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PETTLEP-assisted biofeedback training improves physiological parameters, cognitive performance, and overhand serve accuracy in competitive female volleyball players

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This study examined the effects of an 8-week PETTLEP-assisted biofeedback (BFB) training program on physiological parameters, cognitive performance, and serve accuracy in female volleyball players. Fourteen athletes were randomly assigned to an experimental group (EG) and a control group (CG). The EG underwent an 8-week PETTLEP-assisted BFB training. Participants completed pre- and post-training physiological (e.g., Nexus 10 BFB device), cognitive (e.g., Stroop test), and overhand serve accuracy assessments. Results showed a positive effect of the training on skin temperature, frontalis muscle activity, Stroop effect, and serve accuracy in the EG from pre-to post training. Moreover, significant between-group differences were observed in skin temperature and service accuracy after training. These results suggest that PETTLEP-assisted BFB training is a promising tool for fostering physiological, cognitive, and sport-specific improvement in female volleyball players. Future studies should recruit athletes from other sports disciplines to generalize the results to other athletic populations.

KEY WORDS: Biofeedback, Electrodermal activity, Electromyography, imagery, Skin temperature, volleyball

Introduction

In success-oriented sports, the ability to sustain concentration and focus among the heightened stress stimulation is paramount (Shokri & Nosratabadi, 2021). Within this context, it has been proposed that maintaining a self-regulated mental and physical framework is pivotal for attaining high athletic performance (Hanin, 2000). An athlete competing at an elite level must adeptly respond not only to physiological stimuli induced by intense training

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regimens but also to mental and psychological stimuli such as expectations from coaches, personal goals, and the monotony of repetitive tasks. Effective management of these factors is essential for optimizing performance outcomes, including increased motivation, enhanced athletic performance, and faster recovery (Walsh, 2018). In recent years, interventions rooted in mental health have been extensively integrated with physical training to enrich athletic performance and bolster sports- specific skills among athletes (Rijken et al., 2016; Shokri & Nosratabadi, 2021). Understanding cognitive appraisal (how athletes interpret and respond to stress) is a fundamental component of integrating mental health into athletic training. Appraisal involves two components: primary appraisal, where athletes assess the significance of an event, and secondary appraisal, where they evaluate their ability to handle it (Stanger et al., 2024). In addition, challenge and threat appraisals shape whether a situation is seen as an opportunity for growth or a potential risk, directly influencing performance under pressure (Lazarus, 2000). From a cognitive perspective, athletes who perceive pressure as a challenge rather than a threat show better emotional control and performance, aided by skills like reframing thoughts, staying focused, and regulating emotions (Jones, 2003). Therefore, by addressing the psychological, emotional, and cognitive aspects of performance, integrated training approaches help athletes sharpen mental skills, manage stress more effectively, and sustain peak performance in competitive environments (Fogaca, 2021).

Recent systematic reviews and meta-analyses in applied sports psychology have highlighted knowledge gaps and examined strategies for improving athletes' mental health (Prior et al., 2022; Vella et al., 2021). Specific intervention models based on sports psychology concepts have been developed to help athletes manage stress, enhance coping skills, improve mental health, and optimize performance in competitive settings (Brown & Fletcher, 2017; Ekelund et al., 2023; Rydzik et al., 2023). One such intervention is mindfulness, a self- management strategy that helps athletes develop awareness of internal and external thoughts and feelings without judgment, enhancing attentional control, acceptance, and self-compassion (Noetel et al., 2019; Myall et al., 2023). Another widely used intervention is cognitive behavioral therapy (CBT), which focuses on replacing unhelpful or negative thinking patterns with more constructive and realistic thoughts. CBT is particularly effective for managing anxiety, enhancing focus, boosting confidence, and supporting stress management and goal- setting in athletes (Gustafsson et al., 2017). Imagery is also a key mental technique that involves the creation of experiences by recalling past events or mentally simulating specific actions (Weinberg & Gould, 2023). This technique is commonly used in sport and exercise settings to improve motivation and self-efficacy and to regulate arousal and anxiety (Cumming & Williams, 2013).

Unlike these approaches, biofeedback (BFB) offers a personalized combination of strategies that target physiological and psychological factors that influence performance. BFB enables individuals to achieve psychophysiological coherence by monitoring and gaining control over physiological processes that are typically considered autonomic, using specialized devices (Levy & Baldwin, 2019). This mind-body technique serves as a noninvasive tool for managing and enhancing various physiological parameters, including galvanic skin response (GSR), skin temperature (SKT), electromyographic activity (EMG), heart rate variability (HRV), and electroencephalography (EEG), within a multimodal framework (Pusenjak et al., 2015; Choudhury et al., 2023). Research on BFB models involving HRV, EMG, SCR, SKT, and EEG has shown significant benefits for both psychological and physical performance. For example, HRV-BFB reduces stress and anxiety while improving cognitive function (Makaracı et al., 2023), and EMG-BFB decreases muscle tension to enhance sports performance (Zaichkowsky & Fuchs, 2021). GSR-BFB targets sympathetic arousal to reduce anxiety in sports settings, while SKT-BFB improves stress management by regulating vasoconstriction and the autonomic nervous system (Shokri & Nosratabadi, 2021). EEG-BFB supports emotional regulation by engaging multiple neurobiological mechanisms, including the autonomic nervous system and brain regions (Melnikov, 2021). This multimodal approach provides athletes with real-time feedback on their physiological states, allowing them to control typically involuntary processes through formats such as animations, graphs, and games (Makaracı et al., 2024).

