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Physiological and performance adaptations to beta alanine supplementation and short sprint interval training in volleyball players

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This study aimed to elucidate the impact of combining Beta-Alanine (BA) supplementation with short sprint interval training on cardiorespiratory fitness, anaerobic power, and bio-motor abilities in volleyball players. Twenty young male athletes were randomly divided into 2 equal groups and performed 8 weeks of short sprint interval training while supplementing 4.8 g daily BA or placebo (polydextrose). The players were evaluated for volleyball-specific bio-motor abilities (vertical jump, horizontal jump, spike jump, block jump, 10-m linear sprint, and T-test change of direction speed) and physiological parameters (cardiorespiratory fitness and anaerobic power) pre- and post-intervention. Both groups demonstrated significant ($p \leq 0.05$) improvements in all measured variables over time. A time-regimen interaction was observed in jumping ability enhancement from pre- to post-training, wherein BA elicited more significant changes in both vertical and horizontal jumps compared to the placebo. Analyzing residuals in changes and the coefficient of variations (CV) in mean group changes demonstrated that BA supplementation results in uniformly inducing adaptive changes among individuals. Therefore, in light of these results, it is recommended that coaches and trainers take into consideration the utilization of BA as an ergogenic aid to enhance the vertical and horizontal jumps of volleyball players and increase the homogeneity in adaptive responses over the training period.

Keywords Ergogenic aid, Athletic, Interval training, Physical performance

Volleyball is a dynamic team sport that demands players to execute powerful maneuvers encompassing vertical and horizontal movements interspersed with short rest intervals[1,2]. A typical five-set volleyball match entails each player engaging in more than 250 jumps, highlighting the essential need for rapid recovery to maintain strength and power performance, crucial elements for success in volleyball competitions[2,3]. Besides the vertical jumps, players are required to execute a range of explosive horizontal movements, involving frontal and lateral actions characterized by rapid changes in direction and speed[4,5]. Sustaining these explosive actions consistently throughout a match depends on factors like intramuscular buffering capacity, anaerobic power, and aerobic capacity[2,3]. Therefore, designing an effective training intervention to enhance these metabolic pathways becomes pivotal in optimizing volleyball players' athletic performance.

High-intensity sprint interval training is one of the frequently used effective interventions in optimizing aerobic and anaerobic capacities as well as the overall physical fitness of volleyball players[6–8]. In practical terms, this training approach can be categorized into short sprints lasting 3 to 10 s or longer sprints ranging from 30 to 45 s[9]. While not directly mimicking volleyball movements, sprint interval training remains a viable strategy, especially during the preparatory phase, where shorter durations (less than 5 s) are employed. Studies indicate that employing shorter durations in sprint interval training, such as 5 s, can yield more substantial enhancements in neuromuscular, metabolic, and aerobic capacities compared to longer durations[8]. Given that a standard volleyball rally spans approximately 5 s[10], integrating exercise drills (e.g., short sprint interval training) within a similar timeframe can induce potential advantages for volleyball players, effectively targeting both aerobic and anaerobic metabolic pathways[11].

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Apart from the exercise interventions utilized, the utilization of sports supplements alongside training has seen a significant rise among athletes[12,13]. This complementary approach aims to boost cardiorespiratory and physical fitness, augmenting their training routines[12]. Within the context of a volleyball match, characterized by repetitive high-intensity actions, there is a notable elevation in blood lactate, H^+, and stress hormones, such as cortisol[4]. The utilization of sports supplements has been shown effective in reducing these physiological and biochemical responses.

Beta-alanine (BA), a non-proteinogenic amino acid, occurs naturally in the liver and is present in foods such as chicken, beef, pork, and fish[13]. Through BA supplementation, athletes can increase muscle carnosine levels in both fast-twitch and slow-twitch muscles[14]. Increased carnosine levels enhance the muscles' ability to buffer acid, leading to a delayed onset of muscle fatigue and the potential advantage of inducing greater muscle performance adaptations[15]. Accordingly, BA supplementation is considered a strategy to enhance performance in high-intensity exercises, potentially serving as an ergogenic aid for activities such as sprints and endurance capacity[16]. Improving these attributes could significantly enhance sport-specific performance in volleyball matches. Nevertheless, there is a lack of comprehensive data on the impact of prolonged BA supplementation during short sprint interval training on the physiological and sport-related performance adaptations of volleyball athletes. Inter-individual variability in response to BA supplementation is another critical parameter often overlooked in studies[13,15,16]. The emphasis has predominantly been on the collective outcomes of a group, disregarding the individual differences in how they respond to both training and supplementation. Hence, it becomes imperative to consider optimizing the individual response to supplementation during the training period. Unfortunately, there is a paucity of research on this subject, specifically targeting the analysis of individual responses to short sprint interval training and BA supplementation over a period. Moreover, there is ongoing uncertainty regarding whether incorporating BA supplementation alongside short sprint interval training can lead to volleyball-specific performance and physiological improvements in male players, compared to short sprint interval training alone. Addressing these gaps in knowledge is crucial for a more comprehensive understanding of the potential benefits and individual responses associated with integrating BA supplementation and short sprint interval training in the context of volleyball performance.

