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Research article

The Impact of Running-Based and Drop Jumping Interval Interventions on Cardiorespiratory Fitness and Anaerobic Power of Collegiate Volleyball Players: A Comparative Analysis of Inter-Individual Variability in the Adaptive Responses

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Abstract

This study compared inter-individual variability in the adaptive responses of cardiorespiratory fitness, anaerobic power, and motor abilities of male volleyball players to high-intensity interval training (HIIT) prescribed as repetitive drop jumps (interval jumping) and running-based intervals (interval running). Twenty-four collegiate volleyball players were equally randomized to two training groups executing 11 minutes of interval running or interval jumping during which they ran or repeated drop-jumps for 15 seconds, alternating with 15 seconds of passive recovery. Before and after the 6-week training period, aerobic fitness, cardiac function, and anaerobic power were evaluated using a graded exercise test, impedance cardiography, and a lower-body Wingate test, respectively. Additionally, linear speed, agility, and jumping tests determined motor abilities. Both interventions significantly enhanced maximum oxygen uptake ($\dot{V}O_{2max}$), velocity associated with $\dot{V}O_{2max}$, first and second ventilatory thresholds (VT_1 & VT_2), maximal cardiac output ($\dot{Q}_{max}$), stroke volume (SV_{max}), peak and average power output, vertical jump, change of direction, and linear sprint speed. Interval jumping group demonstrated a significantly greater improvement in squat jump ($p = 0.001$; 95% CI: 2.51 - 5.42) and countermovement jump ($p = 0.001$; 95% CI: 2.11 - 4.61) compared to interval running group. Conversely, interval running group elicited a greater enhancement in sprint speed ($p = 0.002$; 95% CI: 2.53 - 5.71) than interval jumping group. Examining the individual residual in the adaptive responses revealed that interval running induced more homogenized adaptations across individuals in VT_1 ($p = 0.04$; 95% CI: 0.03 - 1.33), $\dot{Q}_{max}$ ($p = 0.03$; 95% CI: 0.04 - 1.64), SV_{max} ($p = 0.04$; 95% CI: 0.02 - 1.75), and maximal sprint speed ($p = 0.01$; 95% CI: 0.72 - 1.95) in contrast to interval jumping. However, the uniformity of adaptations in countermovement jump in response to interval jumping surpassed that of interval running ($p = 0.02$; 95% CI: 0.08 - 1.32). Although both training modalities effectively improved the mentioned variables concurrently, tailoring the HIIT intervention to the reference intensity and training modality specific for each quality may enhance measured quality.

Key words: Sport-specific intervention, aerobic power, training modality, muscular power, cardiac function.

Introduction

Volleyball is a team sport characterized by brief bursts of intense activity, typically lasting 3-9 seconds, interspersed with comparatively longer intervals (10-20 seconds) of low- to moderate-intensity recovery time for local state-league male players (Polglaze and Dawson, 1992; Ramirez-Campillo et al., 2020). The duration of high-intensity activities and resting time between bursts can vary based on the level of players. For example, a time-motion analysis by Sheppard et al. (2007) indicates the duration of rallies ranges between 3 and 40 seconds, with the average rest time being 14 seconds in national team players. Typically, individual actions vary depending on technical and tactical scenarios; however, players perform common movements such as accelerations, decelerations, powerful jumps, explosive changes of directions, and bull-striking (Sheppard et al., 2007). The game's dynamic bursts and strenuous movements rely on anaerobic energy metabolism, and aerobic energy metabolic pathway predominantly fuels low-intensity activities such as walking and jogging (Tao et al., 2024). Research has identified a positive correlation between aerobic fitness and the swift restoration of power in consecutive rounds of intense interval exercise (Tomlin and Wenger, 2001). This finding indicates that aerobic fitness plays a crucial role in a fundamental aspect of volleyball performance – the capacity to execute consecutive decisive actions effectively. Consequently, it is imperative for coaches to focus on improving both aerobic and anaerobic power concurrently (Tao et al., 2024).

Different types of physical conditioning programs have been shown as practical approaches to enhance the aforementioned qualities in volleyball players (Ramirez-Campillo et al., 2020). In various forms, high-intensity interval training (HIIT) has been validated as efficient approach to enhance aerobic metabolic pathways and anaerobic power across a broad spectrum of sports (Laursen and Buchheit, 2019). HIIT interventions can be tailored based on the specific requirements of the sports discipline and the physiological characteristics of the athletes (Sheykhlouvand et al., 2016). Such optimizations are applied by modifying efforts' intensity, duration, and recovery time between bouts (Laursen and Jenkins, 2002). Training modality is another essential parameter required for prescribing sport-specific HIIT interventions. In accordance with the fundamental principle of training specificity, training modality plays a key role in favorably stimulating the dynamics of the game while allowing for specific adjustments to emphasize particular behaviors and actions (Laursen and Buchheit, 2019). In this regard, previous research findings also suggested that, if properly designed, plyometric depth jumps could enhance maximal oxygen uptake (Brown et al., 2010). Later, Ducrocq et al. (2020) suggested that HIIT

