athletic Background	Active participation in the zone, state and national archery sports. Focus on recurve archery.	Active participation in the zone, and state national archery sports. Focus on compound archery.
Sport Performance	Excellent sport performance	Average sport performance
Satisfaction in Sport Performance	High satisfaction	Moderate satisfaction
Sports Mental Toughness	Low scores in confidence and control and a moderate level of constancy.	Low scores in the areas of confidence, control and constancy.
Anxiety Symptoms	Frequent worry, high negative emotion and mood, fatigue, irritability, impulsivity, physical discomfort, impaired quality of sleep, and difficulty concentrating.	Frequent worry, avoidance behaviour, and impaired quality of sleep.
Sport Anxiety Symptoms	Moderate level of somatic, high worry and low confidence disruption	Moderate level of somatic and confidence disruption and high worry.

Assessment Measures

Neurofeedback Training (NFB)

The two archery athletes attended neurofeedback training (NFB) starting in January 2022, with the training concluding in early May 2022. They completed eight sessions of NFB training, totaling approximately 10 hours. The NFB training was conducted at the archery range in Likas, Kota Kinabalu, Sabah, on average once a week, with each session lasting 30 to 45 minutes. Each NFB session consisted of a three-minute baseline set, followed by 10 three-minute intervals of neurofeedback training (e.g., a video game). Neurofeedback intervals were separated by short rest periods every three minutes. The video games included Mazes, Variable-Dot-Mazes, Island, Highway, and Jump Boxes. Participants were able to select the video games they wanted to play in each session. The EEGer Neurofeedback System Device was used for the NFB training, operating on a personal laptop and computer monitor.

Before beginning NFB, the archers were interviewed to examine their anamneses, family history, and current issues. Procedures and possible side effects of the NFB were explained to the archers' parents, and informed consent was obtained. For the administered NFB protocols, the eight sessions aimed at enhancing the Sensorimotor Rhythm (SMR) wave (12 to 15 Hz) while simultaneously inhibiting the theta wave (4-8 Hz) and high beta wave (22-36Hz) at C4 over the right motor area. The reference electrode was placed on A2, with a ground electrode on A1. Many trainers, such as Margaret Ayers, the Othmers, and Lubar (Soutar & Longo, 2011), prefer to begin at the motor strip area. Othmer (2008) stated that the largest and oldest pyramidal cells are in the motor strip area, making it easiest to influence thalamic oscillators from this region. Thus, this protocol was tested to improve symptoms of anxiety and mental toughness.

Sports Performance scale

The scale contains two items. One item is to measure the participant's recent overall sports performance and the second item measures the participant's satisfaction with the current performance in sports. The participant was asked to rate on 10 points scale from 0 (Extremely unsuccessful/ Extremely unsatisfied) to 10 (Extremely successful/ Extremely satisfied).

Sport Anxiety Scale-2 (SAS-2)

The Sport Anxiety Scale-2 (SAS-2) was developed by Smith, Smoll, Cumming, & Grossbard (2006). SAS-2 is a 15-item self-report measure of cognitive (worry and concentration disruption) and somatic trait sports anxiety. Items are rated on a 4- point Likert scale ranging from 1 (not at all) to 4 (very much so). Each component consists of five items. The somatic component is measured with Items 2, 6, 10, 12, and 14; the worry component contains items 3, 5, 8, 9, and 11; and the concentration disruption component contains items 1, 4, 7, 13, and 15. Higher scores on the SAS-2 indicate higher levels of sport anxiety (Teh et al., 2022).

Sport Mental Toughness Questionnaire

The Sports Mental Toughness Questionnaire (SMTQ; Sheard, Golby & Wersch, 2009) is a self-report to determine the level of mental endurance in sports. The SMTQ consists of 14 items with responses rated on a 4-point Likert scale anchored by "not at all true" and "very true." The SMTQ contains 3 subdimension: Confidence (6 items – from items 1 to 6), Constancy (4 items – items 7 to 10), and Control (4 items – items 11 to 14).