After completing a set number of sessions (e.g., 15-20), the process is typically referred to as "BFB training" (Suvorov, 2006; Deschodt-Arsac et al., 2018; Makaracı et al., 2023). It is noteworthy that the use of mental training-oriented methods like BFB training in sports sciences has been on the rise. Notably, several studies have underscored the importance of the connection between BFB and athletic performance (Galloway, 2011; Pusenjak et al., 2015; Keilani et al., 2016; Jiménez Morgan & Molina Mora, 2017; Pagaduan et al. 2020). For instance, Tanis (2008) demonstrated that six weeks of HRV-BFB training can significantly enhance sports-specific performance in women's collegiate volleyball players, improving both closed and open skill execution. Similarly, a single-session neurofeedback application that measures sensorimotor rhythms via EEG has been shown to enhance athletic performance in male volleyball players, emphasizing the importance of teamwork and a collective approach to success (Hosseini & Norouzi, 2017). Additionally, a recent pilot study showed the efficacy of HRV-BFB in regulating autonomic functions and managing stress in highly trained female volleyball players (Makaracı et al., 2023). These findings highlight the growing potential of the BFB as a valuable tool for enhancing mental well-being and athletic performance. In sports like volleyball, where coordination and mental resilience are crucial (Güney et al., 2024), BFB can contribute not only to individual performance but also to team dynamics. However, it is important to note that the specific effects of BFB may vary depending on the intervention's content and duration.

Anthropometric, physiological, and technical factors have historically been the focus of extensive research on understanding sports success. However, a growing emphasis on cognitive functions and psychological factors in recent years has sought to elucidate differences in general abilities and sport-specific skills among athletes (Sabarit et al., 2020). The continuity of cognitive function required for a specific task is closely linked to attention, a vital aspect of the state of consciousness (De Greeff et al., 2018). Performing athletic tasks with minimal cognitive effort is associated with an athlete's capacity to maintain full focus. Therefore, an increase in cognitive function allows for both improved athletic performance and the management of overall fatigue levels during competition with reduced effort. The concept of sports performance and cognitive function, particularly attention, showcase an interconnected relationship (Lautenbach & Laborde, 2016). In volleyball, the combination of rapid decision making, anticipation of opponents' moves, high-pressure situations, and physical-mental synchronization makes it an ideal context for studying the effects of BFB training on cognitive functions (Ashford et al., 2021). This dynamic environment challenges players to read the game and adapt to rapidly changing situations, highlighting the potential benefits of applied psychological interventions and training in improving cognitive performance in sports. In this context, building on the importance of cognitive performance, mental imagery may serve as a powerful tool for athletes to mentally rehearse and refine their skills, further improving both cognitive and physical aspects of performance.

Mental imagery is a complex, multidimensional construct comprising two main elements: imagery use and imagery ability. Recognizing this distinction, cognitive psychologists have developed assessment tools to measure imagery ability along two key dimensions: vividness and controllability (Di Corrado et al., 2020). In addition to thesestructural components, mental imagery also fulfills important psychological functions. Hall et al. (1998) identified that imagery serves both cognitive and motivational purposes at specific and general levels. Based on these functions, they proposed a four-category framework: cognitive specific, cognitive general, motivational specific, and motivational general imagery. This classification highlights the diverse roles of imagery in facilitating skill acquisition, strategic thinking, and psychological preparation, including the enhancement of confidence and motivation. To further enhance the practical effectiveness of imagery, Holmes and Collins (2001) developed the PETTLEP model, which offers a structured framework grounded in the principles of functional equivalence. The PETTLEP approach provides detailed guidelines for creating context-specific, multisensory images that replicate real-life experiences, emphasizing the importance of immersive and realistic imagery. The sport psychology consultants must consider seven key practical factors (i.e., physical, environment, task, timing, learning, emotion, and perspective) when optimizing PETTLEP imagery interventions to ensure the process is both effective and tailored to the unique needs of each athlete. However, it is important to note that the inclusion of all seven PETTLEP elements is not necessarily required for a successful intervention (Scott et al., 2022). Instead, it is recommended that consultants invest time in building rapport with athletes and understanding their individual needs, which allows for the development of personalized PETTLEP interventions (Ely et al., 2020).

