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REVIEW ARTICLE

Impact of Biofeedback Training on Athletic Performance and Mental Well-Being

Biyolojik Geri Bildirim Eğitiminin Atletik Performans ve Mental İyilik Hali Üzerindeki Etkisi

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ABSTRACT

This study employs a systematic review approach to evaluate the effects of biofeedback (BFB) methods on athletic performance and psychological well-being. In accordance with PRISMA guidelines, TR Index, Web of Science, Google Scholar, and PubMed were searched for studies published between 2000 and 2024; of 88 identified papers, 24 met the inclusion criteria for qualitative analysis. The interventions examined included electromyography (EMG), electroencephalography (EEG), electrodermal activity (EDA), heart rate variability (HRV), thermal feedback, and isokinetic dynamometry. These methods were found to reduce muscle tension, enhance autonomic nervous system balance, improve mental focus, and facilitate stress regulation. Specifically, EMG-based feedback supported motor learning by increasing muscle strength and proprioceptive awareness, while EEG-based neurofeedback enhanced performance consistency and mental endurance under pressure. EDA and HRV protocols effectively modulated stress-induced physiological responses, and thermal feedback bolstered relaxation strategies. Although the findings underscore BFB's role as an interdisciplinary tool for optimizing athletes' physical and psychological processes, further large-scale, longitudinal studies are necessary to confirm its long-term efficacy and to develop sport-specific application protocols.

Keywords: Biofeedback, performance, sport

ÖZ

Bu çalışma, sistematik derleme yaklaşımıyla biyolojik geri bildirim yöntemlerinin atletik performans ve psikolojik iyi oluş üzerindeki etkilerini değerlendirmeyi amaçlamaktadır. PRISMA kriterlerine uygun olarak TR Index, Web of Science, Google Scholar ve PubMed'de 2000-2024 yılları arasında yayımlanan 88 çalışmadan 24'ü niteliksel analize dahil edilmiştir. İncelenen modüller arasında elektromiyografi (EMG), elektroensefalografi (EEG), elektrodermal aktivite (EDA), kalp atım hızı değişkenliği (HRV), termal geri bildirim ve izokinetik dinamometre kullanımı yer almış; bu uygulamaların kas gerginliğini azalttığı, otonom sinir sistemi dengesini güçlendirdiği, zihinsel odaklanma ve stres yönetimini iyileştirdiği saptanmıştır. EMG tabanlı geri bildirim motor öğrenmeyi destekleyerek kas gücü ve proprioseptif farkındalığı artırırken, EEG tabanlı nörolojik geri bildirim yüksek baskı altında performans tutarlılığını ve zihinsel dayanıklılığı geliştirmiştir. EDA ve HRV çalışmaları stres kaynaklı fizyolojik tepkileri düzenlerken, termal geri bildirim rahatlama stratejilerini desteklemiştir. Bulgular biyolojik geri bildirimin sporcuların fiziksel ve psikolojik süreçlerini optimize eden disiplinlerarası bir araç olduğunu gösterse de, uzun dönem etkinlik ve branşa özgü protokollerin doğrulanması için geniş örneklemli, uzunlamasına çalışmalar gerekmektedir.

Anahtar Sözcükler: Biyolojik geri Bildirim, performans, spor

INTRODUCTION

In recent years, extensive research has been conducted on various training methods aimed at enhancing athletic performance. Particularly, strength training exercises increase the capacity of muscles to contract against resistance and generate power to overcome it, thereby providing athletes with a higher level of strength advantage. Increasing muscle strength through regular training has become a crucial goal of sports scientists [1].

For athletes to perform at their best under high pressure, managing stress and anxiety effectively is crucial.

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However, even in such situations, skilled athletes may face performance issues and fail to fully realize their potential [2]. Therefore, an elite athlete aiming to maximize performance must learn to adapt not only to the effects of intense training loads but also to mental and psychological factors [3]. In this context, methods used in biological feedback training guide athletes to monitor their physiological and psychological states in real time.

The biological feedback method involves the integration of various techniques, which can be named as EMG (electromyography), EEG (electroencephalography), and EKG (electrocardiography), among others. Different techniques are also used within this perspective in sports and exercise science [4]. However, these methods also have some shortcomings, including individual differences, the separation of psychological and physiological effects, and limited data supporting long-term efficacy. These shortcomings can limit the ability and applicability of biological feedback techniques to provide universally valid results.