Despite the extensive research conducted on the short-term and long-term effects of BA supplementation on different physical performance parameters of athletes post resistance and plyometric training[12–16], the potential advantages of incorporating BA with short sprint interval training as an alternative training strategy for volleyball players have not been thoroughly examined. Presently, there is a lack of understanding regarding the impact of BA supplementation on volleyball players' performance, as well as the adaptive responses of volleyball players to BA supplementation and short sprint interval training. Therefore, the primary objective of this investigation was to evaluate how 8 weeks of BA supplementation and short sprint interval training affect adaptive responses in the lab-based physiological parameters (cardiorespiratory fitness and anaerobic power) and volleyball-specific bio-motor abilities (vertical jump, spike jump, horizontal jump, block jump, 10-m linear sprint, and T-test change of direction speed) in male players. Furthermore, this study analyzed individual responses to the training and BA supplementation to determine the optimal adaptation method.

Methods
Subjects
Sample size was determined using G*Power statistical analyses software (Version 3.1.9.2, University of Kiel, Germany)[17]. The analysis indicated that a total sample size of N = 20 would be adequate to assess the effects of BA supplementation on physiological and sport-related performance in volleyball players with an alpha level of 0.05 and a power (1-beta) of 0.80[13]. Consequently, twenty male trained volleyball players from the local academy with experience in national level competitions at least twice within the two years before their inclusion in the study and the same training habits (i.e., tactical and technical drills for three times a week, lasting between 80 and 90 min each session) volunteered to participate in the study. The players were matched based on their playing positions and then were randomly assigned to two equal groups performing short sprint interval training in conjunction with BA supplementation (n = 10: age = 24.6 ± 2.5 years, height = 182.6 ± 5.5 cm, weight = 81.5 ± 4.1 kg, and volleyball training experience = 8.1 ± 1.7 years) or placebo (PL, n = 10: age = 23.8 ± 2.7 years, height = 181.2 ± 6.7 cm, weight = 79.8 ± 6.9 kg, and volleyball training experience = 8.6 ± 1.9 years). To be eligible for the study, subjects needed to meet specific inclusion criteria, outlined as follows: (a) absence of lower body injuries that could impact testing and training sessions, (b) no participation in regular plyometric, strength, or sprint interval training during the study period and the preceding 3 months, and (c) no consumption of any supplements, specifically BA, within 6 months prior to the study. A comprehensive health history questionnaire was administered during the participant recruitment process to screen for the use of nutritional, drug, and hormonal supplements. Before data collection, the participants were thoroughly informed of the possible risks and discomforts associated with the study. The participants were required to carefully read and sign the informed consent form, which was approved by the Ethics Research Committee of the Hoseo University of Korea and in accordance with the Declaration of Helsinki.

Study design
The present investigation constitutes a longitudinal study employing a randomized, double-blind, placebo-controlled design. The study spanned 10 weeks, from July to September, encompassing one week dedicated to familiarization and pre-testing, 8 weeks allocated to training, and a final week designated for post-testing. Before and after the training phase, participants underwent assessments related to volleyball performance (including vertical jump [VJ], spike jump [SJ], horizontal jump [HJ], block jump [BJ], 10-m linear sprint, and T-test for change of direction speed) as well as lab-based physiological measurements (incremental exercise test using gas

collection system and lower-body Wingate test). These measurements occurred on four separate days with a 24-h interval: DAY 1 involved VJ, SJ, HJ, and BJ; DAY 2 cardiorespiratory fitness test; DAY 3 10-m linear sprint and T-test; and DAY 4 lower-body Wingate anaerobic test. Both groups engaged in volleyball training on non-consecutive days (Monday, Wednesday, and Friday) and completed a short interval training program before their afternoon volleyball practice sessions (5:00 to 7:00 P.M.). Following the training period, participants completed an identical testing procedure, adhering to the same sequence and conditions as the pre-test[18,19]. Based on the current study's methodology, a control group was not utilized due to the similarity in volleyball training routines and intensity among the players. To address the absence of a control group, each individual's changes were examined to elucidate the main effects of training and BA supplementation. Additionally, the inter-subject variability in responses to training and supplementation among individuals was measured to clarify the consistency in adaptations across the groups.