State-Trait Anxiety Inventory

The State-Trait Anxiety Inventory (STAI) was developed by Spielberger, Gorsuch, and Lushene (1970) to measure two different components of anxiety: state and trait. State anxiety is a transitory emotional state characterized by subjective feelings or tension that may vary in intensity over time. Trait anxiety refers to a relatively stable disposition to respond to stress with anxiety and a tendency to perceive a wider range of situations as threatening (Cattell & Scheier, 1961). The STAI-S scale has 20 items that are answered on a 4-point Likert scale based on “how you feel right now, at this moment.” Half of these items are positively worded (e.g., “I feel calm”), and the other half are negatively worded (e.g., “I feel tense”). The STAI-T scale also has 20 items that are answered on a different 4-point Likert scale based on “how do you generally feel.” Seven of these items are positively worded (e.g., “I feel secure”), and the other 13 items are negatively worded (e.g., “I worry too much over something that really doesn’t matter”). One of the STAI-S factors is related to the presence of anxiety (S-anxiety present) and includes all 10 negatively worded items. The other factor of this scale is associated with the absence of anxiety (S-anxiety absent) and includes all 10 positively worded items. Similarly, the STAI-T scale has an anxiety-present factor (T-anxiety present) associated with the 13 negatively worded items and an anxiety absence factor (T-anxiety absent) associated with the seven positively worded items. However, in this case study, we employed only the present factors of state and trait anxiety.

Generalized Anxiety Disorders Scale

The 7-item Generalized Anxiety Disorders Scale (GAD-7; Spitzer et al., 2006) was developed as a screener for generalized anxiety disorder (GAD) in primary care settings. GAD-7 (Spitzer et al., 2006) consists of seven items measuring worry and anxiety symptoms. Each item is scored on a four-point Likert scale (0–3) with total scores ranging from 0 to 21 with higher scores reflecting greater anxiety severity. Scores above 10 are considered to be in the clinical range (Spitzer et al., 2006).

3. Results and Discussion

A post-test was conducted on the two participants approximately six months after the neurofeedback training (NFB). The same set of questionnaires that consisted of the State-Trait Anxiety Inventory (STAI), Sport Anxiety Scale-2, General Anxiety Disorder-7, Sports Performance and Sports Mental Toughness was administered and scored. The results before and after the NFB training were compared and presented in this section.

Sport Performance

The scale contains two items. One item measures the participant's recent overall sports performance, and the second item measures the participant's satisfaction with their current performance in sports. The items were rated on a 10-point scale from 0 (Extremely unsuccessful/Extremely unsatisfied) to 10 (Extremely successful/Extremely satisfied), with the median score being five. The results are presented in Table 2. The analysis showed that Participant F initially scored high on her overall sports performance and satisfaction, but experienced a decline to

a moderate level six months later. This decrease in performance and satisfaction could potentially be attributed to various factors such as heightened expectations, increased demands, and intensified competition.

When Participant F was a regional archery athlete, she probably faced a certain level of competition within her region. However, after being promoted to the national level, the competition likely became more intense. Athletes at the national level often face stiffer competition, competing against the best athletes from around the nation. This heightened competition can create additional pressure and pose challenges for an athlete.

Moreover, the higher expectations associated with being a national player can also contribute to the perceived decline in performance. When an athlete progresses to a higher level, there is often an expectation that their performance should continue to improve or remain consistently high. This expectation can create a significant psychological burden, potentially leading to self-doubt and anxiety, which can negatively impact performance.

On the other hand, Participant V reported improved overall sports performance and satisfaction. In Participant V's case, being a district-level archery athlete and experiencing an improvement in performance likely contributed to her increased satisfaction. As a district-level athlete, Participant V likely possessed a certain skill level and experience in archery. With focused training, consistent practice, and potentially guidance from coaches or mentors, she was able to enhance her skills and perform better in her sport. This improvement might have come from refining technique, increasing physical fitness, developing mental resilience, or a combination of these factors.