This review aims to identify the effective application areas of the targeted biological feedback methods, emphasize their impact on performance enhancement and psychological well-being, bring together existing research to highlight the gaps, and develop a strong foundation for future studies by gaining a more detailed understanding of the contributions of biological feedback techniques to sports performance.

Conceptual Framework

Biofeedback

Biological feedback is a system that provides information to evaluate the individual's condition by producing auditory or visual signals using electronic devices related to the person's physiological states [5]. Officially, biological feedback was defined by The Association for Applied Psychophysiology and Biofeedback (AAPB), representing the field, as "a process that enables an individual to learn how to change their physiological activity to improve health and performance." Through sensitive devices, information about an individual's physiological activity is measured and relayed quickly and accurately to the individual as "feedback," allowing the desired physiological changes to occur. Subsequently, the individual can adopt these changes and maintain the desired state without the device [6].

Biological feedback is a technique that enables individuals to consciously regulate various physiological processes of the body. Since Hans Berger's first electroencephalography (EEG) recording, the measurement, analysis, and regulation of the brain's electrical activity have been referred to as Neurofeedback (NFB) [7]. The importance of NFB in sports lies in the belief that psychological factors affecting athlete performance, such as high self-awareness, stress management, self-regulation, positive insight, and positive self-talk, can be developed through NFB [8]. In biofeedback training, sensors attached to various parts of the body gather internal data, and feedback is provided to individuals. This data is presented using stimuli such as screens, sound, or light, allowing individuals to observe and regulate their internal dynamics [5].

The biological feedback method adopted from the field of psychophysiology is believed to help athletes reach optimal mental and physical performance levels through the proper application of techniques. This adaptation enables athletes to achieve their best physical and mental states, thus assisting in maximizing their performance [9]. It is a method that directly monitors and analyzes the interaction between mental and behavioral activities and physical events by using electrodes and special sensors, providing feedback to teach individuals how to regulate their behavior [10]. Through biological feedback, individuals can observe changes in their bodies related to their emotional states (e.g., sweating during stress or increased heart rate when excited), and the relationship between these conditions can be revealed. This provides the individual with the information to evaluate the process in terms of their emotional and physical states [11].

The concept of biological feedback, introduced in the 1960s, is crucial for studying the harmony between the mind and body. It is used not only to change behaviors by providing feedback from physical movements but

also seen as a form of applied psychophysiology [12]. Significant studies have been carried out in this area, and it has been demonstrated to serve as a clinical tool when integrated with neurological feedback [13].

The Effect of Biological Feedback on Sports Performance and Psychological Well-Being

Biological feedback contributes significantly to reducing the effects of stress through relaxation techniques or training that changes the activity of the target organ, helping individuals maintain their health and improve their performance [14]. Through these trainings, individuals gain better control over their physiological states, improving their self-management skills. These self-regulation abilities not only enhance their personal health and abilities but also positively affect their social lives, allowing them to perform their societal roles more effectively and successfully [5].

The self-regulation skill developed through biological feedback helps athletes become stronger and more balanced, reduces anxiety levels, enables better preparation for competition, improves their ability to cope with challenges, and enhances their endurance, decision-making speed and accuracy, and performance [15]. Wildgoose showed in his study that athletes with high internal discipline perform better in sports [16]. Therefore, helping athletes develop self-regulation skills to achieve higher physical and mental capacities is essential for increasing their success and sustaining long-term performance, as these skills need to be strengthened for athletes to be at their best. In this regard, biological feedback applications help athletes increase their awareness of their bodies through the training and feedback they provide, enabling them to manage both their mental and physical processes in a more mindful manner, ultimately improving their performance through the acquisition of self-regulation skills [17].

Biological feedback training, which is highly beneficial for athletes, helps prevent the sympathetic nervous system from becoming overly active when a person experiences stress or anxiety, enhancing the stability of the autonomic nervous system. This training not only helps athletes cope with stress and anxiety but also teaches them how to effectively manage their autonomic and somatic nervous systems [18]. As a result, athletes can remain calmer and more focused in challenging competitive environments, enhance their performance and lower the likelihood of injury. Based on research, training programs that allow coaches and athletes to analyze and monitor performance in real time, making necessary adjustments to achieve desired results, play an important role in helping individuals gain better self-awareness, increase their mindfulness, and balance their current state [19].