Mental imagery is particularly valuable in volleyball, a sport characterized by rapid decision-making and constant shifts in focus. It allows players to simulate and refine complex skills, enhance strategic thinking, and improve emotional regulation in high-pressure situations (see review by Ribeiro et al., 2019). Consequently, coaches and athletes should incorporate imagery practices into their training programs (Lu et al., 2020). The positive effects of imagery are associated with emotional, cognitive, and psychological improvements in athletes (Slimani et al., 2016), specifically in volleyball (Fortes et al., 2018; Grosso et al., 2024). Moreover, the integration of the PETTLEP-model imagery interventions has demonstrated the potential to enhance the motor performance of athletes across diverse sports disciplines, including golf, skiing, gymnastics, and field hockey (Post & Simpson, 2018). Research has noted that both BFB and imagery interventions, sharing common concepts such as concentration, relaxation, and focus, can positively impact sports performance (Bar-Eli et al., 2002; Galloway, 2011). More specifically, Ferguson et al. (2020) suggested that combining imagery practices with BFB training could optimize psychophysiological responses (i.e., GSR, SKT, EMG, and HRV). Therefore, integrating the PETTLEP imagery model with BFB training may lead to more effective outcomes across physiological, cognitive, and athletic performance domains, supporting the notion that combined interventions offer a comprehensive approach for maximizing benefits (Shokri & Nosratabadi, 2021; Roy et al., 2024).

The Present Study

Given the significant impact of mental and physical factors on volleyball performance, alongside the potency of both defensive and offensive actions (Conejero Suárez et al., 2020), the integrated use of BFB with another mental training model (i.e., PETTLEP) has been proposed as a potentially effective approach, particularly since the effects of BFB on athletic performance have not been definitively established. To the best of our knowledge, no study has examined the effects of PETTLEP-assisted BFB training on sport-specific performance. Moreover, empirical evidence indicates that regular BFB training, typically involving at least 15-20 sessions, is recommended to effectively achieve its positive effects (Suvorov, 2006). Thus, the aim of this study was to investigate the effects of an 8-week PETTLEP-assisted BFB training program on physiological parameters, cognitive performance, and overhand serve accuracy in female volleyball players. We hypothesized that an 8-week PETTLEP-assisted BFB training would improve physiological parameters (i.e., increasing SKT and HRV, decreasing GSR and EMG), cognitive performance (i.e., decreasing Stroop effect), and improving overhand serve accuracy.

Methods

Participants

An a priori power calculation using G*Power 3 was performed to estimate the necessary sample size for differences between two independent means (two groups) (Perez-Gaido et al., 2021). A sample size of six was required for each group based on an alpha level of 0.05 and a power of 0.95. Fourteen female volleyball players aged 18-21 years were recruited from professional teams competing at the national level. The athletes were randomly assigned to the experimental group (n = 7; age 18.24 ± 0.49 years) or the control group (n = 7; age 18.14 ± 0.28 years) group before detailed information was presented about the study. All athletes regularly attended the team training sessions (six times per week). Table I lists the baseline characteristics of the study participants.

Participants met specific eligibility criteria, including the absence of regular psychotherapy, non-use of antidepressants, no previous history of mental disorders, and no prior experience with imagery or BFB training. Additionally, all athletes were non-smokers, maintaining good general health throughout the study duration. Each participant was thoroughly briefed about the experimental procedures encompassing physiological, cognitive, and sports-specific assessments, the duration of PETTLEP practice and BFB sessions, and the potential risks involved. Moreover, verbal and written informed consent was obtained from each participant, ensuring a comprehensive understanding and agreement before participation. The study was approved by the Clinical Research Ethics Committee of Gazi University (Approval ID: 01-2022/25).

Table I
Baseline Characteristics of the Study Participants.

Variables	Group	X̄	SD
Age (year)	Experimental	18.29	0.49
	Control	18.14	0.28
Sports experience (year)	Experimental	9.29	1.98
	Control	10.71	1.70
Body mass (kg)	Experimental	63.15	8.25
	Control	64.52	10.05
Body height (m)	Experimental	1.79	2.34
	Control	1.76	1.93
Body mass index (%)	Experimental	19.16	1.87
	Control	19.87	2.43

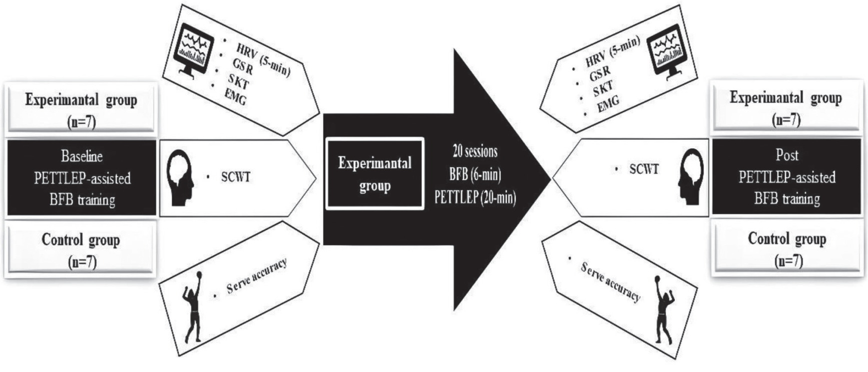
Procedure

We implemented a pretest-posttest control group design in which participants were randomly assigned to either the experimental or control groups. Randomization was performed using a Microsoft Excel spreadsheet. Before starting the study, all procedures were outlined, and the devices and training process were introduced to the athletes. Initially, we collected pre-training data (i.e., physiological variables, cognitive performance, and overhand serve accuracy) from the experimental and control groups. Physiological variables such as GSR, SKT, EMG, and HRV parameters (i.e., heart rate [HR], standard deviation of the N-N intervals [SDNN], and root mean square of successive difference [RMSSD]) related to BFB sessions were measured. The Stroop Color-Word Test (SCWT) was used to assess cognitive performance (Scarpina & Tagini, 2017). Additionally, the athletes completed a "serve accuracy test" on a standard volleyball court (18m x 9m) in accordance with international standards.