When an athlete observes tangible progress and improvement in their performance, it often leads to increased satisfaction. Seeing the fruits of their hard work and dedication can boost confidence and motivation. It also validates their efforts and serves as positive reinforcement, making them more likely to continue striving for further improvement. Moreover, the satisfaction Participant V experienced could be attributed to personal fulfillment and a sense of accomplishment. Observing personal progress from being a district-level athlete to achieving better overall performance can be immensely rewarding. This sense of growth and achievement can contribute to an overall positive outlook on sports performance and increased enjoyment of the sport.

It's important to acknowledge that individual experiences can vary, and other factors might have influenced Participant F and V's performance and satisfaction. Nevertheless, skill development, progress, and personal fulfilment likely played a significant role in the participants' experiences. Focusing on training, setting goals, and maintaining a growth mindset can help the participants sustain their improvements and satisfaction in sports performance.

Table 2

Sport Performance Results of Participants F and V Before and Six Months After Neurofeedback Training

Participants	Neurofeedback Training (NFB)	Sport Performance	
		Overall Performance Score range (1 – 10)	Overall Satisfaction Score range (1 – 10)
F	Before NFB	9	8
	After NFB	7	6
V	Before NFB	4	4
	After NFB	8	8

Sport Mental Toughness

The Sports Mental Toughness Questionnaire assessed three components: confidence, constancy, and control, with a total score ranging from 0 to 42 (with a mean of 21). In the analysis conducted, it was found that both Participants F and V initially had very low scores in total sports mental toughness and its three components before undergoing neurofeedback training (refer to Table 3).

Neurofeedback training is a form of biofeedback that aims to help individuals regulate their brain activity and improve cognitive functions. It involves providing real-time feedback on brainwave patterns and teaching individuals to self-regulate their brain activity for desired outcomes.

After eight sessions of neurofeedback training, it was observed that both participants experienced improvements in their sports mental toughness scores, with Participant V showing particularly noteworthy progress.

The specific areas of sports mental toughness, such as confidence, constancy, and control, likely exhibited improvement following the neurofeedback training. Enhanced confidence can lead to greater self-belief and a stronger belief in one's abilities to perform well in sports. Increased constancy refers to maintaining focus, motivation, and consistency in performance, which can be crucial for achieving long-term success. Improved control involves having a better sense of control over one's emotions, thoughts, and reactions during sports activities.

The neurofeedback training likely contributed to these improvements by helping the participants regulate their brain activity and enhance their cognitive functions. By learning to self-regulate their brainwave patterns, participants could potentially experience better concentration, emotional regulation, and cognitive flexibility, which are important for sports performance and mental toughness.

Table 3

Sport Mental Toughness Score of Participants F and V Before and Six Months After Neurofeedback Training

Participants	Neurofeedback Training (NFB)	Sport Mental Toughness			
		Total Score range (0 – 42)	Confidence Score range (0 – 18)	Constancy Score range (0 – 12)	Control Score range (0 - 12)
F	Before NFB	14	3	9	2
	After NFB	21	6	11	4
V	Before NFB	7	3	3	1
	After NFB	25	10	9	6

Sport Anxiety

The sports anxiety of the participants was measured using Sport Anxiety Scale-2 (SAS-2). It consisted of three components: somatic, worry, and confidence disruption. Based on Table 4, it was discovered that Participant V had high scores in all three components of the SAS-2 before undergoing neurofeedback training. After the neurofeedback training, there was a decrease in scores, particularly in the somatic and confidence disruption components. It is worth noting that the worry component's score remained high even after the training.

The somatic component of the SAS-2 measures the physical symptoms of anxiety experienced by athletes, such as increased heart rate, muscle tension, and nervousness. The decrease in somatic scores suggests that Participant V experienced a reduction in these physical symptoms after the neurofeedback training. The worry component assesses cognitive aspects of anxiety, including worry, self-doubt, and negative thinking related to sports performance. In Participant V's case, although there was an improvement in the worry components, the high score in the worry component indicated that she still experienced cognitive anxiety related to her sports performance even after the neurofeedback training. The confidence disruption component evaluates the extent to which anxiety interferes with an athlete's self-confidence and belief in their abilities. Participant V experienced a reduction to a moderate level in confidence disruption component after the neurofeedback training, indicating that after neurofeedback training anxiety has less disrupted her confidence in her sporting abilities.