Biological feedback and neurofeedback are founded on the concept that every change in the body is parallel to mental activities and emotional responses. As training progresses, athletes can learn to self-regulate according to their goals [20]. These approaches offer an important method for athletes to optimize their performance and enhance their psychological resilience.

By the early 2000s, research expanded further with the use of various biological feedback methods across different sports disciplines. Studies began to focus not only on muscle tension in the body but also on skin response, respiration, and heart rate variability [21]. In Turkey, studies on the effect of biological feedback training on sports performance are limited, but research in this field is increasing globally. In addition to measuring muscle responses through biological feedback training, different parameters have been explored [22]. In Turkey, studies investigating the effects of biofeedback training on athletic performance initially focused on muscle activity via EMG, biofeedback applications in sports have expanded to include heart rate variability (HRV), respiratory rate, galvanic skin response (GSR), body temperature, and brainwave activity (EEG). For example, one study reported that HRV biofeedback training led to significant improvements in performance test results among basketball players [23]. Another randomized controlled trial with international tennis players found positive effects of ten biofeedback sessions on physiological, psychological, and cognitive functions [24]. These findings highlight the growing relevance and potential benefits of biofeedback interventions in Turkish athletic populations.

Perceptual and cognitive skills that affect athletic success are crucial for predicting opponent movements and making quick decisions to gain an advantage. These skills can be developed through methods such as biological feedback [25]. The importance of detecting athletic performance and the mental and emotional aspects of behavior during a sports competition is significant. Research shows a strong statistical relationship between mental preparation and olympic rankings [26]. Through biological feedback training, athletes undergo an important training process to gain the skills necessary to manage competition-induced stress [24].

Biological Feedback Tools and Application Methods

In order to clarify the functional distinctions among the technological tools used in this study, a theoretical differentiation must be made between systems that provide real-time feedback and those designed solely for measurement and evaluation purposes. This distinction is particularly important when assessing the effects of biofeedback applications on performance enhancement and psychological resilience. Biofeedback training represents a holistic approach that enables individuals to recognize signals from their bodies and mental processes and to guide their performance accordingly. By allowing for the monitoring of both physical and psychological development, this method enhances athletes' abilities to self-assess and regulate their responses, promoting a more consistent and effective progression toward their goals. Findings in the literature suggest that such applications contribute not only to performance improvement but also to the development of stress management skills and psychological resilience. In this context, biofeedback systems can be considered to play a critical role in athletic development by addressing both physiological and psychological dimensions [18].

Electroencephalography (EEG) Feedback

Today, a neurologist studying electroencephalogram (EEG) is benefiting from the developments made over the past 75 years in the recognition, recording, visualization, and analysis of cortical electrical activity in EEG [27].

Electroencephalography is a method based on the training of brain waves, which are categorized according to their frequencies. Neurofeedback, as a technique, allows individuals to consciously control their brain waves and involves the recording of EEG during neurofeedback therapy [28]. During neurofeedback therapy, data is collected via EEG, and feedback on psychological and physiological processes is obtained using the principles of biological control theory [29]. Brain waves are signals that result from the brain's neurochemical activities and represent low-frequency electrical activity [30]. Brain waves occur at different frequencies and are classified using classic names such as delta, theta, beta, alpha, and gamma through EEG bands [31]. These 'brain waves' span a broad frequency range, from less than 1 Hz to over 60 Hz. It has been established for a long time that they change with mental states [32].

Electromyographic (EMG) Feedback

The foundation of muscle biofeedback training is to provide individuals with information about tension in a specific muscle area and facilitate their learning to control this by relaxing excessive and inappropriate tension [33]. Muscle contractions are monitored, but instead of directly measuring muscle contractions, this technique evaluates the electrical correlations of the muscles, and these data can be detected using surface electrodes and read in electrical units [34]. However, the effectiveness of this method can vary depending on factors such as individual differences, sensor sensitivity, and the suitability of feedback types. Signals emitted by muscles are transmitted to the user through a visual display or auditory signal corresponding directly to the level of activity, providing feedback through a polygraphic-style line or color interpretation [35].