Following the pre-training measurements, the experimental group engaged in 20 PETTLEP-assisted BFB training sessions over an 8-week period and was supervised by the first author (MM) and an instructor. The PETTLEP imagery protocol lasted 20 minutes just before each BFB session, which in turn lasted for six minutes, including device preparation and post-session feedback. The control group did not undergo any specific training, and they continued their routine volleyball training sessions. After the completion of the training period, post-training data were collected using the same measurements and procedures one day after the final BFB session. All experimental processes related to BFB sessions were conducted in an isolated room within the volleyball club facilities where the athletes belonged, ensuring controlled and consistent conditions. The experimental design of this study is illustrated in Figure 1.

Biofeedback Training

BFB training was implemented within the experimental group over an 8-week period, involving 20 individual sessions. In the first four weeks, the participants attended three sessions



Notes. BFB = Biofeedback ; HRV = Heart rate variability; GSR = Galvanic skin response; SKT = Skin temperature; EMG = Muscular activation; SCWT = Stroop Color-Word Test.

Figure 1. - Study design.

per week, which shifted to two sessions per week for the next four weeks. Each BFB session lasted for six minutes. Participants were informed of the potential stress-reducing effects of increased HRV (Kayacan et al., 2023). BFB training was performed using a BFB device (Nexus 10 MKII, Netherlands) while the software BioTrace+ Software for NeXus-10 (Mind Media B.V., Version V2018A, Netherlands) was used to monitor and control various physiological parameters. The experimental group followed the BFB protocol outlined by Makaracı et al., 2023. Participants were instructed to abstain from consuming caffeine-containing beverages for at least two hours prior to the BFB sessions (Wells et al., 2012).

During the BFB sessions, a range of feedback tools available in the BioTrace software produced by MindMedia, were employed, including playing music, presenting video games, and showcasing natural environments in a randomized sequence to facilitate full concentration and relaxation. To emphasize the significance of balanced breathing rhythm, participants were guided to breathe slowly at 0.1 Hz (equivalent to six cycles per minute) with the assistance of an auditory pacer (Blum et al., 2019). Throughout the monitoring process, participants were advised to maintain their focus and avoid falling asleep. The BioTrace software visually depicted the participants' physiological data after each session, followed by a brief 3-minute discussion that elucidated the benefits of the practic.

PETTLEP Imagery Practice

During the initial session, participants were introduced to the concept of motor imagery, which encompasses all sensory and kinesthetic sensations, along with the potential benefits associated with this practice. Moreover, the participants were requested to maintain an imagery diary to document the number of individual imagery sessions they completed and to note any challenges or difficulties encountered during the process (Wakefield & Smith, 2011). Following the PETTLEP model, a script was developed that incorporates seven essential components: Physical, Environment, Task, Timing, Learning, Emotion, and Perspective. According to the

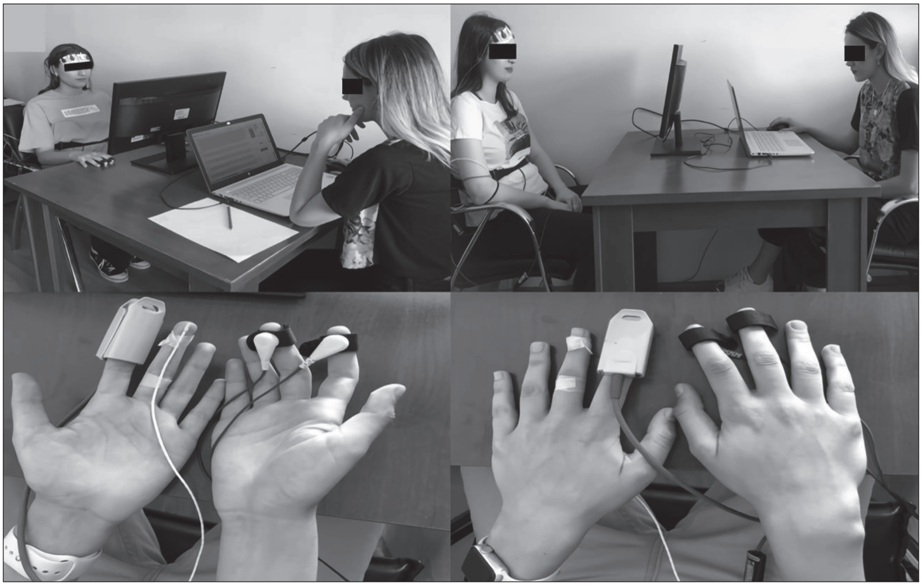


Figure 2. - Representative images of the biofeedback session.