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performed as interval drop jumps at a high work rate adequately stimulates mechanisms that enhance cardiorespiratory fitness and muscular power. They have shown that interval drop jumping may have a superior benefit over running HIIT by concurrently enhancing both endurance and aerobic performance (Ducrocq et al., 2020). Although this method could be a practical approach to enhancing both qualities simultaneously, a vital aspect of such comparative analyses is typically underscored: the homogeneity of the adaptations among athletes with different profiles. Running HIIT is controlled with reference intensities relative to the athlete's physiological capacity and performed in supervised and well-defined sessions. However, individualizing workloads during interventions such as interval drop jumping is complicated, and there are no standardized methods to calibrate the load of interventions precisely. More importantly, athletes with the same levels of muscular power could have varying cardiorespiratory fitness, and performing interval exercise without a reference intensity linked to cardiorespiratory fitness (e.g., %$\dot{V}O_{2max}$) may result in a heterogeneous adaptation across team members. Typically, when presenting responses to various exercise interventions, the convention is to display average group values, assuming that these values accurately reflect individual reactions. However, it is important to acknowledge that individual responses to a standardized intervention can differ significantly among athletes with varying physiological profiles and locomotor abilities (Mann et al., 2014). Furthermore, the workload imposed by sport-specific interventions may be uneven due to the inability of people to control various factors influencing workload (Hill-Haas et al., 2008a; Hill-Haas et al., 2008b). This lack of uniformity in physical stresses may lead to diverse adaptations among athletes within a group or members of team sports (Clemente 2020; Sandford et al., 2021). Accordingly, the aim of this study was to compare the individual adaptations to interval running and interval jumping in volleyball players' physiological and performance measures. Given that current practices and studies may have led to more developed methods for monitoring the workload of interval running compared to interval jumping, we hypothesized that interval running would result in more homogenized adaptations for volleyball players.

Methods

Study design

The study employed a randomized controlled trial, incorporating two experimental groups (Figure 1). The players were matched according to playing position and then were randomly assigned to training groups. The study utilized a randomized-controlled design. Group allocation was decided through the use of a computerized random number generator, leading to group assignments that were unpredictable and based on chance. Prior to initiating the study, participants underwent a series of assessments encompassing laboratory and field-based measurements. These evaluations aimed to gauge cardiorespiratory fitness indicators and volleyball-specific motor abilities. Participants underwent a graded exercise test on the first visit to evaluate maximum oxygen uptake ($\dot{V}O_{2max}$) and related physiological variables. The second visit encompassed the assessment of Wingate-based anaerobic power. Jumping ability was measured during the third testing session, while the fourth occasion involved evaluating change of direction (COD) and linear speed. There was a 24-hour recovery period between testing sessions, during which participants were directed to refrain from alcohol and caffeine. Additionally, they were directed to abstain from engaging in vigorous physical activity during this timeframe (Gharaat et al., 20202). Subjects were also asked to complete food diaries 3 days before baseline testing and to replicate this diet before the post-training test session (Forbes and Sheykhlouvand, 2016). ~48 hours after the last testing session, participants began the six-week training program. Subsequently, 48 hours after the final training session, they underwent the same testing procedure, following the identical order and under the same conditions as the pre-test.

Participants

Twenty-four male collegiate volleyball players gave written informed consent and volunteered to participate in this study. Participants were members of two teams participating in provincial competitions and had at least five years of playing experience. Following the medical screening for any unknown complication or physical injury putting the participants at risk of high-intensity exercise, they were matched based on their playing position (i.e., setter, middle blocker, hitter, and libero). Then they were randomly assigned to two training groups performing interval running (age = 21.9 ± 1.6 years, height = 185.2 ± 1.7 cm, body mass = 79.3 ± 6.8 kg) and interval jumping (age = 21.1 ± 1.3 years, height = 184.9 ± 0.8 cm, body mass = 81.1 ± 4.5 kg). All players were familiar with all-out interval interventions but had not engaged in HIIT over the three months preceding this study. All procedures adhered to the ethical standards outlined in the Helsinki Declaration and were approved by the ethical committee of the Putian University.

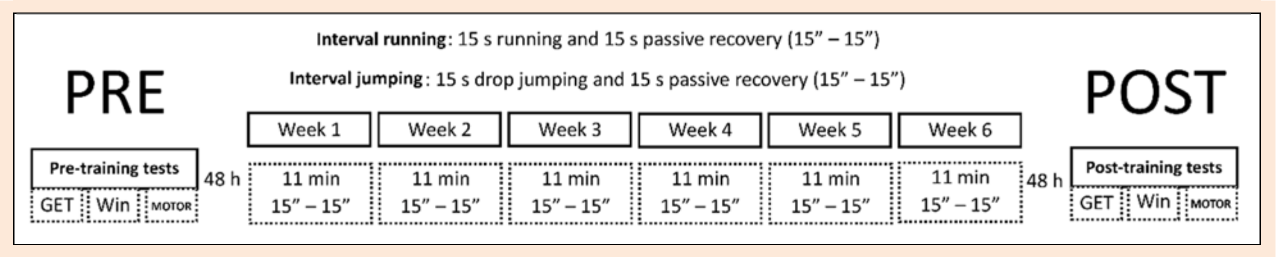

Figure 1. Overview of the experimental protocol. GET, graded exercise test; Win, lower-body Wingate test; MOTOR, motor abilities.