Testing procedures

The performance assessments were carried out on a volleyball court, whereas the measurement of physiological variables occurred in a laboratory maintained at a temperature range of 27–29 °C. Participants were explicitly instructed to maintain regular physical activity throughout the study. They were advised to abstain from alcohol and caffeine consumption, as well as refraining from intense physical activity within 24 h proceeding each testing session. A standardized 15-min warm-up routine was administered to all participants before the tests. Moreover, participants were directed to ensure a minimum of 9 h of sleep and to wear identical footwear for both the pre and post-tests.

Anthropometric measures

To assess the participants' body mass, an electrical scale (Tanita, BC-418MA, Tokyo, Japan) was employed while wearing light clothing and barefoot. Furthermore, their height was measured using a stadiometer (Seca 222, Terre Haute, IN, United States).

Sport-specific performance measures

Jumping ability

The jumping ability of volleyball players was assessed through VJ[20], SJ[21], BJ[22], and HJ[23]. The VJ, SJ, and BJ jumps were measured using a wall-mounted vertical jump tester (VERTEC Power System, USA) positioned on the volleyball court. The VJ assessment was utilized to evaluate vertical jumping capability by jumping upwards to measure lower body power[20]. The SJ was employed to evaluate the vertical jumping ability of players using a standard run-up (i.e., four-step approaches) for a volleyball spike, specifically focusing on their maximum reaching[21]. Furthermore, the BJ serves the purpose of evaluating the transition from eccentric to concentric movement in jumps accompanied by arm swinging, measuring the highest point achieved by the fingertips of both hands during the jump, starting from chest level[22]. The HJ required participants to jump horizontally, aiming for the maximum achievable distance, with the landing measured by a tape measure securely fixed to the floor. Prior to the jump performance tests, all participants completed 3 submaximal jumps as a warm-up. They then executed 3 maximal jumps for each test, with a 30-s rest period between each attempt. Additionally, a 5-min rest interval was implemented between each jump test. The highest score achieved in each test was selected for subsequent analysis.

10-m linear sprint

To assess the acceleration speed, participants were instructed to sprint 10 m between two electronic timing gates (Brower Timing Systems, Draper, UT, USA) positioned at the start (0 m) and end (10 m) of a linear track. The fastest sprint time achieved out of the three attempts, with a 1-min rest interval, was chosen for subsequent analysis[20].

T-test change of direction speed

The T-test was employed to evaluate volleyball players' change of direction (CoD) speed, forward sprinting, and back-pedaling abilities[24]. This test was administered on a volleyball court, and time was measured using electronic timing gates with a nearest of 0.001 s. The best performance from the two trials, following a 3-min rest period, was chosen for further analysis.

Physiological parameters

Cardiorespiratory fitness

A graded exercise test was conducted on a treadmill (SportsArt, USA) by utilizing a breath-by-breath gas collection system (Hans Rudolph Inc., located in Shawnee, KS, USA) to measure maximum oxygen consumption (VO_{2max}) which previously described[25]. Briefly, the test began at a speed of 8 km/hr and increased by 1 km/hr every 3 min until the participants reached a point of volitional exhaustion. Several criteria were utilized to determine if the athlete achieved VO_{2max}, including a) a stabilization of VO_2 despite an increase in workload, b) a respiratory exchange ratio of more than 1.1, c) a blood lactate concentration of 8 mmol/L or higher, d) a maximum heart rate equal to or greater than 95% of the age-predicted maximum (220–age)[26,27]

Lower-body Wingate test

A 30-s maximal Wingate anaerobic test evaluated the peak power output (PPO) and average power output (APO) of the lower body. This test utilized a mechanically braked cycle ergometer (model 894E, Monark, Sweden), and the resistance was adjusted to 0.075 kg/kg of the participant's body mass. Participants initiated the test by pedaling at maximum speed against the device's inertial resistance, and then a personalized load was added. Throughout the 30-s duration, participants were verbally encouraged to maintain their maximum effort. The PPO was the highest power achieved at the 5-s mark, while APO represented the average power output throughout the test[28].