PETTLEP model, imagery should closely approximate actual movement preparation and execution to maximize effectiveness. As previously mentioned, the use of cognitive-specific imagery has been shown to enhance performance in tasks that involve precise aiming (Hall et al., 1998). In line with this principle, all imagery sessions were conducted using a standard volleyball, ensuring that the imagery experience closely mirrored the real-life physical demands of the sport. To further align with the PETTLEP model's emphasis on context and environment, these sessions were held within the same facility where the BFB training was administered (see review by Scott et al., 2022). Participants were guided to mentally visualize themselves in their volleyball jerseys while holding the ball (i.e., physical). Additionally, they were instructed to simulate a high-pressure competitive environment (e.g., match point) during serves by watching game footage and fan videos, as well as listening to relevant audio recordings (i.e., environment). The participants were encouraged to focus internally and imagine executing the serve tailored to their skill level (i.e., task) and to envision the timing and speed of the serve, simulating real-time execution in slow motion (i.e., Timing). Moreover, they were prompted to visualize improvements in their serving skills and concentrate on the finer nuances of this skill (i.e., learning). Participants were also encouraged to visualize their positive emotions and physiological responses during the serve (i.e., emotion) while considering each attempt from either an internal (first-person) or external (third-person) perspective, depending on what best aligned with their personal experiences (i.e., perspective). Weekly consultations were held with the participants to gauge the effectiveness of their imagery practices. They were also given the opportunity to suggest any alterations or additions to their imagery scripts, which were subsequently incorporated into subsequent imagery sessions (Smith et al., 2007). Each imagery practice was conducted just before the BFB sessions on the same day to ensure a seamless integration of both intervention methods. The total duration of the PETTLEP imagery intervention was 8 weeks, in alignment with the BFB training. While the optimal duration for PETTLEP interventions can vary, most studies involving athletes have used time frames of 4 to 6 weeks, demonstrating that these durations can be effective in producing meaningful outcomes (Wakefield & Smith, 2009; Lu et al., 2020; Fang et al., 2023)

Measures

Physiological parameters: The physiological parameters were recorded by measuring GSR, SKT, EMG, and HRV data for multimodal BFB training. We used five sensors connected to the BFB device (Nexus 10), including RESP, blood volume pulse (BVP), ExG, GSR, and temperature, to collect physiological data before and after BFB training. The skin conductivity, in micro Siemens (μS), was measured with a GSR sensor attached to the bent fingers of the non-dominant hand using Velcro strips. Additionally, peripheral SKT was monitored within a range of 10-40°C using a sensitive thermistor affixed to the third finger of the dominant hand. The room temperature during sessions was maintained at 22°C. Participants were asked to maintain the peripheral temperature of their hand at a minimum of 30°C during the recording process. Surface EMG activity in m. frontalis was captured using a dual-channel ExG sensor to estimate the overall stress reactions. This entailed the placement of pre-gelled Ag/AgCl EMG electrodes with a diameter of 24 mm over the left frontalis muscle, with EMG measurements expressed in microvolts (mV). To collect HRV data, a belt-type stretch respiration sensor was fastened to the participants' chests, facilitating the recording derived from electrocardiogram recordings. Additionally, a BVP sensor positioned on the index finger was used to record HR. The HRV time-domain parameters included HR (bpm), SDNN (ms), and RMSSD (ms). All sensors and equipment transmitted the collected data to a laptop computer via Bluetooth connection. The BFB device software automatically saved session-specific data after each session. A sampling frequency of 2048 Hz was set for each sensor, ensuring the comprehensive capture of physiological data with high precision and detail.

Cognitive performance: The cognitive performance (i.e. inhibition) was measured using the SCWT. This involved participants identifying the color in which a word was printed while inhibiting the impulse to read the word itself which may be printed in a different color. The SCWT used in our study comprised three tables arranged in 10 rows and 10 columns each, consisting of color words printed in black ink, colored squares, and color words printed with incongruent ink. The colors used in our study were yellow, blue, green, and red. Each measurement was performed on A4-sized paper. A 60-s recovery interval was allowed between each table trial. Participants were stopped if an error was detected, and they were allowed to proceed with the test after correcting the error. The time required to complete the task, which serves as a measure of SCWT performance, was recorded using a stopwatch.The Stroop effect, which reflects cognitive inhibition, was calculated by subtracting the completion time of congruent trials from that of incongruent trials (Scarpina & Tagini, 2017).

Service accuracy test: This study employed the Serve Accuracy Test, which is part of the Volleyball Skills Test Battery developed by Bartlett et al. (1991). Participants engaged in a 10-min general warm-up followed by a 10-min trial of overhand serves on a standard volleyball court. In this test, participants were tasked with delivering 10 consecutive overhand serves from the service zone to the opposite court. The hitting area was demarcated by lines defining target areas, with values ranging between two and four points (Figure 3). Touching the lines within the hitting area was scored as the highest point. Failed services were either scored as zero points or repeated. The maximum achievable score was 40 points. All serve trials were conducted using an official game ball (MIKASA MVA-200 leather volleyball with a circumference of 65– 67 cm), with participants taking part in the test individually to ensure procedural blinding for other participants.

