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Endurance training and physiological variables: effects on sub-elite volleyball players
Entrenamiento de resistencia y variables fisiológicas: efectos en jugadores de voleibol de subélite

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Abstract. Volleyball is perceived as a physically demanding sport that involves rapid changes in speed, deceleration, and abrupt alterations in movement direction. It has been emphasized that physiological attributes such as VO$_2$max, PIF, PEF, and FVC play a crucial role in the athletic performance of individuals participating in dynamic sports, aiding them in effectively managing critical situations. Hence, the aim of this research was to evaluate the impact of endurance training on physiological parameters among volleyball athletes. A randomized controlled trial was carried out with 24 male players (mean age 21,58; SD±2,46 years). The assessment of physiological characteristics involved the utilization of a dry spirometer for VO$_2$max measurement and the Multistage Fitness Test for assessing PIF, PEF, and FVC. A two-way Anova analysis was executed to ascertain any disparities in physiological parameters from pre-test to post-test. The results indicated notable variances in physiological traits (VO$_2$max, PIF, PEF, and FVC) among volleyball participants following the implementation of the Tabata intervention regimen. These metrics are instrumental in enhancing physiological capabilities to attain superior athletic performances. When designing training regimens, it is imperative to consider physiological functional elements aligned with the specific demands of the sport.

Key words. VO$_2$max; physiology; sport; exercise; Tabata training.

Resumen. El voleibol se percibe como un deporte físicamente exigente que implica cambios rápidos de velocidad, desaceleración y alteraciones bruscas en la dirección del movimiento. Se ha enfatizado que los atributos fisiológicos como el VO$_2$max, el PIF, el PEF y el FVC juegan un papel crucial en el rendimiento atlético de las personas que participan en deportes dinámicos, ayudándolos a manejar de manera efectiva situaciones críticas. Por lo tanto, el objetivo de esta investigación fue evaluar el impacto del entrenamiento de resistencia sobre los parámetros fisiológicos en atletas de voleibol. Se llevó a cabo un ensayo controlado aleatorizado con 24 jugadores varones (edad media 21,58; DE±2,46 años). La evaluación de las características fisiológicas implicó la utilización de un espirómetro seco para la medición del VO$_2$máx y la prueba de aptitud multietapa para evaluar el PIF, el PEF y el FVC. Se ejecutó un análisis de Anova de dos vías para determinar cualquier disparidad en los parámetros fisiológicos desde el pre-test hasta el post-test. Los resultados indicaron variaciones notables en los rasgos fisiológicos (VO$_2$max, PIF, PEF y FVC) entre los participantes de voleibol después de la implementación del régimen de intervención Tabata. Estas métricas son fundamentales para mejorar las capacidades fisiológicas para lograr rendimientos atléticos superiores. A la hora de diseñar regímenes de entrenamiento, es imprescindible tener en cuenta los elementos fisiológicos funcionales alineados con las demandas específicas del deporte.

Palabras clave. VO$_2$max; fisiología; deporte; ejercicio; Entrenamiento de Tabata.

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Introduction

Volleyball is a sport with substantial physical demands that necessitates a high standard of physical fitness. To perform optimally during competitions, volleyball athletes must possess advanced training in a variety of physical and physiological aspects (Aidar et al., 2022; Latino, & Tafuri, 2023, 2024a,b; Tafuri, & Latino, 2024). The musculature must exhibit strength, elasticity, explosiveness, coordination, and the ability to endure extended periods of intense physical activity with breaks. Furthermore, volleyball players must efficiently recover from exertion in preparation for subsequent matches. Achieving these requirements entails the utilization of the body's energy production systems by the muscles, particularly the cardiovascular and respiratory systems (Mazzeo et al., 2016; Rocca et al., 2016).