Graded exercise test

Following a 10-minute warm-up comprising five minutes of jogging and five minutes of dynamic stretching, athletes performed the graded exercise test on a treadmill (Technogym, Cesena, Italy). The test started at an initial intensity of 8 $km \cdot h^{-1}$, with velocity increasing by 1 $km \cdot h^{-1}$ every three minutes. Each stage had 30 seconds of relief intervals, during which blood lactate concentration was measured through earlobe blood sampling. A breath-by-breath gas collection system (MetaLyzer 3B-R2, Cortex, Germany) continuously recorded cardiorespiratory fitness measures throughout the test. The device measured $\dot{V}O_{2max}$, as well as the first and second ventilatory thresholds (VT_1 and VT_2), following standard criteria (Alejo et al., 2022; Dai and Xie, 2023). The minimal velocity that $\dot{V}O_{2max}$ elicited was established as $v\dot{V}O_{2max}$ as long as it could be maintained for a minimum of one minute. Two independent researchers localized the first and second ventilatory thresholds (VT_1 and VT_2). The VT_2 identification criterion was a continuous rise in the $\dot{V}_E$ equivalent for O_2 ($\dot{V}_E\ \dot{V}O_2^{-1}$) and the $\dot{V}_E$ equivalent for CO_2 ($\dot{V}_E\ \dot{V}CO_2^{-1}$) ratio curves in relation to the decrease in end-tidal O_2 tension ($P_{ET}O_2$). The first ventilatory threshold (VT_1) was also established as the point where an increase in $\dot{V}_E\ \dot{V}O_2^{-1}$ and $P_{ET}O_2$ occurred without a simultaneous rise in the $\dot{V}_E\ \dot{V}CO_2^{-1}$ (Alejo et al., 2022). If the researchers disagreed, the differences were resolved either by consensus after discussion or, if necessary, through consultation with a third expert. Also, cardiac hemodynamics were continuously measured throughout the test using impedance cardiography (PhysioFlow, Manatec, France), and cardiac output ($\dot{Q}_{max}$) and stroke volume (SV_{max}) were non-invasively recorded.

Lower-body Wingate test

A 30-second all-out Wingate test determined the participants' peak power output (PPO) and average power output (APO). At the beginning of the assessment, participants were instructed to pedal at their maximum speed against the inertial resistance of the ergometer (894E, Monark, Sweden). Subsequently, a resistance equivalent to 0.075 kg per kilogram of body mass was applied, and the electronic revolution counter was initiated. Continuous verbal encouragement was given throughout the test, and the device's software computed both PPO and APO (Tao et al., 2024).

Change of direction

Change of Direction (COD) performance was evaluated using the MAT test, a modified version of the T-test. This test evaluates athletes' COD-related abilities, including multi-directional running speed, linear sprints, shuffling to the right and left, and backpedaling. Because of the repeated sprints involving changes in direction over a brief distance, the MAT test is a more dependable and sport-specific test of agility compared to the T-test (Sassi et al., 2009). In summary, as depicted in Figure 2, the participants initiated the test by sprinting forward from cone A towards cone B and touching its base. Subsequently, they executed a shuffle to cone C while maintaining a forward-facing position without crossing their feet, then shuffled to the right towards cone C and touched it. Finally, they shuffled back to cone B and ran backward to the initial point at cone A. The reliability coefficient (ICC) for this test was 0.95.

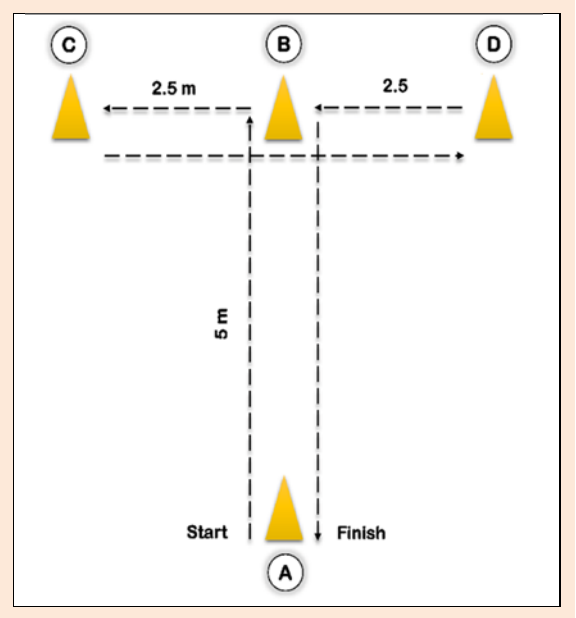

Figure 2. **MAT-test for evaluation of change of direction ability.**

Maximal sprint speed

After a general warm-up, participants completed two maximal 20-meter sprints between photocells (Freelap BLE 424, USA). They were directed to initiate the test standing with the front foot at least 0.5 meters behind the starting gate. The test commenced with a self-selected start time, and the 20-meter sprint time was recorded to the nearest 0.01 seconds. There were three-minute rest intervals between efforts, and the athlete's best performance was chosen for subsequent analyses. The ICC for this test was 0.94.

