The Investigation of Biofeedback and Neurofeedback Training on Athletic Performance-systematic Review

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Abstract

The investigation of biofeedback and neurofeedback training on athletic performance-systematic review. The present study aimed to systematically review the impact of biofeedback and neurofeedback training on sports performance. We investigated both theoretical and practical aspects of biofeedback and neurofeedback techniques. The screened articles involved athletes from various individual and team sports. Participants of the reviewed studies had different levels of experience, from novice to professional. We examined multiple devices and instrumentation (EEG, EMG, Nexus 10, telemetry, etc.) that may facilitate athletes' mental preparation. We also provided an overview of the protocols used with different monitoring devices. This study reviewed current biofeedback and neurofeedback techniques for preparing competitive athletes. Research has shown that athletes using the biofeedback method in their training routines are far more effective in terms of mental preparation than control groups. The researchers also found that the techniques used by athletes needed to be developed and adapted to more sports. This review identified different groups that could benefit from biofeedback-based interventions in sports. Interventions have generally had a positive effect on coping with anxiety.

Keywords: Biofeedback, Neurofeedback, Training, EEG, Athletic Performance.

Introduction

The enhancement of athletic performance is an ever-growing challenge in the physical and mental preparation process of athletes. Today, it is necessary to assess the outcomes of the training process regularly. High-level motor performance and acquiring skills are based on adequate brain processing (Seidel-Marzi & Ragert, 2020). “Biofeedback” and particularly “neurofeedback” are supporting self-regulation mechanisms. The Association for Applied Psychophysiology & Biofeedback provides the latest definition of biofeedback. "Biofeedback is a process that enables an individual to learn how to change physiological activity to improve health and performance" (AAPB, 2022). Like other forms of biofeedback, neurofeedback utilizes "monitoring devices to provide moment-to-moment information to an individual on the state of their physiological functioning” (ISNR, 2022). These feedback mechanisms support the enhancement of athletic performance. Mental and cognitive practices may directly influence athletes' psychological state as part of a psychological training routine. These training routines actively implement psychobiological and neurophysiological interventions (Gee, 2010). Since the 1980s, researchers have reported biofeedback techniques as one of the most effective mechanisms for developing self-regulation skills (Bar-Eli & Blumenstein, 2004; De Witt, 1980; Kendra, 2019). The biofeedback mechanism is supported by internal processes that are not generally consciously controlled (Zaichkowsky & Fuchs, 1988). Biofeedback aims to implement strategies, and techniques into relevant performance situations (Blumenstein, Bar-Eli, & Tenenbaum, 1997). There are many different pathways of the biofeedback mechanism. The effectiveness of different types of biofeedback may vary. Therapeutic implementations may differ according to individual recommendations. Nowadays, neurofeedback (EEG Biofeedback) is a widely used and popular technique among sports professionals (Ring et al., 2015; Schwartz & Andrasik, 2017). Depending on the type of physical activity, there are several neurofeedback-based training programs. These procedures may induce concentration and strengthen mental focus by altering the sensorimotor rhythm. Another beneficial effect of neurofeedback-based training protocols is diminishing anxiety and performance limitations by regulating EEG bands (alpha, theta) anxiety (Crivelli, Fronda, & Balconi, 2019; Mirifar, Beckmann, & Ehrlenspiel, 2017). Neurofeedback may efficiently trigger and maintain an individual's optimal nervous system activity and arousal (Balogh, 2020). Hans Berger created the first human electroencephalography (EEG) imaging device in the mid-1920s; since then, EEG has become one of the most widely used brain imaging procedures (Millett, 2001). Various brain functions may be effectively optimized by using “EEG-neurofeedback training (EEG-NFB)” (Chen, Ros, & Gruzelier, 2013). Regular practice of EEG-neurofeedback training may improve concentration on the task, reduce fear, increase emotional control, and enhance motor coordination.

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A high level of kinesthesis and motor control is necessary in sports such as gymnastics, combat sports, and ball sports, and in winter sports: skiing, ice skating, hockey, and snowboarding. Regular EEG-neurofeedback training may improve psychophysical balance and, thus, sports performance (Besserve et al., 2008; Kerick, Douglass, & Hatfield, 2004). The role of non-invasive procedures such as neurofeedback is to develop and acquire skills related to self-regulation of brain activity (Mirifar et al., 2017); however, it is still necessary to understand the best protocols to apply since athletes and non-athletes have different outcomes (Domingos et al., 2020), and even the noise can influence the results (Domingos et al., 2021).