Volleyball constitutes a high-intensity, prolonged aerobic activity in which aerobic/anaerobic mechanisms are engaged intermittently. The intermittent nature of dynamic sports performance predominantly relies on the aerobic element that sustains a high level of intensity throughout the match, retards fatigue, and facilitates expedited and enhanced recovery between matches (Supriatna, Suryadi, Haetami, & Yosika, 2023). The assessment of aerobic capacity (VO$_2$max) offers insights into the player's health status, aids in assessing the impacts of training, and has implications for the early identification of athletes (Ranković et al., 2010). It serves as a gauge of the circulatory and respiratory system's efficacy in furnishing fuel and oxygen during prolonged physical exertion (Taylor, Buskirk, & Henschel, 1955; Latino, Saraiello, & Tafuri, 2023; Morsanuto et al., 2023). Aerobic capacity stands as one of the most dependable and valid physiological metrics in the realm of exercise physiology and is frequently utilized as an indicator of cardiovascular fitness in athletic endeavors. Theoretically, heightened maximum oxygen uptake correlates with improved performance; a physical performance aspect intricately linked to alterations in athletes' physiological attributes. Upon scrutinizing the aerobic contribution and its significance during a match, it becomes apparent that volleyball athletes necessitate a relatively substantial aerobic power, conventionally quantified by VO$_2$max (Parengkuan,

& Lahay, 2022). Thus, in scenarios where game intensity is elevated, a superior maximum oxygen consumption ensures a robust reservoir of aerobic energy generation, culminating in diminished lactate accumulation. A situation where oxygen consumption during gameplay approximates 60% of VO_2 max underscores the significance of the anaerobic threshold; a high threshold inhibits lactic acid production during game phases (Anmama, Fenanlampir, & Souisa, 2023).

Aerobic and anaerobic endurance are of paramount importance in volleyball matches owing to the game's high intensity. Volleyball athletes typically operate at 85-90% of their maximum heart rate (HRmax) and 75% of their maximum oxygen consumption (VO_2max) (Alvarez et al., 2015). Consequently, it is crucial for each volleyball player to possess a considerable level of endurance. Notably, a high degree of aerobic capacity is essential for attaining success in volleyball; thus, the evaluation of VO_2max holds significant value as it is pivotal in elite sports and serves as a reflection of an athlete's physical prowess (Latino, Tafuri, Saraiello, & Tafuri, 2023; Taware, Bhutkar, & Surdi, 2013).

Another critical consideration involves the training regimen or methodologies employed by coaches to enhance their athletes' physical stamina. Various training approaches can be utilized, such as tabata training. This research specifically focused on investigating the efficacy of the Tabata training method.

Tabata training is designed to enhance both the aerobic and anaerobic systems, resembling HIIT (High Intensity Interval Training) with elevated intervals and intensity (Setiawan et al., 2020). In practical terms, tabata training involves four-minute sessions comprising eight intervals (Fazriyati et al., 2013). The duration of each interval is set at 20 seconds at a high intensity level. Within the four-minute timeframe, athletes engage in high-intensity physical training for 20 seconds followed by a continuous 10-second recovery period. Tabata exercises are conducive to fat burning, boosting pre and post-training metabolism, enhancing both aerobic and anaerobic capacities, improving athletes' mental well-being, demonstrating effectiveness and efficiency in implementation, and can be integrated into a variety of physical pursuits. Despite an extensive body of literature extolling the numerous health advantages of Tabata, its utilization in volleyball remains limited due to its perceived lack of enjoyment. Given the inconclusive outcomes of Tabata studies and the identified research gap, there is a compelling rationale to delve deeper into the Tabata training methodology. Therefore, the primary aim of this investigation was to assess the impact of endurance training on the physiological parameters of volleyball players.

Methods

The researchers employed an experimental approach in the current study. As highlighted by Fraenkel (2012), experimental research stands out as the sole method capable of effectively scrutinizing hypotheses concerning cause-and-effect associations. Suherman and Rahayu (2015) further emphasize that experimental research differs from other forms of inquiry in its unique focus on directly manipulating the dependent variables. Consequently, the study adopted a randomized controlled design to investigate the impact of a Tabata program on the aerobic capacity of sub-elite volleyball players. The intervention spanned 12 weeks, during which participants were randomly assigned to either the experimental or control group. Following randomization, the researchers assessed the baseline equivalence between the groups, implementing double blinding to ensure that both participants and assessors remained unaware of the group allocation. While the experimental group underwent a Tabata training program, the control group solely engaged in regular exercise training. Over the 12-week period, both groups partook in their respective exercise regimens twice weekly, with evaluations conducted before and after the training sessions.

Participants

The determination of the sample size was accomplished utilizing the A-priori Sample Size Calculator for Student t-Tests software, aiming to detect a substantial effect size (Cohen's $d = 0.8$) with a significance level (α) set at 0.05 and a study power of 80% for a two-tailed hypothesis testing. A total of 24 male volleyball players, divided into 12 Control and 12 Experimental groups, were purposefully chosen for the study, with their ages ranging from 18 to 25 years ($M=21.58$; $SD\pm2.46$).