One of the goals of EMG training is often to establish criteria. For example, muscle tension above 2 microvolts is considered relaxed, tension between 1 and 2 microvolts is considered mild relaxation, and values below 1 microvolt are regarded as deep relaxation [36]. Based on these criteria, athletes can monitor and manage their muscle tension, enabling them to reach the targeted relaxation levels, which helps reduce muscle tension,

cope with stress, and improve their overall performance.

Electrodermal Activity (EDA) Feedback

Galvanic skin response, also known as skin conductivity (EDA), is measured through the fingers and reflects the skin's electrical conductivity [37]. Stress, emotional arousal, and other psychological factors are often associated with changes in skin conductivity, linked to an increase or reduction in the fluid output from sweat glands. These changes are detected through electrodes used to measure electrodermal activity; electrodermal activity feedback can help individuals monitor their skin conductivity through visual or auditory feedback and optimize a desired emotional state or stress level. By monitoring skin conductivity, it can assist individuals in regulating their emotional state [38].

In feedback therapy and emotional state monitoring, such as when an individual is in a stressful situation or feels anxious, an increase in skin conductivity can be observed. Measured through an electrodermal activity sensor, this can help determine the person's stress level and apply appropriate stress management techniques [39].

When athletes' arousal levels rise, increased sympathetic activity leads to more moisture being released from sweat glands, which increases electrodermal activity and proves effective in determining the athlete's emotional regulation ability [40]. When an athlete experiences a change in emotional state or an increase in anxiety, skin conductivity can be rapidly affected [41].

Heart Rate Variability (HRV) Feedback

Sudden changes in sinus rate or fluctuations in the average heart rate during a particular time frame can be explained by heart rate variability (HRV), which can be described as the presence of these fluctuations in a coherent manner [42]. The most commonly used measurements in HRV assessment are SDNN (Standard Deviation of NN Intervals) and RMSSD (Root Mean Square of Successive Differences) and HRV (Heart Rate Variability) typically decreases at high heart rates, making SDNN standardizable against this effect by dividing the RR (Intervals between successive R-waves on the ECG) interval [43]. This includes teaching the athlete to control their breathing rate and pattern, which encourages more parasympathetic nervous system activation and helps improve sympathetic-parasympathetic balance [44]. The effectiveness of breathing exercises and biological feedback techniques can significantly improve athletes' stress management and overall psychology, positively contributing to their performance [45]. Research has shown that regular breathing exercises and feedback applications help athletes manage both physical and mental stress by optimizing their nervous system balance [21]. Consequently, applying these techniques is crucial for improving athletes' overall performance and managing stress.

Heart rate variability training has proven to be beneficial for athletes in managing pre-competition anxiety, reducing stress, increasing self-confidence, maintaining emotional balance, and improving performance [46]. In this context, heart rate variability (HRV) training not only facilitates the regulation of psychological states but also enables conscious control over physiological responses. One of the key factors in improving HRV is respiratory rhythm. Therefore, regulating breathing plays a central role in HRV-based interventions. Through respiratory sensors, an individual's breathing rate and depth can be monitored, providing athletes with physiological awareness and supporting the development of self-regulation skills [47].

A respiratory sensor measures an individual's breathing rate and determines the relative depth of their breath, providing a detailed analysis of respiratory activity. It can also be worn over clothing [48]. This enables a clearer understanding of how breathing influences heart rate and examining the relationship between breathing and factors such as stress levels, physiological responses, and emotional states. These technologies can help athletes and individuals improve stress management and overall well-being through respiratory regulation, thereby creating positive effects on performance and lifestyle.

Thermal Feedback

Thermal feedback is generally the process of converting changes in skin temperature, typically in the fingers and hands, into auditory or visual signals [49]. After sensors are placed on the skin, temperature data is read and reflected in real time for analysis, and the processed data is finally presented visually or audibly. For example, information is conveyed to the user through color changes on a screen or different sounds from a sound device [50]. During measurement, stress can lead to sympathetic nervous system activation, causing peripheral vasoconstriction, which in turn lowers body temperature, and skin temperature values are divided into specific ranges. For example, a temperature between 18-21°C represents high sympathetic activation, while 32-35°C represents low sympathetic activation [51]. In this context, thermal feedback technology can be considered effective for stress management and monitoring physiological responses, as the data helps users better understand and control their stress levels.