Jumping ability

The participants' jumping ability was evaluated by administering squat jump (SJ) and countermovement jump (CMJ) tests. During the SJ, participants placed their hands on their hips, widened their shoulders, flexed their knees to about a 90-degree angle for a 3-second, and executed a vertical jump with maximal effort (Ramirez-Campillo, et al., 2013). In the countermovement jump (CMJ) assessment, participants were directed to place their hands on their hips, adopt a wide stance with feet and shoulders apart, and execute a descending motion (without limiting the knee angle). Following this descent, they propelled themselves into a vertical jump with maximum effort and were asked to land upright (Ojeda-Aravena et al., 2021). The participants performed three consecutive jumps with 2-minute rest intervals between trials, and the analysis considered the best performance for further examination. The ICC for CMJ and SJ was 0.96 and 0.97, respectively.

In addition to evaluating SJ and CMJ, the participants' drop-jump (DJ) height and power were measured to identify the drop height eliciting the highest power output ($W \cdot kg^{-1}$). Participants performed a sequence of drop jumps using both feet from heights of 20, 30, 40, 50, and 60 centimeters (Byrne et al., 2010). The drop jumps were repeated three times at each height, with a 1-minute passive recovery between repetitions. Power output and jump height were estimated by ground contact, and the flight times were measured using an optoelectronic measurement system (Optojump Next, Version 1.3.20.0, Microgate, Bolzano, Italy) with an accuracy of 0.001 s. The drop height that resulted in the highest power output was then employed for interval jumping (Ducrocq et al., 2020).

Training interventions

Participants completed three sessions per week of HIIT during the off-season phase of the preparatory period. They were engaged in typical volleyball training sessions on Sunday, Tuesday, and Thursday, which comprised technical and tactical drills lasting 60 - 90 minutes. In addition to this training schedule, they completed three sessions per week of interval interventions on Saturday, Monday, and Wednesday in the afternoon (~ 5:00 P.M.). The training intervention was retrieved from the study of Ducrocq et al. (2020), who compared interval running or interval jumping interventions and concluded that both protocols adequately stimulate adaptive mechanisms involved in cardiorespiratory fitness. In both groups, participants executed 11 minutes of interval running or interval jumping, during which they ran or repeated drop-jumps for 15 seconds, alternating with 15 seconds of passive recovery. The intensity of interval running was set at 120% $v\dot{V}O_{2max}$. This running velocity verified to induce the longest duration spent in the red zone ($_{T}\dot{V}O_{2max}$) (Dupont et al., 2002), which typically involves reaching an intensity surpassing 90% of their $\dot{V}O_{2max}$ (Laursen and Buchheit, 2019). During interval jumping, participants executed drop-and-jump sequences using their respective athletic footwear. They moved back and forth between two stackable plyometric boxes one meter apart and started from the drop height that optimized power output. According to Ducrocq et al. (2020), nine drop jumps per 15 s result in a non-significant difference in $_{T}\dot{V}O_{2max}$ compared to interval jumping. Accordingly, the jumping frequency was set at 9 jumps per 15 s, and participants performed 198 drop jumps per session. Participants were directed to touch the hard linoleum surface with both feet and execute a rapid, high jump toward the box in front of them. The frequency of drop jumps was regulated by a specially created soundtrack, featuring a beep for each instance when participants were required to perform a drop and jump between the boxes.

Statistical analysis

The statistical analyses were performed using SPSS software version 24.0 (IBM Corp., Chicago, IL), and the sample size was determined through G*Power software (Faul et al., 2007). Descriptive statistics were presented as Mean ± SD. The normality of distribution was assessed using the Shapiro-Wilk test, and the homogeneity of variances was examined with Levene's test. A two-factor mixed analysis of variance (ANOVA) was conducted, incorporating the between factor [groups (interval running & interval jumping)] and the repeated factor [trial (pre-training vs. post-training)], to analyze significant interactions or main effects. In accordance with the study design (ANOVA: repeated measure, within-between interaction), a minimum of 6 participants was initially calculated, assuming an effect size of 0.8, an alpha level of 0.05, and a power (1 - β) of 0.95. However, to enhance statistical power to detect true effect, and anticipating potential participant dropout during the data collection phase, the sample size was increased to include 12 participants in each group. Using this sample size, the effect size for G*Power calculations would be 0.31. Inter-individual variability in the adaptive changes was assessed through two methods. Firstly, individual percent changes from pre- to post-training were computed for each variable, and the coefficient of variations (CVs) in the adaptive changes was determined as the ratio of the standard deviation to the mean group changes. Secondly, individual residuals in percent changes were calculated as the square root of the squared difference between the individual percent change and the mean percent change for each tested variable. Subsequently, the group mean residuals for each intervention were compared between interval running and interval jumping interventions using t-test to determine their effects on inter-subject variability in the magnitude of the adaptations. The α level was set at 0.05.

Results

Every player exhibited absolute compliance, leading to a 100% success rate. Additionally, there were no documented instances of injuries linked to the training or testing interventions. Table 1 and Table 2 indicate the effects of training interventions over the training period. Interval jumping resulted in significantly greater changes in SJ (p = 0.001; 95% CI: 2.51 - 5.42) and CMJ (p = 0.001; 95% CI: 2.11 - 4.61) compared to interval running. By contrast, the change in sprint speed in response to interval running was significantly greater than that of interval jumping (p = 0.002; 95% CI: 2.53 - 5.71).