In order to be eligible for participation, individuals were required to have a minimum of three years of experience playing at the National level. On the other hand, individuals with a history of cardiorespiratory disorders or lower extremity musculoskeletal injuries within the past three months were excluded from the study.

All participants and controls were given a comprehensive explanation of the study's nature, and the detailed procedures of the study were elucidated to them. Subsequently, written informed consent was obtained from all participants.

Procedures

Subjects and controls were summoned in the early hours of the morning, specifically between 8 am and 9 am, after having a light breakfast. They were instructed to adhere to their usual sleeping patterns and refrain from engaging in strenuous physical activity 48 hours prior to the data collection process.

All evaluations were carried out across two distinct sessions. Initial assessments involved participants completing a questionnaire to provide demographic details including age, gender, medical history, smoking habits, and various other characteristics. Following this, athletes underwent the Multistage Fitness Test and spirometry to evaluate their aerobic capacity before and after the intervention.

Individuals partaking in the study underwent personalized evaluations, with each assessment being conducted in a consistent order, at the same time each day, and under similar experimental circumstances. The entire assessment process and physical activity routines were overseen, defined, and supervised by two experienced fitness professionals.

Measures

Physiological Performance

The Multistage Fitness Test (MSFT) developed by Léger, Mercier, Gadoury, and Lambert in 1988, was employed to assess the maximal oxygen uptake (VO_2max). Originating in the early 1980s, the MSFT was designed to evaluate the peak oxygen consumption across different age groups from children to adults. Its purpose was to provide a practical and cost-efficient estimation of maximal oxygen consumption in a real-world setting. Studies indicate that the MSFT is a dependable indicator of maximal oxygen uptake. During the MSFT, participants were directed to shuttle run back and forth between 20-meter distances following an auditory cue (beep). The initial speed was set at 8.5 km/hr, with increments of 0.5 km/hr every minute. Each individual had to finish a stage before the next beep sounded, striving to complete as many shuttles as possible. Failure to maintain the prescribed pace for two consecutive shuttles or premature test termination due to exhaustion led to discontinuation. The formula by Flouris et al. (2005) was applied to calculate the maximal oxygen uptake.

Peak Inspiratory Flow (PIF), Peak Expiratory Flow (PEF), and Force Vital Capacity (FVC) were assessed utilizing a portable electronic spirometer designed for physiological measurements. The assessments took place within controlled laboratory environments. Participants proceeded with the experimental protocol and alleviated any apprehensions. Ensuing the guidelines of the American Thoracic Society, participants performed forced inhalation and exhalation maneuvers while seated, with their nostrils obstructed. Employing the spirometer's mouthpiece tube, each participant executed a maximal inhalation succeeded by a robust exhalation until complete air expulsion. Each participant underwent a minimum of three trials, with the top three endeavors selected for subsequent analysis. Verbal support and stimulation were employed to elicit the most effective inhalation and exhalation efforts from the participants. The procedure concluded with a maximal inhalation by the individual.

Intervention training

The Tabata method involves participating in high-intensity interval training for a period of four minutes. The regimen includes eight sets, each comprising 20-second intervals of vigorous physical activity followed by 10 seconds of rest. Because of its high intensity, Tabata proves to be efficacious in enhancing anaerobic endurance and cardiorespiratory fitness within a restricted timeframe (Olson, 2014). The Tabata training regimen administered to the experimental group consisted of warm-up, primary exercise, and cool-down. Illustrations of primary exercises executed were as follows: (1) Squat; (2) Push-up; (3) Dynamic lunges; (4) High knee; (5) Spider crawl; (6) Plank; (7) Mountain Climber; (8) Russian twist.

The training duration lasted 4 minutes, with each exercise session enduring 20 seconds and being followed by a 10-second rest period.