BA supplementation

Throughout the 8-week training period, the BA group received a daily dosage of 4.8 g of beta-alanine (Pure Organic Ingredients, Utah, USA). This amount was divided into six equal doses of 0.8 g, taken at two-hour intervals throughout the day, following the protocol by Trexler et al.[14]. In parallel, participants in the PL group were provided with an equivalent dose of polydextrose. Both the beta-alanine (BA) and polydextrose (PL) were encapsulated, and participants were instructed to take them with juice. Notably, the capsules were devoid of any information regarding their composition, ensuring that investigators and participants remained unaware of the contents until the study's conclusion. Weekly forms and controlled supplement packets were employed to monitor adherence to the supplementation protocol, enabling the assessment of whether participants used or abstained from using BA or PL. In this investigation, the utilization of sustained-release version of the supplement was employed to reduce the paresthesia associated with BA ingestion. In addition, the PL group in the present study is utilized to monitor the psychological outcomes of the supplementation that was previously recommended in studies involving a supplement group[13]. This study design, which includes a PL group receiving polydextrose, is widely acknowledged as the gold standard for evaluating the effectiveness of BA treatments in the study.

Physical activity and diet control

Throughout the study, participants were instructed to adhere to their regular dietary and physical activity routines. Furthermore, they were tasked with documenting their food intake over three days preceding the initial testing and replicating the same dietary regimen before the post-training test session (Table 1). The Nutritionist IV diet analysis software was employed to ascertain the total consumption of calories, protein, carbohydrates, and fats.

Training program

The participants engaged in their regular volleyball training practice during off-season, incorporating tactical drills, technical exercises, and simulated competitive games on Monday, Wednesday, and Friday, lasting 80 to 90 min each afternoon (from 5:00 to 7:00 P.M). Each training session is initiated with a 15-min warm-up consisting of 5 min of running, 5 min of stretching, and 5 min of sprint and ballistic movements. Prior to volleyball training, both the BA and PL groups underwent a short sprint interval training program involving 4 sets of 10 × 5-s all-out running-based efforts with a 15-s recovery between trials and a 3-min self-paced rest interval between sets[8]. A specialized strength and conditioning coach closely monitored all training sessions to ensure the athletes' adherence to the prescribed training program.

Statistical analysis

The data are presented as mean ± SD. The normality of distribution was assessed using the Shapiro–Wilk Normality test. A repeated-measures ANOVA (2 [group] × 2 [time]) was employed to identify significant differences between the two groups for each tested variable. Effects size (ES), determined by Hedges' g, and were categorized as trivial (< 0.20), small (0.20–0.60), moderate (0.60–1.20), large (1.20–2.00), or very large (> 2.00). The significance level was set at 0.05, and the 95% confidence interval (CI) was also reported[29]. Magnitude-based inferences were favored over conventional null hypothesis testing due to the potential bias introduced by small sample sizes and the limited ability to assess practical significance. The scale for interpreting the probabilities was as follows: possible = 25–75%; likely = 75–95%; very likely = 95–99.5%; most likely > 99.5%[29]. The coefficient of variation (CV) was computed to assess inter-individual variability in adaptations over time[30,31]. Individual percent changes from pre-training to post-training were calculated for each variable, and the mean ± SD of these changes was determined. The CV (ratio of SD to the mean) of percent changes was then calculated for each variable. Additionally, individual residuals in changes were computed as the square root of the squared difference between individual change and mean group change for each tested variable. Ultimately, the inter-subject

Groups	Variables			
	Energy intake (kcal.d^{-1})	Carbohydrate (g.d^{-1})	Fat (g.d^{-1})	Protein (g.d^{-1})
BA				
Pre	2940 ± 171	463 ± 32	78 ± 25	99 ± 16
Post	3004 ± 196	478 ± 28	79 ± 23	105 ± 19
PL				
Pre	2910 ± 197	475 ± 35	76 ± 21	106 ± 21
Post	2980 ± 201	488 ± 42	78 ± 22	110 ± 18

Table 1. Dietary intake for the BA and PL groups pre- and post-training period. Data are reported as mean ± SD.