After the 6-week training period, a significant time-regimen interaction ($p \leq 0.05$) was found in residuals of individual changes in VT_1, $\dot{Q}_{max}$, and SV_{max}, maximal sprint speed, and CMJ. Interval running resulted in lower residuals in individual changes in VT_1 (p = 0.04; 95% CI: 0.03 - 1.33), $\dot{Q}_{max}$ (p = 0.03; 95% CI: 0.04 - 1.64), SV (p = 0.04; 95% CI: 0.02 - 1.75) (Figure 3), and maximal sprint speed (p = 0.01; 95% CI: 0.72 - 1.95) (Figure 4) compared to interval jumping. By contrast, interval jumping resulted in lower residuals in individual changes in CMJ (p = 0.02; 95% CI: 0.08 - 1.32) than interval running (Figure 4).

Discussion

This study compared volleyball players' adaptive responses to interval jumping and interval running in terms of cardiorespiratory fitness, anaerobic power, and motor abilities. Our results indicated that both interventions effectively stimulate adaptive mechanisms involved in enhancing the mentioned qualities over a 6-week training period. Interval jumping resulted in a greater change in jumping ability than interval running. By contrast, interval running led to a more substantial change in sprint speed than interval jumping. Comparative analysis of the individual residuals in the adaptive responses indicated interval running results in more uniform adaptations across individuals in VT_1, $\dot{Q}_{max}$, SV_{max}, and maximal sprint speed compared to interval jumping. However, the homogeneity of the adaptations in CMJ in response to interval jumping was significantly greater than that of interval running.

Our results indicated that employing 192 drop jumps per session (a commonly used training modality for elevating explosive power performance), when conducted at a pace of nine jumps every 15 seconds, positively stimulates measures of aerobic fitness and cardiac hemodynamics to the extent that recognized for generating beneficial adaptive changes. Our results further elaborate on the previous findings made by Ducrocq et al. (2020), which showed that engaging in interval jumping elicited a similar response in the cardiorespiratory and oxidative systems as interval running. In another study, Brown et al. (2010) indicated that performing a single session of eight sets of 10 depth jumps from a height of 0.8 meters interspersed by 3-minute rest intervals between each set results in eliciting ~83% of $\dot{V}O_{2max}$ and recommended including plyometric depth jumping into a comprehensive program effectively prepares athletes for competitions involving both aerobic and anaerobic metabolic components. Our results corroborate these findings by demonstrating a favorable translation of interval jumping-induced responses to adaptive changes in the cardiorespiratory system. It seems that maintaining $\dot{V}O_{2max}$ in higher levels as a result of increased work rate through increased jump frequency per minute with reduced recovery time between work intervals could be a possible mechanism explaining interval jumping effects on cardiorespiratory fitness improvements. Elevated aerobic fitness could be attributed to enhanced oxygen delivery to active muscles (i.e., the central component of aerobic fitness), as evidenced by the enhanced $\dot{Q}_{max}$ and SV_{max} in our study, or the ability of active muscles to extract and utilize delivered oxygen (i.e., the peripheral component of aerobic fitness) (Sheykhlouvand et al., 2022; Sheykhlouvand ang Gharaat, 2024). Lower residuals in the individual changes in response to interval running in VT_1, $\dot{Q}_{max}$, and SV_{max} imply its potential to elevate these elements across individuals uniformly. The more controllable load of interval running could effectively impose the same degrees of external load, leading to receiving homogenized homeostatic stress by team members. It is essential to acknowledge that individual responses to a standardized intervention can vary significantly among athletes due to their divergent physiological profiles, locomotor abilities, and the differing workloads imposed on them by the intervention (Du and Tao, 2023). Although interval jumping resulted in significant improvements in measures of aerobic fitness, current practices and studies may have led to more developed methods for monitoring the workload of interval running compared to interval jumping, and athletes experience divergent homeostatic stress during interval jumping.

Table 1. Adaptive changes in cardiorespiratory fitness over the training period.