Statistical Analysis

Data were presented in the form of group mean (M) values and standard deviations (SD). Prior to conducting any analysis, the dataset underwent thorough scrutiny for missing data, outliers, normality through the utilization of the Shapiro-Wilk test, and homoscedasticity by employing the Bartlett criterion. The findings indicated that all measures exhibited homoscedasticity and followed a normal distribution. Subsequently, parametric tests were utilized to conduct inferential statistical analyses. A two-way ANOVA design, involving group (experimental/control) and time (pre/post-intervention) with repeated measures on the time dimension, was executed to assess the influence of the exercise program on physiological measures. Whenever 'Group x Time' interactions yielded significance, paired t-tests were carried out to discern noteworthy differences. The partial eta squared ($\eta 2p$) value was calculated to gauge the effect size, with delineations of small ($\eta 2p < 0.06$), medium ($0.06 \leq \eta 2p < 0.14$), and large ($\eta 2p \geq 0.14$). Additionally, Cohen's d was computed to determine the effect sizes between groups, categorized as small ($0.20 \leq d < 0.50$), moderate ($0.50 \leq d < 0.79$), and large ($d \geq 0.80$). A distribution-based method was used for estimation of the minimal clinically important difference (MCID): the 0.5 × SD. In the 0.5 × SD distribution-based method, the following equation was used to estimate the minimal clinically important differences: 0.5 × SD of the change in all the variables score from baseline to post-test, where 0.5 corresponds to a moderate effect size (Cohen, 2013).

Statistical significance was defined as a threshold of $p < 0.05$. The entirety of the analyses was conducted using IBM SPSS version 25.0 (IBM, Armonk, NY, USA).

Results

All participants underwent the allocated treatment conditions as per assignment, and no instances of injuries were documented during the entire duration of the experiment. The individuals involved in the study displayed uniformity in terms of age, gender, and anthropometric characteristics ($p > 0.05$) (Table 1). The data outcomes for all variables under consideration are presented in Table 1.

Table 1.
Changes in VO$_2$max and Spirometric values after a 12-week Tabata exercise program.

	Experimental Group (n = 12)			Control Group (n = 12)		
	Baseline	Post-test	Δ	Baseline	Post-test	Δ
V0$_2$max	48.45 (1.88)	57.38 (3.20)†*	8.92 (1.67)	47.78 (2.42)	47.68 (2.15)	-0.10 (0.67)
PIF	128.86 (1.66)	136.63 (2.39)†*	7.76 (2.51)	127.78 (2.30)	127.28 (3.75)	-0.50 (1.88)
PEF	2.60 (0.23)	2.90 (0.23)†*	0.30 (0.34)	2.47 (0.29)	2.35 (0.25)	-0.12 (0.25)
FVC	4.02 (0.70)	5.20 (0.17)†*	1.18 (0.76)	4.06 (0.62)	3.86 (0.75)	-0.20 (0.47)

Note: values are presented as mean (± SD); Δ: pre- to post-training changes; †Significant 'Group x Time' interaction: significant effect of the intervention ($p< 0.001$). *Significantly different from pre-test ($p< 0.001$); $^{\Omega}$ BMI percentile indicates the relative position of the child's BMI number among children of the same sex and age.

VO$_2$max

A two-factor repeated measures ANOVA found a significant 'Time x Group' interaction for the VO$_2$max ($F_{1,22} = 340.76$, $p < 0.001$, $\eta^2_p = 0.93$, large effect size). The post-hoc analysis revealed a significant improvement in the score for this variable ($t = 18.46$, $p < 0.001$, $d = 5.32$, large effect size) in the intervention group. The MCID based on the effect size (0.5 × SD) were 0.8 points. No significant changes were found for the control group ($p > 0.05$).

PIF, PEF and FVC

A two-factor repeated measures ANOVA found a significant 'Time x Group' interaction for the *PIF* ($F_{1,22} = 82.92$, $p < 0.001$, $\eta^2_p = 0.79$, large effect size)*, PEF* ($F_{1,22} = 8.96$, $p < 0.001$, $\eta^2_p = 0.91$, large effect size), *and FVC* ($F_{1,22} = 28.46$, $p < 0.001$, $\eta^2_p = 0.76$, large effect size). The post-hoc analysis revealed a significant improvement in the score for *PIF* ($t = 10.68$, $p < 0.001$, $d = 3.08$, large effect size), *PEF* ($t = 2.99$, $p < 0.001$, $d = 0.86$, large effect size) and *FVC* ($t = 5.36$, $p < 0.001$, $d = 1.54$, large effect size) in the intervention group. The MCID based on the effect size (0.5 × SD) were 1.25 for the PIF, 0.17 for the PEF, and 0.38 for the FVC. No significant changes were found for the control group ($p > 0.05$).