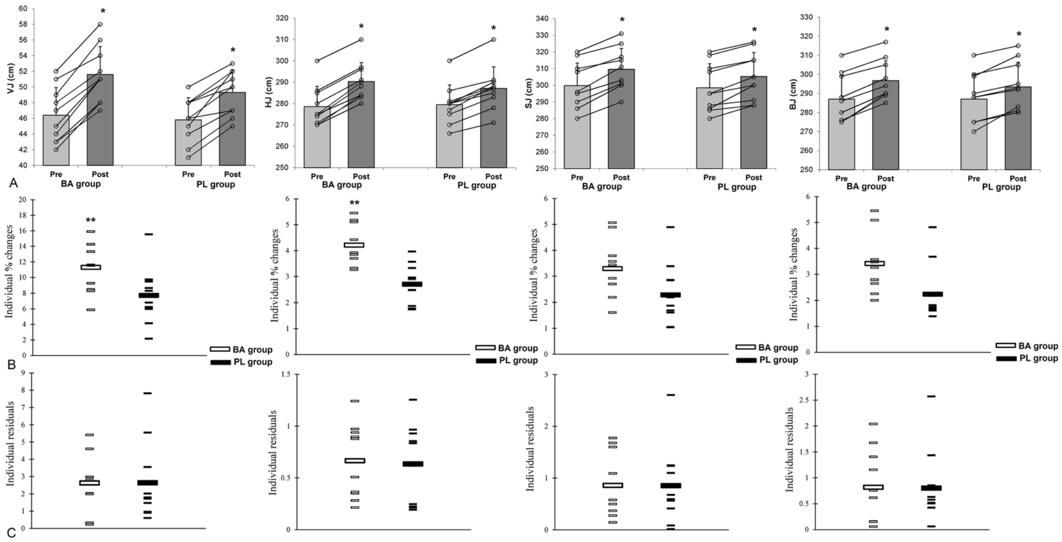

Figure 1. Mean group change (**A**), individual changes (Δ%) (**B**), and residuals in Δ% (**C**) in vertical jump (VJ), horizontal jump (HJ), spike jump (SJ), and block jump (BJ) for the BA and PL groups. * Denotes significant differences compared with pre-training ($p \leq 0.05$). ** Denotes significant differences between the groups ($p \leq 0.05$).

variability in adaptive responses to interventions was evaluated by comparing between-group mean residuals for each variable[30,31].

Results

No significant ($p > 0.05$) difference was observed between the BA and PL groups during the pre-test in sport-related performance and physiological variables. After training period, both interventions significantly improved the VJ (BA, $p = 0.001$, ES = 1.40, 95% CI 0.43 to 2.38 [Large, Most likely beneficial]; PL, $p = 0.001$, ES = 1.18, 95% CI 0.23 to 2.13 [Moderate, Very likely beneficial]), HJ (BA, $p = 0.001$, ES = 1.22, 95% CI 0.27 to 2.18 [Large, Very likely beneficial]; PL, $p = 0.001$, ES = 0.75, 95% CI − 0.15 to 1.66 [Moderate, Likely beneficial]), SJ (BA, $p = 0.001$, ES = 0.72, 95% CI − 0.19 to 1.62 [Moderate, Likely beneficial]; PL, $p = 0.001$, ES = 0.45, 95% CI − 0.44 to 1.34 [Small, Likely beneficial]), and BJ (BA, $p = 0.001$, ES = 0.81, 95% CI − 0.10 to 1.73 [Moderate, Likely beneficial]; PL, $p = 0.001$, ES = 0.47, 95% CI − 0.42 to 1.36 [Small, Possibly beneficial]) (Fig. 1).

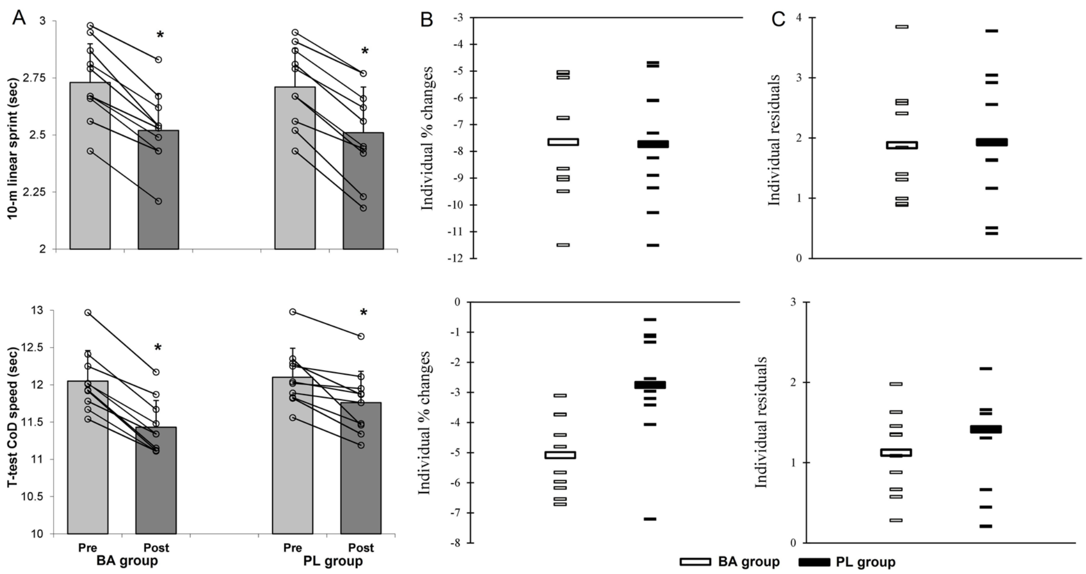

Figure 2. Mean group change (**A**), individual changes (Δ%) (**B**), and residuals in Δ% (**C**) in 10-m linear sprint, and T-test CoD speed for the BA and PL groups. * Denotes significant differences compared with pre-training ($p \leq 0.05$).