The Purpose of the Study

We investigated the effect of biofeedback and neurofeedback training on sports performance. We performed a systematic review of both theoretical and practical aspects of biofeedback and neurofeedback techniques. The screened articles involved athletes from various individual and team sports. Participants of the reviewed studies had different levels of experience, from novice to professional. We examined multiple devices and instrumentation (EEG, EMG, Nexus 10, telemetry, etc.) that may facilitate athletes' mental preparation. We also provided an overview of the protocols used with different monitoring devices.

Methods

Procedures

Our analysis processed studies from team sports and individual sports, such as basketball, football, hockey, baseball, swimming, dance, shooting, athletics, fencing, golf, and karate, gymnastics. We reviewed several studies which examined different training protocols adapting various cognitive and emotional self-regulation techniques. Biofeedback and neurofeedback training may improve athletes 'performance in sport-specific tasks. We thoroughly reviewed 23 studies on the results of biofeedback and neurofeedback in sports. The use of peripheral biofeedback and neurofeedback is increasingly popular in sports psychology. It aims to alleviate competitive stress, anxiety, and muscle tension.

Data Collection and Analysis

We conducted a keyword-based search involving Pubmed, Scopus, Medline, and Google Scholar databases. The terms sport, neurofeedback, and biofeedback were used as keywords. First, we identified 71 records through database searching, then removed 44 duplicate records. We screened forty-five records and excluded 18 of them. Finally, we included 18 studies and five reports in our review (Figure 1).

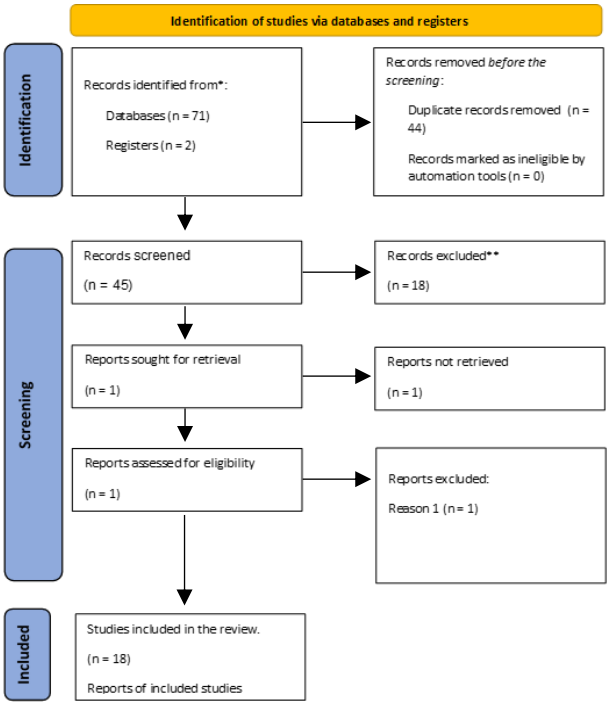

Figure 1. PRISMA 2020 flow diagram (Page et al., 2021).

Results

We thoroughly reviewed and examined the effect of biofeedback and neurofeedback techniques on sports performance. Additionally, we were interested in focusing on various sports where neurofeedback may be helpful. In the present study, 23 studies included different sports (Figure 2).

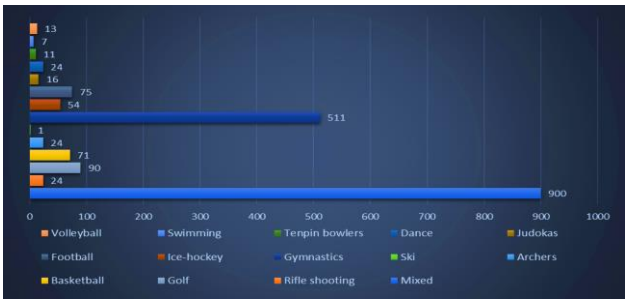

Figure 2. Distribution of Participants by Sports.

The gender ratio also varied in the studies. Most studies investigated men and women, but some looked at only one gender (Figure 3).

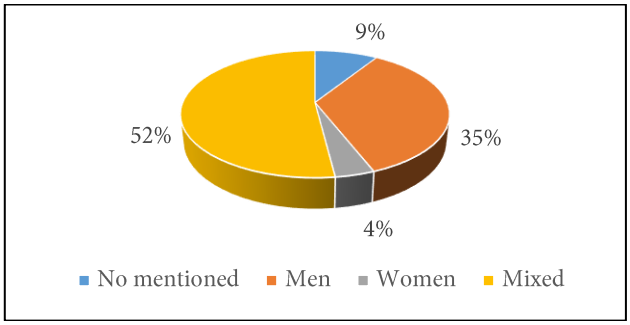

Figure 3. The Proportion of Gender Distribution.