Isokinetic Dynamometer

Isokinetic dynamometry is a method of testing and exercising that evaluates torque production of limb muscles at a constant angular velocity. The system adapts to the force exerted by the individual while maintaining a pre-set movement speed, allowing for the assessment of both concentric and eccentric muscle contractions [52]. t is commonly utilized in post-operative or post-injury rehabilitation to compare the strength of the affected limb with the unaffected side [53]. Such evaluations can serve as reference points in clinical decision-making processes, such as determining readiness to return to sport [54]. Compared to isometric tests, isokinetic assessments provide more comprehensive data by analyzing muscle performance throughout the entire range of motion [55]. Additionally, software-assisted biofeedback during testing offers real-time information to both the clinician and the patient, enabling detailed analysis of parameters such as peak torque, endurance, and agonist-antagonist ratios. Even in individuals with low muscle strength, torque analysis can be performed by comparing passive and active measurements [56].

Manual muscle testing (MMT) and hand-held dynamometry (HHD) may not always be sensitive enough to detect muscle strength deficits [57]. Isokinetic dynamometers are among the most expensive strength assessment tools and require reconfiguration for each joint tested, making them less practical for large-scale or multi-joint evaluations. In such cases, referring patients to specialized physiotherapy clinics may be necessary [58]. For broader assessments involving multiple joints, more feasible and accessible methods such as MMT, HHD, or quantitative muscle analysis (QMA) are often preferred by clinicians [59].

Isokinetic dynamometers offer immediate visual and auditory cues during assessments, enabling individuals to exert their full effort. This real-time feedback plays a critical role in accelerating proprioceptive recovery, particularly in athletes rehabilitating from anterior cruciate ligament (ACL) reconstruction. According to Wang et al. (2023), such feedback mechanisms led to a 30-40% improvement in knee flexion and extension strength and enhanced kinesthetic awareness by more than 30%. These benefits contribute to increased motivation and self-confidence, as athletes gain better control over voluntary muscle contractions [60].

Studies utilizing electromyographic biofeedback (EMG-BF) have demonstrated that enhancing motor unit activation can lead to significant improvements in quadriceps muscle strength in athletes. According to Alonazi et al. (2021), strength training supported by EMG-BF resulted in a statistically significant increase in muscle strength by the fourth week compared to the control group ($p = 0.0008$). These systems provide real-time visual or auditory feedback on muscle contraction levels, promoting conscious muscle engagement. This not only contributes to improvements in muscular strength but also enhances the athlete's psychological sense of control during exercise by reinforcing the feeling of "I am in control." [61].

The feedback mechanism provided by isokinetic dynamometers facilitates athletes' focus on performance not only at the physical level but also cognitively. Thompson (2025) argued that such feedback accelera-

tes motor learning and contributes to greater consistency in performance outcomes. Furthermore, the author noted that in isokinetic mode, torque and power outputs exhibit a high degree of correlation, which may reduce cognitive load during measurement. This reduction, in turn, allows the effects of feedback to be perceived more distinctly [62].

Biological Feedback Applied in The Field of Sports Sciences

The highly competitive environment of sports is directly linked to financial rewards, indicating that athletic success has become even more significant. Therefore, enhancing athletes' psychological resilience and mental toughness has become a frequently emphasized necessity in studies [63]. Research in the field of sports highlights the importance of improving not only the physical capacities of athletes but also their mental resilience. This means that athletes can make a significant difference both on the field and beyond in their personal development and performance.

Moreover, the application of various psychological strategies and techniques can help athletes cope with mental challenges and optimize their performance [64]. In this context, integrating mental training, stress management, and psychological support programs can have positive effects on both the athletes' performance and their overall quality of life.

Today, it is necessary to approach athletes' training in a more holistic context. From this perspective, using advanced technology, biological data can now be collected from athletes [65]. Perceptual-cognitive abilities, such as attention, memory, time perception, and sensory coordination, have a significant impact on athletic success. These skills can help athletes predict their competitors' moves and make quicker and more accurate decisions. The development of these abilities is vital for athletes as it reduces anxiety and enhances the ability to understand and appropriately respond to their opponents' strategies. This skill development can be facilitated through biofeedback interventions [66].

MATERIAL AND METHODS

Research Model

This study was designed as a systematic review. A systematic review is a type of literature review that aims to answer a specific research question by systematically searching, appraising, and synthesizing all relevant studies in the field according to predefined criteria. Only studies that meet certain quality standards are included, and their findings are combined to generate a comprehensive synthesis (67). In this review, the methodology was conducted in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines.