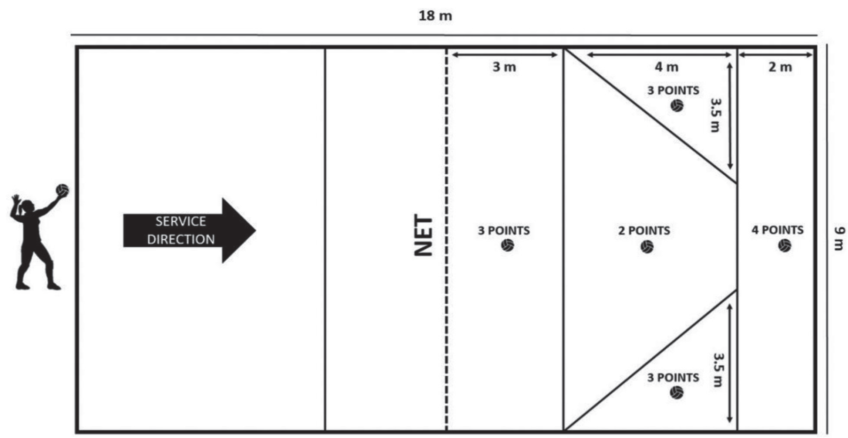


Figure 3. - Service accuracy test protocol.

Statistical Analysis

Before statistical analysis, HRV data were manually checked for artifact removal. Then, we extracted the most relevant HRV parameters that represented vagal tone in the time domain (e.g., RMSSD, SDNN, and HR), using Bio Trace software. The SPSS (v25; SPSS Inc., Chicago, IL, USA) statistical package for personal computers was used in all analyses. All descriptive data are reported as means and standard deviations. The Shapiro–Wilk test was used for data distribution analysis, and Levene's test was used to check the equality of error variances. Baseline between-group differences in the measured parameters were assessed using the independent sample t-test. The paired sample t- test was used to determine differences in repeated measures analysis (pre-post). One-way analysis of covariance (ANCOVA), with a between-group factor of group (experimental and control), was used to determine if there were group differences in the outcomes at post-training. The significance level was set at $p \leq .05$.

Results

There were no significant differences between the experimental and control groups at baseline in terms of physiological, cognitive, and sports skills ($p > .05$). For more information about the baseline results, see Figure 4.

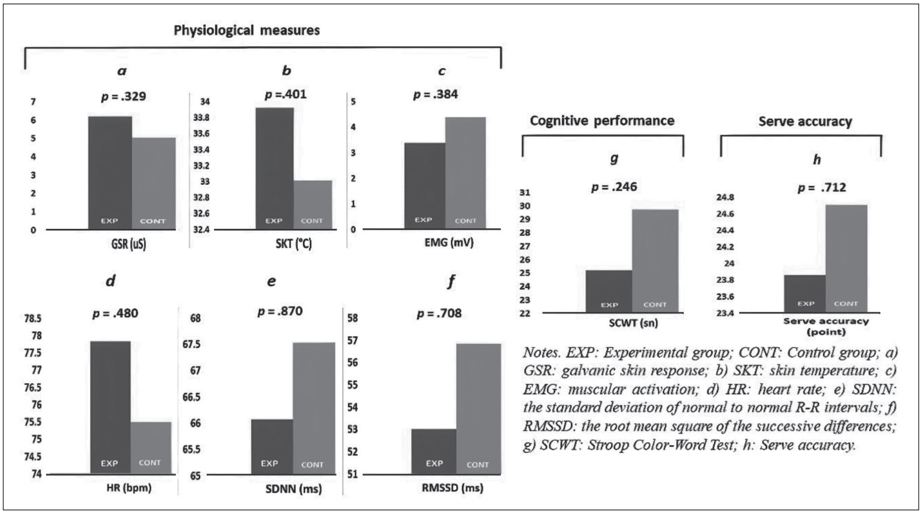


Figure 4. - Pre-test comparisons between the groups

TABLE II
Paired Sample T-Test and ANCOVA Findings Related to Physiological Parameters after 8 Weeks of PETTLEP-Assisted BFB Training

Parameters	Unit	Group	Pre-intervention*	Post-intervention*	t	p^a	p^b
GSR	uS	Experimental	6.19 ± 2.84	4.44 ± 1.38	2.196	.070	.481
		Control	5.03 ± 1.02	4.37 ± 1.19	2.392	.054	
SKT	˚C	Experimental	33.92 ± 1.18	35.86 ± 0.16	-4.369	**.005**	**.020**
		Control	33.00 ± 2.51	34.64 ± 1.12	-2.210	.069	
EMG	µV	Experimental	3.38 ± 0.76	2.58 ± 0.72	3.018	**.023**	.109
		Control	4.39 ± 2.85	4.10 ± 2.32	0.700	.510	
HR	bpm	Experimental	77.83 ± 6.29	74.86 ± 9.44	1.099	.314	.512
		Control	75.46 ± 5.90	74.61 ± 5.65	1.279	.248	
SDNN	ms	Experimental	66.07 ± 13.23	70.62 ± 19.83	-0.676	.524	.530
		Control	67.53 ± 18.87	64.94 ± 15.79	0.196	.851	
RMSSD	ms	Experimental	53.00 ± 22.40	57.64 ± 24.40	-1.833	.117	.556
		Control	56.84 ± 23.72	59.43 ± 21.57	-0.902	.402	

Notes. *Data are presented as mean ± standard deviation. [a]Values were obtained from paired-sample t-test; [b]Values were obtained from ANCOVA test with baseline values as a covariate. GSR: galvanic skin response; SKT: skin temperature; EMG: electromyographic activity; HR: heart rate; SDNN: the standard deviation of normal to normal R-R intervals; RMSSD: the root mean square of the successive differences.