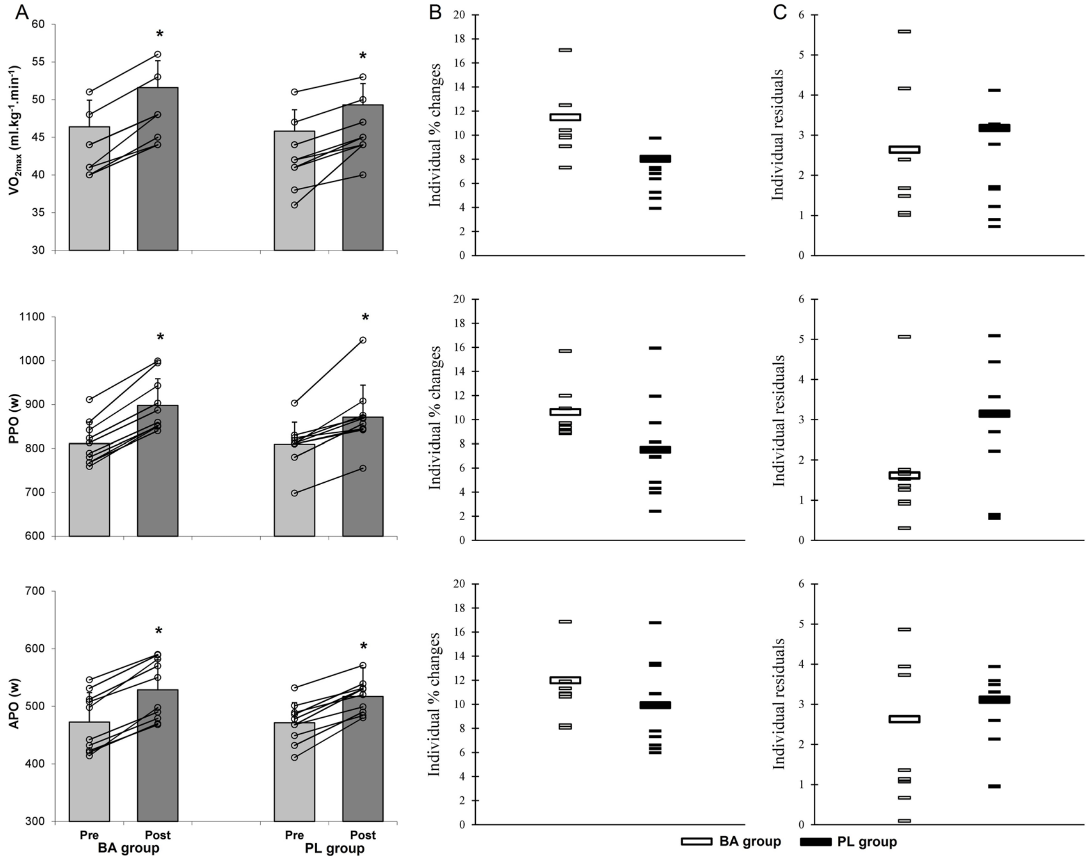

Figure 3. Mean group change (**A**), individual changes (Δ%) (**B**), and residuals in Δ% (**C**) in $\dot{V}O_{2max}$, PPO, and APO for the BA and PL groups. * Denotes significant differences compared with pre-training ($p \le 0.05$).

Upon comparing the percent change in the jumping ability of players, the BA group showed greater adaptive responses than the PL group in the VJ ($p = 0.01$) and the HJ ($p = 0.01$). In addition, the BA and PL groups indicated similar residuals in changes in jumping ability tests. By contrast, the BA group indicated lower CV in these tests than the PL group (Fig. 4).

After training period, both the experimental groups demonstrated meaningful effects in improvements of the 10-m linear sprint (BA, $p = 0.001$, ES = − 1.22, 95% CI − 0.26 to − 2.17 [Large, Most likely beneficial]; PL, $p = 0.001$, ES = − 0.96, 95% CI − 0.03 to − 1.88 [Moderate, Very likely beneficial]), and T-test CoD speed (BA, $p = 0.001$, ES = − 1.54, 95% CI -0.54 to -2.54 [Large, Very likely beneficial]; PL, $p = 0.048$, ES = − 0.81, 95% CI 0.1 to − 1.73 [Moderate, Likely beneficial]) (Fig. 2).