Research groups

As part of the literature review, the databases TR Index, Web of Science, Google Scholar, and PubMed were systematically searched for publications between 2000 and 2024. The search strategy utilized both Turkish and English keywords related to biofeedback and sports performance (e.g., "biofeedback," "heart rate variability," "electrodermal activity," "EEG," "EMG," "sports performance," "psychological well-being," and their possible synonyms) in various combinations. Appropriate filters (such as publication year and subject area) were applied to narrow down the results, and the reference lists of the identified articles were also manually screened.

In this systematic review, studies published in the field of sports sciences that investigated the effects of biofeedback methods on athletic performance and psychological well-being were included. In total, 88 studies were examined: 11 from TR Index, 34 from Web of Science, 30 from Google Scholar, and 13 from PubMed.

The studies were evaluated according to predefined inclusion and exclusion criteria. The inclusion criteria were as follows: (1) participants comprised healthy athletes or sportspersons (excluding clinical populations); (2) the study included a biofeedback intervention (e.g., EMG, EEG, heart rate variability, electrodermal activity) investigating effects on performance or psychological well-being; (3) the study was conducted using an experimental or quasi-experimental design (e.g., controlled

trial, randomized controlled trial, pre-test/post-test design); (4) the article was an original research paper published in a peer-reviewed journal and accessible as a full text; (5) the publication was in either Turkish or English.

The exclusion criteria were as follows: (1) studies in which the participant group consisted solely of clinical populations; (2) case reports or studies involving biofeedback interventions with a single participant; (3) editorial articles, commentaries, or review papers that did not present original data.

According to these criteria, an initial screening was conducted at the title and abstract level, followed by a detailed review of the full texts of the eligible studies. Ultimately, only studies meeting all inclusion criteria were included in the review. The detailed flow of the study identification, screening, eligibility, and inclusion process is illustrated in Figure 1.

Data Collection Tools

The data for this study were collected by exploring pertinent keywords and their corresponding English terms and synonyms in TR index, Google Scholar, Web of Science, and PubMed databases. These tools were used to identify and review the most pertinent studies related to biological feedback and its impact on athletic performance and psychological well-being.

Ethics Approval

Since this study is a literature review, it does not require ethics committee approval. The study relies on previously published research and does not include the gathering of new data from human participants.

Collection of Data

As part of the literature review, the TR Index, Web of Science, Google Scholar, and PubMed databases were systematically searched for publications dated between 2000 and 2024. The search strategy utilized both Turkish and English keywords related to biofeedback and sports performance (e.g., "biofeedback," "heart rate variability," "electrodermal activity," "EEG," "EMG," "sports performance," "psychological well-being," and their possible synonyms) in various combinations. Appropriate filters (such as publication year and subject area) were applied to narrow down the results, and the reference lists of the identified studies were also manually screened.