Several studies aimed to examine whether biofeedback in the preparation period for training could improve psycho-physiological control of competing anxiety and improve athletic performance in participants or in a control group study to compare athlete behaviors in terms of athletes in the same sports. Part of it benefited from this biofeedback or neurofeedback method or not, and there is this difference in preparation and competitive outcome in favor of the methods studied. "Alpha-theta neurofeedback" has demonstrated a significant improvement in performance among regular music listeners. In recent years, researchers such as (Domingos et al., 2021; Raymond et al., 2005) focused on sports and the athletic environment. These investigations compared and evaluated alpha-theta neurofeedback with another form of biofeedback, the so-called "heart rate variability (HRV) biofeedback." We investigated a new approach to EEG NFT, specifically the so-called "function-specific instruction (FSI) approach." (Chen et al., 2013). Several studies focused on whether a single FSI protocol effectively improved "frontal midline theta (FMT) activity" and increased performance (Raza, Li Yin Ong, & Kuan, 2019). "Heart rate variability biofeedback (HRV-BFB)" is a valuable tool in treating stress in different populations. Some studies aimed to examine portable biofeedback-based stress management devices. Rhythmic breathing, "actively self-generated positive emotions," We evaluated HRV, EEG patterns, and self-reported anxiety and self-esteem measures (Dziembowska et al., 2016). Paul and Garg (2012) examined the effect of heart rate variability biofeedback training on sports performance in different disciplines. Researchers investigated whether there is a difference between training two or three times a week to increase alpha activity and improve cognition (Domingos et al., 2021). Prior studies examined the relationship between anxiety and performance in basketball and investigated the effectiveness of biofeedback protocols while coping with stress-inducing situations (Jimenez Morgan & Molina Mora, 2017). Cumming and Hall (2002) demonstrated the effects of EEG-neurofeedback training during physical training to improve mental performance and physiological parameters. Tanis (2012) suggested that heart rate variability (HRV) biofeedback training protocols coupled with emotional regulation may have performance benefits among female college volleyball players.

Discussion

In athletics, exercise and physical activity are not just a means to enhance performance. No skill and psychological differences in a high-level sporting activity determine the winner or loser. Athletes must compete in tense situations and experience excitement in responding. Biofeedback and neurofeedback interventions used, especially in sports psychology, provide two aspects of psychological interventions: technological and traditional (Mikicin et al., 2015). Other researchers investigated the use of images on the competitiveness of athletes during the off-season. The researchers analyzed the possible relationship with physical fitness. Raza et al. (2019) examined the effect of using "MUSE-EEG headband" as a training tool for neurofeedback on anxiety and performance in ten-pin bowling. A study evaluated the effect of biofeedback training on physiological (EEG) and behavioral interventions in semi-professional athletes (Ferguson, Hall, & Divine, 2020). Zadkhosh, Zandi, and Hemayattalab (2018) investigated the impact of neurofeedback training versus mindfulness techniques on performance in football players. They found that properly executed neurofeedback training may be a viable alternative to reduce anxiety under pressure. Çelik and Sarı (2022) conducted a study involving competitive archers. The researchers investigated the effectiveness of neurofeedback training on archery performance. They also examined the return of athletes to certain sports using neurofeedback techniques. Research findings have demonstrated that biofeedback and neurofeedback positively affect the mental preparation of athletes. Researchers suggested that experimental group participants successfully controlled their psycho-physiological parameters more than their control group counterparts (Pusenjak et al., 2015). In several studies, the results demonstrated a significant improvement in selected parameters after neurofeedback training. Rostami et al. (2012) conducted a study examining the performance of rifle shooters using neurofeedback training. An in-depth analysis of the participants' EEG profiles demonstrated an average of 25 percent increase in performance. Statistical analysis showed differences in response time, concentration, heart rate variability, and respiratory rate among professional shooters. Studies demonstrated that athletes developed high self-regulatory abilities after implementing biofeedback techniques. Olympic-level athletes using biofeedback significantly correlate their self-regulatory abilities and world rankings.