Upon comparing percent change and residuals in changes, the BA and PL groups indicated similar results in a 10-m linear sprint, and both groups showed the same CVs. In the T-test CoD speed, although the BA group showed more changes with lower residuals in changes than the PL group, these differences were not statistically significant ($p > 0.05$). In addition, the BA group indicated lower CV in the CoD speed than the PL group (Fig. 4).

After training period, both the experimental groups significantly enhanced $\dot{V}O_{2max}$ (BA, $p = 0.001$, ES = 1.22, 95% CI 0.26 to 2.17 [Large, Very likely beneficial]; PL, $p = 0.006$, ES = 0.80, 95% CI − 0.11 to 1.71 [Moderate, Likely beneficial]), PPO (BA, p = 0.001, ES = 1.50, 95% CI 0.51 to 2.49 [Large, Very likely beneficial]; PL, $p = 0.014$, ES = 0.94, 95% CI 0.01 to 1.86 [Moderate, Likely beneficial]), and APO (BA, $p = 0.001$, ES = 1.04, 95% CI 0.11 to 1.97 [Moderate, Very likely beneficial]; PL, $p = 0.001$, ES = 1.05, 95% CI 0.12 to 1.99 [Moderate, Very likely beneficial]) (Fig. 3).

Upon comparing percent change and residuals in changes, although the BA group indicated more changes than the BA group in physiological variables with lower residuals in changes, these differences were not statistically significant ($p > 0.05$). In addition, the BA group indicated lower CVs in the physiological variables than the PL group (Fig. 4).

Discussion

Numerous studies have investigated the acute and long-term effects of BA supplements on various aspects of physical and physiological performance in different sports[12–16]. However, the potential effects of combining BA supplementation with short sprint interval training on adaptive responses related to cardiorespiratory fitness, anaerobic power, and sport-specific performance in volleyball players have not been explored previously. Our results indicated that short sprint interval training is suitable for enhancing physiological and performance adaptations in volleyball players. BA supplementations could induce significantly greater gains in the VJ and HJ. Additionally, in regard to other variables, the BA group showed more changes with reduced inter-individual variability; however, these differences did not reach statistical significance. Consequently, when aiming to improve

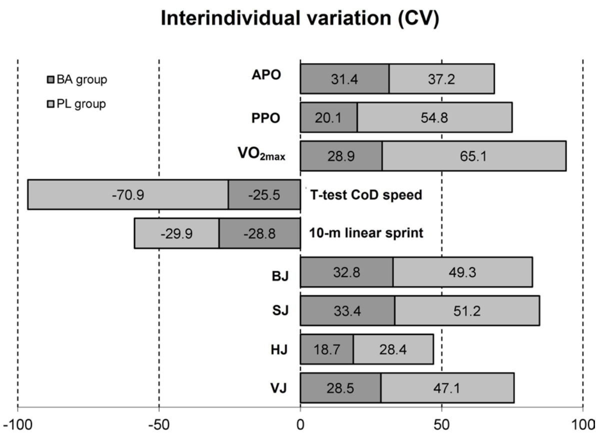

Figure 4. Coefficient of variations (CV) in adaptive responses in physiological parameters and sport-specific performance measures in the BA and PL groups.

the VJ and HJ performance of volleyball players, BA supplementation leads to greater changes with more uniform adaptations compared to the PL group.

Regarding jumping ability, both groups indicated positive adaptive changes following the 8-week of short sprint interval training. These findings are in accordance with previous studies reporting improvements in the jumping abilities of athletes following different forms of sprint interval training[7,11,32,33]. The foot contact type during sprint interval training resembles that of exercises involving the stretch–shortening cycle (such as plyometric exercises)[6], which is consistent with tasks requiring jumping and contributes to the improvement in jump performance. Moreover, this training may enhance the mechanical properties of the muscle–tendon system, improve coordination among muscle fibers, and increase the firing rate of alpha motor neurons during interval trials, ultimately leading to gains in jump performance[11].

When examining individual responses to training, the BA group exhibited significantly greater improvements than the PL group in the VJ and HJ. The BA group displayed more substantial changes in the SJ and BJ than the PL group, although these differences did not reach statistical significance. Both the BA and PL groups demonstrated similar residuals in changes, but the CV for the variables was lower in the BA group. These findings endorse using BA supplementation during the training period for volleyball players, as it induces greater gains and results in more consistent adaptations among players. BA supplementation during short sprint interval training was associated with an increase in muscle carnosine content[14]. This enhancement contributes to intracellular proton buffering, leading to an improvement in physicochemical buffering constituents and extracellular bicarbonate levels[16]. These effects enable muscles to work more efficiently with lower metabolites[13]. Importantly, BA helps maintain intramuscular pH and limits acidosis induced by short sprint interval training[12], ultimately contributing to greater adaptive changes in the jumping ability of volleyball players.