Regarding Participant F, a similar pattern was observed regarding sports anxiety scores, with high scores in the somatic and worry components before the neurofeedback training. However, Participant F reported a low score in the confidence disruption component before and after the training suggesting that anxiety had a minimal impact on her self-confidence in sports.

The findings suggested that neurofeedback training may have helped both participants, particularly Participant V, reduce somatic symptoms and confidence disruption associated with sports anxiety. However, the high worry component score for Participant V and anxiety symptoms in both participants before and after training highlights the need for continued neurofeedback training and strategies to address cognitive anxiety and enhance overall sports performance.

Table 4

Sport Anxiety Score of Participants F and V Before and Six Months After Neurofeedback Training

Participants	Neurofeedback Training (NFB)	Sport Anxiety		
		Somatic Score range (0 – 15)	Worry Score range (0 – 15)	Confidence Disruption Score range (0 -15)
F	Before NFB	9	14	3
	After NFB	5	11	2
A	Before NFB	7	15	9
	After NFB	5	10	5

State-Trait Anxiety and Generalized Anxiety Disorders

The State-Trait Anxiety Inventory (STAI) and the Generalized Anxiety Disorder scale (GAD-7) were used to assess anxiety in Participant F and Participant V. The STAI measured both state anxiety (current feelings of anxiety) and trait anxiety (general disposition towards anxiety), while the GAD-7 specifically measured worry and anxiety symptoms.

According to Table 5, Participant F initially reported very high scores in both state and trait anxiety on the STAI, indicating high levels of current anxiety and a general disposition towards anxiety. Additionally, Participant F reported high scores on the GAD-7, suggesting the presence of significant worry and anxiety symptoms.

Participant V, on the other hand, reported very high scores in trait anxiety on the STAI, indicating a tendency towards anxiety as a general characteristic. Similarly, Participant V had high scores on the GAD-7, indicating the presence of worrisome and anxious symptoms.

After the neurofeedback training, both Participant F and Participant V experienced decreases in their state-trait anxiety and generalized anxiety disorder scores. For Participant F, the scores decreased to a moderate level, indicating a reduction in both current anxiety and the general disposition towards anxiety. For Participant V, the scores decreased to a low level, suggesting a significant reduction in both trait anxiety and the presence of worrisome and anxious symptoms.

These findings suggest that the neurofeedback training had a positive impact on reducing anxiety levels for both participants. It helped Participant F move from a very high level of anxiety to a moderate level, and Participant V experienced a more substantial improvement, moving from a very high level to a low level of anxiety.

Table 5

State-Trait Anxiety and Generalized Anxiety Disorders Score of Participants F and V Before and Six Months After Neurofeedback Training

Participants	Neurofeedback Training (NFB)	Anxiety		
		State Anxiety Score range (10 – 40) Median = 15	Trait Anxiety Score range (11 – 44) Median = 16.5	Generalized Anxiety Disorders Score range (0 – 21) Median = 10.5
F	Before NFB	33	37	18

	After NFB	19	24	15
V	Before NFB	13	43	21
	After NFB	13	17	4

Conclusion

The information provided suggests that after eight sessions of neurofeedback training (NFB) that targeted rewarding SMR (12-15 Hz), inhibiting theta (4-8 Hz), and inhibiting high beta (22-36 Hz), there were significant positive changes observed in the participants' sports mental toughness scores. Furthermore, the training also had a beneficial effect on reducing anxiety levels for both participants. These findings align with the notion that neurofeedback training can induce cellular-level changes in the brain, leading to improved behavioural, cognitive performance and brain functioning. It is essential to consider that the effects of neurofeedback training can vary among individuals, and additional factors such as motivation, training protocols, and individual differences can impact the outcomes. Nonetheless, the findings suggested that the neurofeedback training had a positive impact on both sports mental toughness and anxiety levels in both participants. These findings align with the general understanding of neurofeedback's potential benefits in improving brain function and psychological well-being.

Conflict Of Interest

The authors declare that they have no competing interests in the publication of this paper.

Consent

Written consent was obtained from the participants' parents to publish the case. A copy of the written consent is available for review by the Chief Editor.

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