Table II shows the Paired Sample t-test results for ve ANCOVA findings related to physiological parameters after 8 weeks of PETTLEP-assisted BFB training in both groups.

The experimental group showed significant improvements in SKT and EMG ($p = .005$; $p = .023$), whereas GSR, HR, SDNN, and RMSSD were not affected by the training ($p > .05$). The control group did not show any significant changes after the training ($p > .05$). ANCOVA revealed a significant group difference, as reflected by a higher post-training SKT (F(1-11) = 7.379; $p = .020$) in the experimental group, which explained 40% of the variance between the groups ($\eta^2 = .401$). The ANCOVA for the other parameters did not reveal any group differences ($p > .05$). Table III shows the Paired Sample t-test results for ANCOVA findings related to cognitive performance and serve accuracy after 8 weeks of PETTLEP-assisted BFB training in both groups.

The experimental group showed significant improvement in SCWT and serve accuracy ($p = .006$; $p = .002$ respectively). The control group did not show any significant change after training ($p > .05$). ANCOVA did not reveal a significant group difference in SCWT ($p > .05$). A significant group difference was found, as reflected by the higher post-training serve accuracy (F(1-11) = 10.251; $p = .008$) in the experimental group, which explained 48% of the variance between the groups ($\eta^2 = .482$).

Discussion

The present study aimed to examine the effects of an 8-week PETTLEP-assisted BFB training program on physiological parameters, cognitive performance, and overhead serve accuracy in competitive female volleyball

Table III

Paired Sample T-Test and ANCOVA Findings Related to Cognitive Performance and Serve Accuracy After 8 Weeks of PETTLEP-Assisted BFB Training

Parameters	Unit	Group	Pre-intervention*	Post-intervention*	t	p^a	p^b
Stroop	sn	Experimental	25.21 ± 7.19	20.61 ± 6.25	4.135	**.006**	.116
		Control	29.73 ± 6.67	28.12 ± 8.39	1.312	.237	
Serve accuracy	point	Experimental	23.86 ± 4.41	29.57 ± 1.90	-5.377	**.002**	**.008**
		Control	24.71 ± 4.07	24.29 ± 4.57	0.224	.830	

Notes. *Data are presented as mean ± standard deviation. [a]Values were obtained from paired-sample t test; [b]Values were obtained from ANCOVA test with baseline values as a covariate. SCWT: Stroop Color-Word Test.

players. In accordance with the study hypothesis, our findings demonstrated the positive effect of 8-week PETTLEP-assisted BFB training on SKT, muscle activation (m. frontalis), cognitive performance, and serve accuracy.

It is well-established that computer-assisted BFB trainings enhance concentration, emotional regulation, and meditation (Frank et al., 2010). Several studies have demonstrated the potential of combining mental training interventions, such as the PETTLEP model, with applied sport psychology strategies (i.e., BFB) to improve athletic performance (Rusciano et al., 2017; Shokri & Nosratabadi, 2021; Fang et al., 2023). The increasing use of applied psychology techniques in competitive athletes suggests that PETTLEP-assisted BFB has significant potential in influencing physiological, cognitive, and athletic outcomes. Supporting this idea, Ferguson et al. (2020) proposed that integrating BFB with additional self-regulation strategies, such as imagery, could further benefit high-performance athletes, particularly those from university athletics teams. The authors emphasized that combining these two mental strategies could enhance the regulation of both cognitive (psychological) and autonomic (physiological) processes, thereby improving athletic performance. In our study, we examined the autonomic effects of PETTLEP-assisted BFB training using various physiological markers, such as GSR, SKT, EMG, and HRV, even though studies often focus on one of these measures. Consistent with our hypothesis, we observed an increase in the SKT in the experimental group compared with the control group after training. Notably, an organism's response to acute stress can adversely affect athletic performance by decreasing peripheral SKT (Herborn et al., 2015). Therefore, the observed positive effects of the training are particularly noteworthy with respect to their contribution to managing stress management induced by competition. While several studies conducted in different populations have highlighted the positive effects of relaxation and mental health-enhancing interventions (Kaushik et al., 2006; Brennan et al., 2012; Prato & Yucha, 2013), we found that only one study had specifically investigated changes in SKT among elite-level athletes (Makaracı et al., 2024). In this recent randomized controlled trial, the authors indicated that 10 sessions of multimodal BFB improved physiological functions such as HRV, EMG, GSR, and SKT in international tennis players. While their findings support our study, it is important to note that their sample (i.e., tennis players) did not exactly match our population. Our results indicated a significant decrease in EMG activity (m. frontalis) in the experimental group after training. In stressful situations, the activation level of the m. frontalis typically increases, and EMG assessment in the frontal region is associated with general and specific anxiety patterns (Zullino et al., 2015). Therefore, the observed decrease in the m. frontalis activation level in our study indicates a positive effect of the training. Given that anxiety and stress hold considerable sway in athletic performance among competitive athletes, the reduction in m. frontalis activation represents a significant finding. Furthermore, several studies exploring EMG-BFB training have noted a reduction in the pain generally experienced in the neck and shoulder muscles following the training (Voerman et al., 2007; Ma et al., 2011). However, note that the sample groups in these studies may not possess the same physical and mental profile as the athletes in our study. Consequently, a thorough discussion of our findings concerning SKT and EMG results related to competitive athletes may have some limitations due to the varying contexts and demographics across the studies. These points highlight the need for careful interpretation of our findings within the specific context of elite athletes and the potential implications for their performance and well-being.