	Interval jumping		**Interval running**	
	Pre	**Post**	**Pre**	**Post**
$\dot{V}O_{2max}$ (ml·kg^{-1}·min^{-1})	46.7 ± 2.9	49.2 ± 3.3	47.6 ± 2.5	50.4 ± 2.9
P-value	0.001 ⁑		0.0001 ⁑	
%Δ	5.3		5.9	
ES	0.8		1.0	
CV of mean %Δ	44%		20%	
v$\dot{V}O_{2max}$ (km·h^{-1})	13.3 ± 0.8	14.1 ± 0.6	13.5 ± 0.9	14.5 ± 0.6
P-value	0.001 ⁑		0.0001 ⁑	
%Δ	6.0		7.4	
ES	1.1		1.3	
CV of mean %Δ	68%		44%	
VT_1 (%$\dot{V}O_{2max}$)	70.6 ± 2.5	74.1 ± 3.4	70.5 ± 2.1	74.4 ± 2.0
P-value	0.005 ⁑		0.002 ⁑	
%Δ	4.9		5.5	
ES	1.1		1.9	
CV of mean %Δ	38%		19%	
VT_2 (%$\dot{V}O_{2max}$)	83.2 ± 2.9	86.9 ± 3.2	84.0 ± 3.1	88.6 ± 3.3
P-value	0.002 ⁑		0.001 ⁑	
%Δ	4.4		5.4	
ES	1.2		1.4	
CV of mean %Δ	37%		19%	
$\dot{Q}_{max}$ (l·min^{-1})	29.0 ± 1.6	30.5 ± 2.1	28.7 ± 1.9	30.4 ± 1.9
P-value	0.001 ⁑		0.0001 ⁑	
%Δ	5.1		5.9	
ES	0.8		0.9	
CV of mean %Δ	42%		19	
SV_{max} (ml·b^{-1})	149.2 ± 8.5	157.0 ± 11.3	154.8 ± 8.5	163.2 ± 8.9
P-value	0.006 ⁑		0.0002 ⁑	
%Δ	5.2		5.4	
ES	0.7		0.9	
CV of mean %Δ	44%		18%	

Values are means ± SD; %Δ, within group changes from pre- to post-training; ES, effect size. $\dot{V}O_2$max, maximum oxygen uptake; v$\dot{V}O_2$max, velocity associated with $\dot{V}O_2$max; VT_1, first ventilatory threshold; VT_2, second ventilatory threshold; $\dot{Q}_{max}$, maximal cardiac output; SV_{max}, stroke volume. N = 12 for each group. ⁑ Significantly greater than pre-training value ($P < 0.05$).

Table 2. Adaptive changes in motor abilities over the training period.

	Interval jumping		Interval running	
	Pre	Post	Pre	Post
PPO (W)	749.8 ± 43.1	805.1 ± 51.7	800.8 ± 49.0	854.9 ± 55.9
P-value	0.002 ⁑		0.003 ⁑	
%Δ	7.3		6.7	
ES	1.1		1.0	
CV of mean %Δ	21%		20%	
APO (W)	490.9 ± 49.5	524.9 ± 51.5	482.8 ± 43.1	513.0 ± 47.8
P-value	0.001 ⁑		0.006 ⁑	
%Δ	6.9		6.2	
ES	0.7		0.6	
CV of mean %Δ	21%		22%	
20-m sprint (s)	3.38 ± 0.06	3.34 ± 0.11	3.39 ± 0.12	3.22 ± 0.15
P-value	0.08		0.001 ⁑	
%Δ	–1.9		–5.2 §	
ES	0.4		1.2	
CV in mean %Δ	92%		18%	
COD (s)	7.95 ± 0.25	7.74 ± 0.24	7.89 ± 0.24	7.69 ± 0.25
P-value	0.004 ⁑		0.004 ⁑	
%Δ	–2.7		–2.6	
ES	1.19		1.17	
CV of mean %Δ	31%		33%	
SJ (cm)	37.5 ± 1.5	40.3 ± 1.4	37.4 ± 1.7	38.7 ± 1.8
P-value	0.008 ⁑		0.01 ⁑	
%Δ	7.4 ‡		3.4	
ES	1.2		0.7	
CV of mean %Δ	16%		57%	
CMJ (cm)	43.0 ± 1.5	45.9 ± 1.6	43.2 ± 1.7	44.7 ± 1.9
P-value	0.004 ⁑		0.002 ⁑	
%Δ	6.7 ‡		3.5	
ES	1.8		0.8	
CV of mean %Δ	15%		53%	

Values are means ± SD; %Δ, within group changes from pre- to post-training; ES, effect size. PPO, peak power output; APO, average power output; COD, change of direction; SJ, squat jump; CMJ, countermovement jump. N = 10 for each group. ⁑ Significantly greater than pre-training value ($P < 0.05$); § Significantly greater changes than the interval jumping group ($P < 0.05$). ‡ Significantly greater changes than the interval running group ($P < 0.05$).