The results demonstrated that both interventions positively affected the 10-m linear sprint and T-test CoD performance after the 8-week training period. Our findings support previous research showing increased linear sprint and CoD speed in male athletes after sprint interval training[11,33]. The observed improvements are likely attributed to neuromuscular adaptations that induce gains in sprint and CoD speed[11]. The interval training employed in this study, characterized by short durations (≤ 5 s), necessitated rapid changes in muscle action, particularly in muscles with lower ground contact and fast-twitch muscle fibers, leading to adaptations in linear sprint and T-test CoD speed[6,33].

Upon analyzing inter-individual responses to the training, it was observed that both the groups indicated similar training effects with residuals in changes in the 10-m linear sprint after the 8-week training. BA supplementation could not favor adaptations in very short-duration exercises (i.e., sprinting speed), which aligns with previous statements[14]. Regarding CoD performance, the BA group demonstrated more significant percent changes with lower residuals, suggesting a favorable impact of BA on adaptations in CoD speed. BA seems to positively affect anaerobic glycolysis pathways, reducing lactate accumulation and improving mitochondrial coupling, ultimately optimizing training adaptations through enhancements in CoD speed[15]. BA supplementation increases carnosine levels, which act as an ergogenic aid, promoting calcium sensitivity of the muscular contractile apparatus and enhancing intracellular H^+ ion buffering[14]. These mechanisms contribute to adaptations in rapid changes in muscle action, leading to greater gains in CoD speed following short sprint interval training[13]. Moreover, BA induced consistent adaptations among subjects, resulting in lower residuals in changes and CV.

Both the BA and PL groups indicated significant changes in the VO2max, PPO, and APO after the 8-week training period. Our findings support previous research indicating improvements in male athletes' cardiorespiratory fitness and anaerobic capacities after sprint interval training[7,25,34,35]. Enhancements in cardiorespiratory fitness could be attributed to either an increase in the oxygen delivery (i.e., central component) or the improved ability of the active muscles to utilize delivered oxygen (i.e., peripheral component)[28,36–39]. Potential explanations for the enhanced anaerobic power may involve an increased discharge rate and recruitment of high-threshold motor units[39], elevated total creatine content in active muscles[40], and an improved buffering capacity of muscles[8,32,41].

Upon analyzing individual responses to the training, it was observed that BA supplementation had a favorable impact on physiological adaptations, reflected by lower residuals in changes and CV. There appears to be an augmentation in the total creatine content in active muscles and an improvement in muscle buffering capacity following BA supplementation, which may contribute to the observed improvements in physiological tests[13,15]. Furthermore, BA can potentially enhance the fatigue threshold following short sprint interval training, thereby improving intramuscular acidosis capacity[14]. This enhancement is thought to delay neuromuscular fatigue pathways and elevate muscle activation rates, limiting acidosis and improving time to exhaustion through gains in cardiorespiratory and anaerobic performance[12]. Therefore, coaches seeking to enhance these abilities may consider incorporating BA into their training regimens to optimize adaptations with minimal variation effects. Nevertheless, further research is warranted to fully understand the biochemical aspects of adaptations in both aerobic and anaerobic capacities when utilizing BA supplementation.

A few limitations exist in the present study that need to be acknowledged. The primary limitation is the small number of subjects, which presents interesting possibilities for future research. However, the study's optimal sample size was determined by G*power. Additionally, the absence of laboratory measurements for changes in blood pH, lactate concentration, and neuromuscular adaptations (e.g., EMG) limits the study's ability to determine the metabolic conditioning and muscular adaptations that occurred in volleyball players' anaerobic and aerobic capacity, as well as bio-motor ability. Therefore, the ergogenic effects of BA on physical performance adaptations during jumping tests may not be solely attributed to underlying physiological mechanisms. This discussion is speculative, and further research is required to investigate this crucial question.

Conclusion

Our findings suggest that short sprint interval training is an effective method to improve sport-related performance and physiological adaptations in volleyball players.

Furthermore, supplementation with BA can boost adaptations in jumping abilities (i.e., VJ and HJ) compared to PL while minimizing inter-individual variability in adaptive changes in physiological measures and bio-motor abilities. Based on these findings, coaches, and trainers should consider incorporating BA as an ergogenic aid to enhance vertical and horizontal jumps in volleyball players.

Data availability

The datasets employed and/or analyzed in the current study can be provided upon a reasonable request from the corresponding author.

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Competing interests

The authors declare that they have no competing interests.

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