Professional gymnasts using "SMR and HRV biofeedback training" demonstrated improved performance, especially in balancing ability. We observed changes in baseline brainwave activity and compared the pre- and post-test data. Still, the changes are difficult to interpret because they occurred in the "beta band," which was not part of the reward (SMR) and was not inhibited (theta) in the neurofeedback training protocol. In ice hockey, the results

demonstrated that all participants of the study reduced their respiration rate to meet the goal of 6 breaths/minute and reduced the number of breaths during the final performance evaluation compared to the initial measurement. Perry, Shaw, and Zaichkowsky (2011) found an increased shooting accuracy in standing and passing puck conditions. The researchers experienced a significantly reduced mean anxiety score only in the intervention group but not in the control group. Participants in the biofeedback group demonstrated statistically significant improvements in heart rate variability measures. We observed changes in the performance "spectra of theta and alpha brain waves" and alpha asymmetry. In the biofeedback-trained group, we may also experience improved self-control of the central nervous system and flexibility of the autonomic nervous system. Stress management techniques based on HRV biofeedback may help reduce stress in young male athletes (Dziembowska et al., 2016).

Maszczyk et al. (2018) conducted a study involving EEG and dynamic balance tests before and after the final workout. Statistical analysis showed that the EG group's dynamic equilibrium scores improved significantly during the post-test. The study provided evidence for the positive effect of neurofeedback training on the dynamic balance of judoka. Results of related literature support that HRV BFB protocols are beneficial for anxiety management. It seems that various HRV BFB techniques reduce anxiety, and thus, there appears to be a possible relationship between HRV BFB and performance optimization (Paul & Garg, 2012). In football, results demonstrated improved sports performance scores and reduced anxiety measures. The improvement was significant in the neurofeedback group rather than the control group. In addition, the biofeedback group showed a more substantial improvement in sports performance scores and decreased anxiety scale scores (Arns et al., 2008).

Cumming and Hall (2002) found significant differences between the mindfulness and neurofeedback groups on the sports anxiety scale. ANOVA tests showed differences depending on the qualification and skill level of the athlete in the use of images during the off-season and physical and technical preparation seasons. Specifically, athletes at the national level performed significantly more imaging than at the regional level, regardless of function, physical fitness, or technical skills. In addition, correlational analysis showed that highly- skilled athletes tend to use more images during the off-season. The EEG-MUSE neurofeedback training experiment showed higher performance scores in bowling athletes than in the control group (Raza et al., 2019). In trained athletes participating in individual sports (fencing, swimming, athletics, skiing), the training routine increased the alpha and beta1 performance at rest with closed eyes. In contrast, participants in the trained group performed at the same level in all frequency bands as the members of the control group. Subjects in the control group demonstrated a decreased beta one band performance in the second measurement compared to the first (Pop-Jordanova & Demerdzieva, 2010). Professional golfers performing neurofeedback training were able to lower their high frontal alpha power before hitting a putt. In the neurofeedback training group, elevated cortical activity, could not selectively elevate performance because both groups similarly improved their stroke performance. In these cases, statistical analysis demonstrated a significant difference in pre-competition mental level, pre-competition excitement level, post-competition excitement level, and SMR / theta ratio (Arns et al., 2008). Mikicin et al. (2020) conducted a study on the effect of EEG-neurofeedback training on the endurance performance of competitive swimmers. The researchers measured an average of 55 ml/kg/min and above the maximal aerobic capacity value, significantly increasing the effect of specific EEG-neurofeedback interventions (Mikicin et al., 2020). Overall, qualitative analyses have revealed several benefits of biofeedback training. Research has demonstrated that these interventions may reduce physical and mental stress, improve cognitive performance, and enhance physical fitness. (Zadkhosh et al., 2018).

Conclusions

Biofeedback interventions help manage anxiety. They provide more effective screening, understanding, and control of physiological factors. However, we highlighted that further research is needed among athletes on specific health issues. This study reviewed current biofeedback and neurofeedback techniques for preparing athletes to compete at a higher level. Previous studies provided evidence that athletes using the biofeedback method in their training routines are far more effective in terms of mental preparation than control groups. Researchers also found that the techniques used by athletes needed to be developed and adapted to more sports. Our study may benefit researchers and practitioners in mental health care, developing specific interventions. We provided an overview of various biofeedback-based psychological interventions and treatment approaches, including music therapy. We examined the different anxiety treatment methods, including pulse and respiration monitoring

and physical activity. We presented data using electroencephalography (EEG) and electromyography (EMG). This review identified different biofeedback-based techniques in sports. These interventions have generally had a positive effect on coping with anxiety.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study. Written informed consent has been obtained from the athletes to publish this paper.

Data Availability Statement: The data used in the study were stored on data storage devices and paper.

Conflicts of Interest: The authors declare no conflict of interest.

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