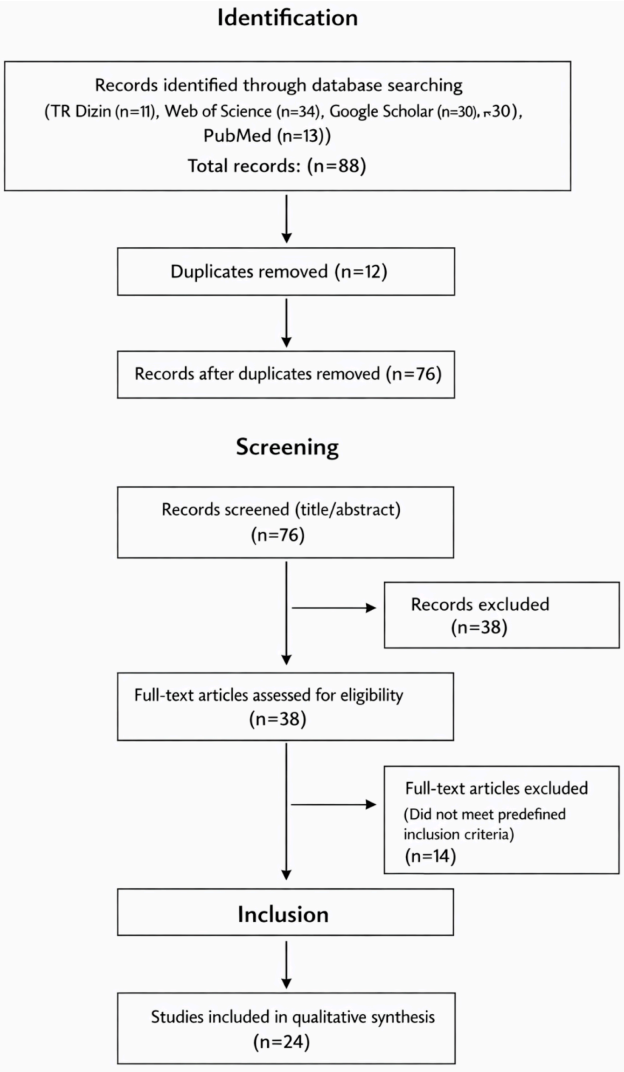

Figure 1. Flow diagram of study selection process.

Analysis of Data

A qualitative research method was employed to analyze and synthesize the findings of the selected studies. The analysis process was conducted in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. Through this analysis, it was aimed to provide a comprehensive understanding of the effects of biofeedback training on athletic performance and psychological well-being by synthesizing the existing literature in the field.

DISCUSSION

This review examines the effects of biofeedback (BFB) techniques on sports performance and offers an in-depth overview of the literature in this area. Studies have demonstrated that biofeedback is an indispensable tool for enhancing athletes' mental and physical performance. However, there are some similarities, differences, gaps, and contradictions in the current research. In this section, the main findings in the literature will be discussed, the positive and negative effects of biofeedback on athletes will be addressed, and recommendations for future studies will be provided.

In studies addressing the relationship between mental and physical functioning, it is suggested that biofeedback can improve both areas. For example, early research provided findings related to mental activities and skin temperature [68], while today, the expanded applications of biofeedback have been examined in various sports [69]. Nevertheless, there is scarce information on the long-term impacts of biofeedback on enhancing athletes' mental resilience. Although the effects of mental preparation on performance are emphasized, further studies are required to assess if these effects can be maintained over time [70].

When examining the diversity of applications, it is observed that breathing exercises and feedback techniques generally show positive results [45]. However, the effectiveness of these techniques varies significantly across different sports and individual athletes. In this context, biofeedback applications need to be optimized according to the unique requirements of each sport. In particular, more comprehensive studies should be carried out to explore the long-term impacts of biofeedback techniques used in high-competition environments.

Studies such as those by Zaichkowsky and Fuchs suggest that biofeedback techniques have positive effects on stress management and performance enhancement, but the validity of these findings remains unclear across different populations and sports [71]. Furthermore, claims that biofeedback techniques positively impact athletes' mental resilience are largely based on theoretical frameworks and are not supported by concrete, large-scale studies. While Lehrer, emphasized the effectiveness of biofeedback in enhancing mental resilience and focus, more data is needed to confirm the accuracy and sustainability of these effects [45].

The potential contributions of biofeedback to athletic populations have been thoroughly examined in the extant body of literature. Research shows that these techniques can improve stress management, increase self-confidence, and enhance overall quality of life [72]. Additionally, breathing exercises and other feedback techniques can help athletes cope with both physical and mental stress by optimizing their nervous system balance [21]. However, some athletes may find biofeedback applications challenging or uncomfortable, which may negatively affect their efficiency. Given that the effects can vary based on individual differences and sports disciplines, their general applicability can be questioned. Quantitative, discipline-specific evidence supports this nuance: for instance, heart rate variability biofeedback in stressed basketball players produced statistically significant improvements in reaction time, concentration, and shooting performance [73]. Further, structured breathing exercises such as cyclic sighing have been shown to reduce respiratory rate and improve mood and anxiety in healthy individuals [74]. Importantly, a randomized controlled trial with international tennis players demonstrated that ten sessions of multimodal biofeedback led to measurable improvements in skin temperature, state anxiety (≈15% decrease), and cognitive performance [24]. These findings underscore the necessity of quantitative, data-driven analyses when evaluating biofeedback applications in relation to individual differences and specific sports disciplines.