Discussion

The objective of this study was to evaluate the impact of a Tabata training regimen on the respiratory physiological responses of sub-elite volleyball players. The results indicate that incorporating an endurance exercise protocol such as this into regular volleyball training sessions may lead to a significant improvement in the long-term aerobic performance of sub-elite volleyball players.

The initial discovery in this investigation indicates that Tabata represents a training technique that exerts a notable influence on enhancing the endurance capacity of volleyball competitors. This is attributed to the structured nature of the Tabata training method, which integrates high-intensity exercises within relatively brief time frames. These results align with previous research suggesting that the Tabata training program positively affects various respiratory parameters (PEF, PIF, and FVC) (Cüce, Yapıcı, & Atabaş, 2021; Farì et al., 2023; La Torre et al., 2023; Megahed, Al-Torbany, Al-Ghool, & Tarek, 2023). Aerobic training primarily focuses on improving cardiovascular health, enhancing lung capacity, and optimizing oxygen utilization. During aerobic activities, individuals engage in continuous rhythmic motions that require consistent and controlled breathing, thus facilitating increased lung capacity and strengthening respiratory muscles over time, ultimately benefiting PEF (Corvino et al., 2020; Gottlieb, Levi, Shalom, Gonzalez, & Meckel, 2024; Guerra et al., 2014; Muscogiuri et al., 2016).

Herlan and Komarudin (2020) asserted that Tabata represents a form of cardiorespiratory exercise regime incorporating high-intensity movements within brief intervals, interspersed with periods of rest or low-intensity movements to facilitate an active recovery phase between intervals. This assertion finds validation in a previous study indicating that Tabata has the potential to enhance cardiorespiratory fitness (Vo$_2$max) by 4% to 46% over a training duration spanning from 2 to 15 weeks. It was previously demonstrated in research that the utilization of Tabata training could result in a more rapid augmentation of VO$_2$max (Patah et al., 2021). The elevation in VO$_2$max levels can be attributed to the escalation in stroke volume (the volume of blood expelled by the heart in a single beat), which is prompted by the robust and swift contracting capability of the cardiac muscle (Scott et al., 2016). Furthermore, Tabata has been shown to promote mitochondrial biogenesis, encompassing the enlargement and proliferation of mitochondria and ATP cells, thereby bolstering cardiovascular capacity across various levels of exercise intensity (Tabata, 2019). Noteworthy is the succinct nature of Tabata training, typically lasting a mere four minutes per session, rendering it a convenient choice for individuals grappling with time constraints amidst their busy schedules (Hough, 2021). The adoption of high-intensity Tabata training stands to enhance cardiorespiratory capacity, particularly in terms of lung and heart function, consequently fostering improved oxygen transportation efficiency throughout the body during physical exertion.

The results of the conducted study suggest that Tabata training represents an efficacious model for augmenting physical stamina. This training approach emphasizes high-intensity interval training (HIIT), encompassing activities like sprinting, rapid jump rope exercises, and high-intensity weightlifting. The primary aim is to elicit an elevation in metabolic rate and enhance anaerobic endurance, thereby yielding a favorable boost in endurance levels among volleyball players.

Nonetheless, this study does possess certain limitations. Scholars propose the utilization of a more comprehensive research tool to explore the impacts of this training regimen on athletes' psychological well-being, as well as gathering input from coaches regarding the application of Tabata training. Future investigations could involve incorporating gender and age as selection criteria for participants to enrich the breadth of data supporting the advancement of training protocols for physical endurance in volleyball athletes.

Conclusions

This investigation unveiled crucial insights regarding the impact of a Tabata training intervention on the physiological attributes of volleyball players. Evidently, the results of the executed study suggest that Tabata training represents an efficacious model for augmenting physical stamina. Moreover, this data can be leveraged to formulate training recommendations and oversee the progression of athletes subsequently. The Tabata training approach emphasizes high-intensity interval training (HIIT), encompassing activities like sprinting, rapid jump rope exercises, and intense weight training. The primary aim is to elicit an elevation in metabolic rate and enhance anaerobic endurance, thus fostering a more pronounced improvement in endurance levels among volleyball practitioners.

Hence, when devising the training regimen, it is imperative to consider physiological functional elements in alignment with the specific demands of the activities.

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