Although some of the physiological parameters measured after the training did not achieve statistical significance, they still indicated promising trends that warrant further exploration. Notably, we observed a tendency toward positive changes in GSR and HRV (e.g., HR, SDNN, and RMSSD) following an 8-week PETTLEP-assisted BFB training. Studies with clinical objectives have highlighted that BFB and mental relaxation interventions can reduce skin conductivity (Micoulaud-Franchi et al., 2014; Nagai et al., 2019; Scavone et al., 2020). Accordingly, it can be inferred that controlling skin conductivity is advantageous for achieving optimal performance under demanding competitive conditions and stress. Nevertheless, further investigation is required to confirm this hypothesis. Furthermore, research has shown that HRV- BFB training can induce changes in cardiac parameters linked to HRV in athletes (Rijken et al., 2016; Perez-Gaido et al., 2021). PETTLEP-assisted BFB training may have the potential to influence autonomic functions; however, the extent of these effects could be influenced by factors such as the duration of the training, the number of sessions, and the specific sport discipline of the athletes.

Cognitive abilities are vital in sports because they enable athletes to sustain their performance and respond adaptively to external stimuli or high-stress situations during competitions (Lautenbach et al., 2016). For example, volleyball players must exhibit advanced cognitive skills to effectively track the ball's movement and assess positions both individually and as a team (De Waelle et al., 2021). However, the specific effects of BFB training on cognitive performance in competitive athletes have not been extensively examined. Our study revealed an enhancement in the Stroop effect after an 8-week PETTLEP-assisted BFB training, which is consistent with previous studies (Sherlin et al., 2009; Sutarto et al., 2013; Prinsloo et al., 2013). These observations underscore the potential of BFB training to positively impact cognitive performance, offering promising implications for its role in enhancing athletic ability. On the other hand, Sutarto et al. (2010) reported that HRV-BFB training improved Sternberg and D2 attention test results but not Stroop test results. These discrepancies can be attributed to differences in sample groups and study procedures. Considering again the effect of cognitive skills on sportive performance, the potential effect of PETTLEP-assisted BFB training on cognitive performance in athletes appears to be worth investigating.

BFB training has been shown to reduce sympathetic activity, increase perceived relaxation, and improve sports performance (Pruneti et al., 2023). Based on these findings, we anticipated an improvement in sport-specific performance, specifically overhand serve accuracy, following the 8-week PETTLEP-assisted BFB training. Our results revealed a positive impact on serve accuracy in the experimental group compared to the control group. These findings underscore the importance of relaxation and imagery-based interventions in enhancing sports skills. Notably, only a few studies have demonstrated the effectiveness of interventions targeting mental relaxation and stress management in improving volleyball- specific skills. A unique aspect of our study is the link between BFB training and enhanced tennis serve accuracy, as noted by Galloway (2011). Furthermore, Velentzas et al. (2010) emphasized the close relationship between volleyball-specific performance and mental imagery. Thus, it is reasonable to conclude that PETTLEP-assisted BFB training can be a valuable tool for improving overhand serve accuracy in competitive female volleyball players. Additionally, the relatively short duration of each session and the low level of specialized expertise required for such an intervention make it feasible to incorporate BFB training into athletes' regular routines without adding significant strain to their already demanding schedules. Over time, this approach could provide affordable and accessible training options, even for athletes without access to advanced technology within their facilities.

Although our study provides valuable insights, several limitations should be acknowledged. First, we did not assess the validity and reliability of the PETTLEP imagery intervention itself. Incorporating validated measures of imagery ability would have enhanced our ability to track changes in participants' imagery skills throughout the intervention. In addition, the absence of a post-manipulation check is a notable limitation. A post-manipulation check similar to that used by Ferguson et al. (2020) could have provided valuable data on the effectiveness of the intervention. Another limitation concerns the generalizability of our findings. Our sample consisted of athletes from one sport (i.e., volleyball), and the intervention was specifically tailored to their needs. Thus, the findings may not be directly applicable to athletes from other sports or to populations with varying levels of experience in mental training. Future research with more diverse sample sizes is needed to assess the broad applicability of these results.

Conclusion

We demonstrated that 8-week PETTLEP-assisted BFB training increased SKT and decreased frontalis muscle activation. Additionally, cognitive and sports-specific performance (overhand serve accuracy) improved from pre-training to post-training. These findings suggest that PETTLEP-assisted BFB training, a simple and non-invasive technique, could be a useful tool for enhancing cognitive and sports-specific performance in competitive female volleyball players. Future studies should try to recruit athletes from other sports disciplines to generalize the results to broader athletic populations. Future studies could benefit from using comparison groups that receive alternative interventions/trainings with similar goals, such as other BFB protocols (i.e., EEG) or different imagery models, to assess the relative effectiveness of the PETTLEP approach.

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