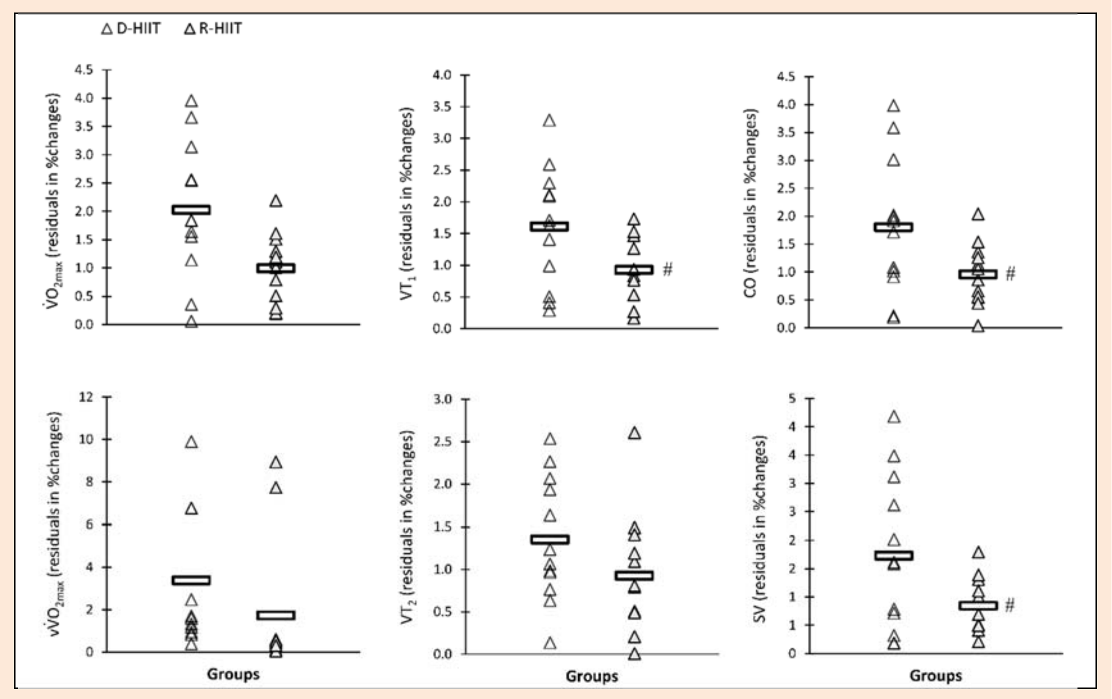

Figure 3. Residuals in individual changes in response to interval jumping and interval running over the training period in maximum oxygen uptake ($\dot{V}O_{2max}$), velocity associated to $\dot{V}O_{2max}$ ($v\dot{V}O_{2max}$), first ventilatory threshold (VT_1), second ventilatory threshold (VT_2), maximal cardiac output ($\dot{Q}_{max}$), and stroke volume (SV_{max}). Individual residuals in percentage change are shown by triangles, and mean group residuals in percentage change is shown by horizontal bars. # Significantly lower residuals in individual changes than interval jumping.

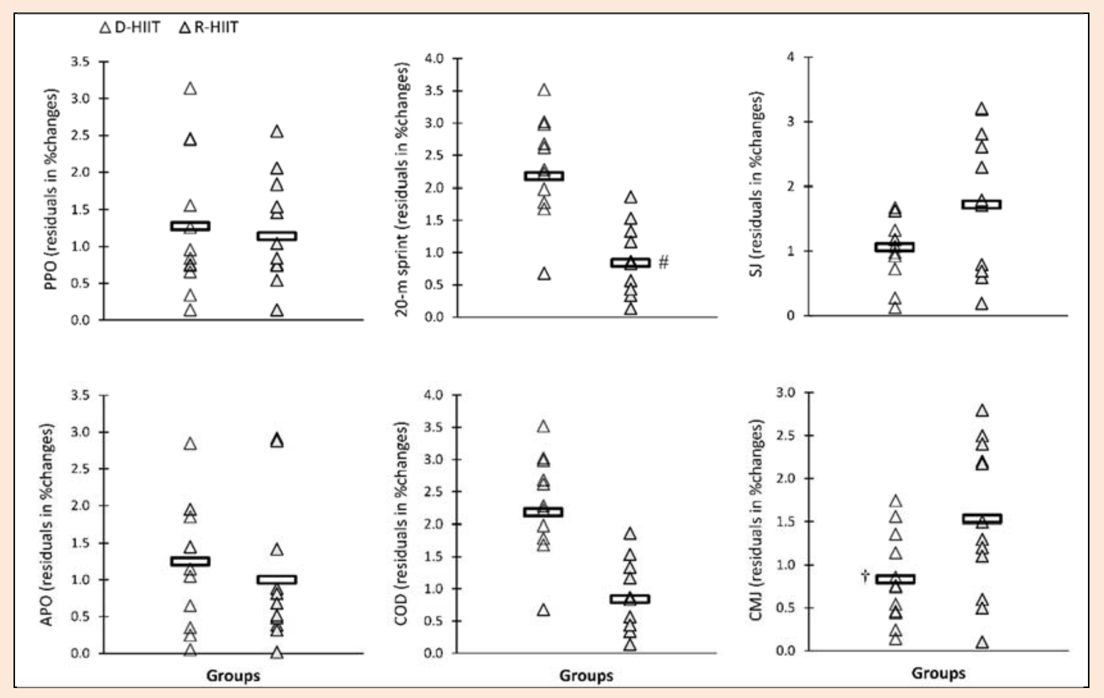

Figure 4. Residuals in individual changes in response to interval jumping and interval running over the training period in peak power output (PPO), average power output (APO), change of direction (COD) squat jump (SJ), and countermovement jump (CMJ). Individual residuals in percentage change are shown by triangles, and mean group residuals in percentage change is shown by horizontal bars. † Significantly greater changes than interval running.

One plausible explanation to diversity in the homogeneity of adaptations could be the difference in the intensity of the participants' explosive drop jumps, leading to inter-subject variability in the adaptive responses over the training period. The cumulative homeostatic stress encountered during exercise sessions is influenced by factors like exercise intensity and duration, acting as a triggering stimulus for adaptive responses (Mann et al., 2014). According to Flück (2006), at the cellular level, adaptation to exercise training arises from the collective impact of specific transcriptional and translational micro-adaptations occurring after each exercise session. Consequently, the heterogeneous acute exercise stimulus received may explain the individual variabilities in the training responses that accumulate over time (Mann et al., 2014).