At this point, findings related to isokinetic dynamometry and EMG-based biofeedback systems stand out. The evidence discussed above reveals that these technologies play a significant role not only in enhancing athletic performance but also in supporting rehabilitation processes. In addition to providing objective and measura-

ble data on muscle function, these systems contribute to motor learning and psychological engagement through real-time feedback. Notably, improvements in knee flexion and extension strength, enhanced kinesthetic awareness, and greater voluntary muscle control suggest that biofeedback is not merely a physical training tool, but also a cognitive facilitator. However, despite these promising outcomes, the widespread implementation of such technologies remains limited due to factors such as high cost, technical complexity, and the need for joint-specific setup. Moreover, the existing evidence primarily focuses on short-term results, with a lack of studies investigating their long-term effects. In order to fully understand the lasting benefits and practical applicability of these systems, future research should include diverse athletic populations, account for individual differences, and compare various types of biofeedback within sport-specific contexts. Only through such comprehensive approaches can the clinical and performance-enhancing potential of biofeedback technologies be fully realized.

For biofeedback to be more effectively utilized in sports sciences and psychology, it is essential to tailor applications to the unique characteristics of athletes. Additionally, applying these techniques to athletes of various age groups and skill levels can help spread their use. Furthermore, training programs supported by sports psychology techniques can enhance mental resilience and stress management. For example, biofeedback techniques supported by cognitive-behavioral therapy or mindfulness practices can help athletes cope with stress more effectively.

Future research should thoroughly examine the effects of biofeedback on athletes' motivation, mood, and psychological well-being. Comparative studies should also be conducted to explore how these effects differ between professional and amateur athletes. In team sports, the impact of feedback on intra-team interaction and coordination should be explored. Finally, to assess the effectiveness, research should be performed using larger and more uniform sample groups. Comparing different biofeedback techniques can provide clear results on which application is more effective under specific conditions.

This comprehensive review examines the effects of biofeedback on sports performance and psychological well-being and provides a detailed exploration of application techniques. Studies show that biofeedback provides significant benefits, such as improving stress management, enhancing focus, increasing performance, and reducing the risk of injury.

Biofeedback tools allow athletes to monitor and manage their muscle activity, emotional states, stress levels, and body temperature. For example, electromyography feedback is effective in reducing muscle tension and supporting physical relaxation, while electrodermal activity feedback provides information on monitoring stress and emotional responses. Heart rate variability feedback plays an important role in improving nervous system balance, and thermal feedback tracks body temperature and stress-related changes. Each of these tools helps athletes better understand and improve their performance.

Although biofeedback applications are not yet widespread in Turkey, an increasing number of studies aimed at enhancing athletes' psychological resilience have been observed. Although biofeedback applications are not yet widespread in Turkey, an increasing number of studies aimed at enhancing athletes' psychological resilience have been observed. However, the existing literature in this field has notable gaps and limitations. First, biofeedback applications in Turkey are quite limited, and most research has been conducted with small sample groups. This raises questions about the generalizability and reliability of the findings. Furthermore, the lack of studies comparing variety of biofeedback techniques makes it challenging to accurately evaluate the effectiveness of these methods.

Future studies should explore the long-term impacts of biofeedback techniques in greater detail and the differences in their applications across various sports. This will be essential in assessing whether these methods are genuinely effective. In particular, it has been emphasized that biofeedback applications should be cust-

omized to meet athletes' individual needs, but research in this area needs to be supported by more personalized and large-scale data. Existing research often focuses on general approaches, and situations where individual differences are not considered are frequently observed.

In conclusion, biofeedback stands out as a valuable tool with the potential to enhance athletic performance. However, in order to clearly demonstrate its long-term effects and effectiveness, large-scale, longitudinal, and methodologically consistent studies are needed. The widespread adoption of these applications in Turkey could present significant opportunities for improving athletic performance and promoting a healthy sports lifestyle. Nevertheless, further scientific research and practical implementation are required to ensure the reliability and effective use of this potential.

CONCLUSION

Biofeedback emerges as a promising interdisciplinary tool that bridges physiology, psychology, and performance science. While its role in enhancing athletic performance is increasingly supported by research, validating its long-term effectiveness requires large-scale, long-term, and methodologically sound studies. The broad implementation of these techniques-particularly in developing sports science communities such as Türkiye-could make a significant contribution to both individual athlete development and broader public sports health initiatives.

Conflict of Interest

The authors declared no conflicts of interest with respect to authorship and/or publication of the article.

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Author Contributions

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