Elevated anaerobic power and motor abilities were other important findings of this study. Our results align with the previous findings indicating the positive effects of different HIIT interventions on PPO and APO. In line with our experiment, Fereshtian et al. (2017) indicated that three weeks of running intervals performed at 100-130% $v\dot{V}O_{2max}$ increases PPO and APO in trained athletes. Likewise, Sheykhlouvand et al. (2016) indicated that three weeks of paddling HIIT performed at 100 - 130% $v\dot{V}O_{2max}$ significantly enhanced PPO and APO in well-trained individuals. Other studies implementing all-out Wingate-based interval pedaling (Farzad et al., 2011) and cranking (Sheykhlouvand et al., 2018) reported remarkable elevations in PPO and APO in trained individuals. Also, Song and Sheykhlouvand (2024) have recently indicated that six weeks of short sprint *all-out* running intervals and taekwondo-specific repeated interval kicks significantly increase PPO and APO in well-trained athletes. The mentioned studies attributed the enhanced PPO and APO to increased muscle phosphocreatine concentration and anaerobic enzyme activities (Farzad et al., 2011; Song and Sheykhlouvand, 2024), muscle buffering capacity (Sheykhlouvand et al., 2018), and improvement in motor unit recruitment (Dolci et al., 2020; Sheykhlouvand et al. 2016). Also, the elevated vertical jump could be attributed to the improvement of the muscle-tendon system's mechanical properties, enhanced muscle coordination, and an increased alpha motor neurons' firing rate (Buchheit and Laursen, 2013). Repeated drop jumps performed at the intensity eliciting the greatest power output ensure the same degrees of external explosive loads and facilitate more uniform adaptations compared to interval running. On the other hand, the duration of foot contact during interval running resembles the utilization of the stretch-shortening cycle observed in jump training (Lee et al., 2020). Therefore, this action induces adaptive alterations in the neuromuscular systems and improves vertical jump performance (Fang and Jiang, 2024).

Our results indicated both interval jumping and interval running effectively enhanced COD with no difference in the changes and homogeneity of the adaptations. Improving rapid force development and increasing power generation in the lower extremities are essential for facilitating COD (Miller et al., 2006). During activities demanding a change of direction, the leg extensor muscles undergo rapid transitions between eccentric and concentric muscle actions with minimal ground contact time (Miller et al., 2006; Clemente et al., 2022). It seems, both interval jumping and interval running adequately stimulate adaptive mechanisms involved in COD performance enhancements. Enhanced linear sprint speed is another adaptation to interval jumping and interval running. In line with our findings, previous studies have suggested that interval training positively influences athletes' sprint performance within a training duration of 4 to 6 weeks (Lee et al., 2020; Arazi et al., 2017). Studies indicate that interval training programs have been correlated with improvements in sprint acceleration and velocity, alongside enhancements in stride length. These findings contribute to overall gains in sprint performance (Clemente et al., 2022; Rimmer and Sleivert, 2000). On the other hand, the notable improvements in muscle actions, particularly the smooth transition from eccentric to concentric contractions of the leg extensor muscles with minimal ground contact time, coupled with the activation of fast-twitch muscle fibers triggered by drop jumps, play a vital role in enhancing linear speed (Clemente et al., 2022; Rimmer and Sleivert, 2000; Arslan et al., 2022). Personalized running intervention and a higher homeostatic external load imposed over the training period could result in more consistent adaptations to interval running across participants. This study has a potential limitation due to the exclusive inclusion of male participants, which confines the findings' applicability solely to males without extending to females. Moreover, our capacity to closely monitor participants' sleep quality and rigorously track dietary habits was restricted. It is important to note that our results are related explicitly to interval interventions conducted within the conditions of this study. The likelihood of comparable results with different reference intensities or training volumes remains uncertain.

Conclusion

Our findings demonstrated that both interval jumping and interval running produced significant improvements in key indicators of cardiorespiratory fitness, anaerobic power, and motor abilities over the course of a 6-week training program. A comparative analysis of inter-individual variability in response to the training modalities highlighted distinct patterns of homogeneity in the adaptations. Interpretation of the outcomes mentioned above led us to conclude that although both training modalities effectively improve the mentioned variables concurrently, tailoring the HIIT intervention to the reference intensity and training modality specific for each quality will likely have a more optimal impact on the measured quality.

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The experiments comply with the current laws of the country in which they were performed. The authors have no conflict of interest to declare. The datasets generated during and/or analyzed during the current study are not publicly available but are available from the corresponding author who was an organizer of the study.

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Key points

- Interval jumping performed using drop height that results in the highest power output can effectively enhance cardiorespiratory fitness and anaerobic power in male collegiate volleyball players.
- Interval running has a superior effect to interval jumping in uniformly enhancing ventilatory threshold, cardiac hemodynamics and linear sprint speed.
- Interval jumping leads to more substantial and homogenous adaptations in jumping ability than interval running.
- Prescribing HIIT intervention according to the reference intensity specialized for an attribute will likely produce a more optimal impact on that quality.

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