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Short-Term Effects of Repeated-Sprint Training on Vertical Jump Ability and Aerobic Fitness in Collegiate Volleyball Players During Pre-Season

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ABSTRACT

International Journal of Exercise Science 15(6): 1040-1051, 2022. The aim of this study was to assess the effect of repeated-sprint training (RST) on vertical jump ability and aerobic power in college volleyball players. Nineteen male volleyball players, aged between 18-24 years, were randomized into the RST group (RST; n = 10) and control group (CG; n = 9). The RST included 2-3 sets of 6x30m all-out sprints, twice per week, in addition to the regular training routine. The control group performed only the regular volleyball training sessions (i.e. mainly of technical-tactical drills). All players performed a maximal graded treadmill test, vertical countermovement jump (CMJ), and repeated-vertical jump ability (RVJA) test before and after 6-weeks of the training program. The following variables were determined from the RVJA: peak ($RVJA_{peak}$), average ($RVJA_{mean}$), and rate of decrement ($RVJA_{Dec}$). A two-way ANOVA with repeated measures showed an interaction effect on CMJ ($F_{(1,17)} = 6.92$; $p = 0.018$; $\eta^2 = 0.289$), $RVJA_{peak}$ ($F_{(1,17)} = 4.92$; $p = 0.040$; $\eta^2 = 0.225$), maximal oxygen uptake ($F_{(1,17)} = 9.29$; $p = 0.007$; $\eta^2 = 0.353$) and maximal speed attained in the treadmill test ($F_{(1,17)} = 8.66$; $p = 0.009$; $\eta^2 = 0.337$), with significant improvements only on the RST group. In conclusion, RST, twice per week, improved RVJA and aerobic power in comparison to regular skill-based volleyball training.

KEY WORDS: Team sport, physical fitness, high-intensity efforts, athletic performance

INTRODUCTION

Volleyball is a team sport characterized by short bouts of high-intensity actions interspersed by low-intensity activities or passive recovery (33, 41). High-intensity actions rely on players' neuromuscular ability to perform volleyball technical skills (45). For instance, it has been previously demonstrated that volleyball players perform on average 30 jumps per set (42). Moreover, volleyball players perform at least one jump action during a rally of a total of ~45 rallies per set (33). Since a volleyball match may have up to five sets, players experience a high level of muscular fatigue (38). Therefore, the ability to maintain volleyball skills under muscular fatigue conditions plays an important role in the training and matches outcomes.

Vertical countermovement jumps are characterized by the utilization of the stretch-shortening cycle (SSC) of the skeletal muscle, in which the kinetic energy stored during the eccentric phase of the movement is used to improve the concentric phase (24, 27). The same phenomena occur during sprints actions (16, 24), which may explain the positive relationship previously reported between countermovement vertical jump (CMJ) height and maximal running sprints attained during 30-40m distances (1, 25, 40). These correlational data are supported by previous studies that showed that sprint-based training methods (i.e. repeated sprint training) increased CMJ performance (3, 22). However, to date, the impact of RST on repeated-jump ability (RVJA) has not been investigated. Of note, improvements on a single vertical jump, may not necessarily translate into improved RVJA, as required during volleyball training sessions and matches (41). In addition, it has been previously found a negative relationship between changes in the RVJA and perceived internal training load in a sample of high-level college volleyball athletes during 6-week in the preseason (14). This data suggests that players with higher RVJA are able to cope better with external training and competitive loads; thus, strength and conditioning coaches should aim at developing the players' RVJA performance.

Repeated-sprint training (RST) might be used to develop the players' physical fitness (3, 15, 22, 44). The RST is characterized by repeated "all-out" sprints (< 10 s) interspersed with short recovery periods (< 60 s) (16), which approximates the effort: rest ratio seen in volleyball matches (33, 34). Although RST does not involve volleyball-specific actions, it seems to be an interesting training stimulus that could be implemented during the preseason for improving neuromuscular, metabolic, and aerobic capacity (9). It is well-established that higher maximum oxygen uptake (VO_{2max}) plays an important role in recovering from repeated high-intensity actions in sports of intermittent nature, which represent a key factor to maintain high-intensity efforts performance (5, 15). In addition, it was found that players who displayed a high level of aerobic power can cope better with training loads (31). Therefore, volleyball training should at improving both anaerobic and aerobic ability. However, most of the investigations on volleyball players have focused on improving the lower limbs mechanical power output and technical-tactical aspects, and little attention has been direct to improving aerobic power (37). In this regard, RST appears to be an effective training mode purposed to improve multicomponent physical performance (i.e. sprints, repeated sprint ability, and jump) and VO_{2max} (6).

Considering that volleyball actions such as serves, blocks, and spikes play a key role in volleyball training sessions and competitive matches, there is no doubt that strength and conditioning coaches must develop jump performance in volleyball players. In addition, it is also important to improve the players' ability to maintain jumping performance under conditions of neuromuscular fatigue to cope better with the games' physiological demands. Hence, identifying training methods capable of concurrently increasing the RVJA and aerobic power might be useful for strength and conditioning coaches working with volleyball players. To the best of the authors' knowledge, this is the first study that aimed to investigate the short-term effects of RST on RVJA and aerobic power in a sample of volleyball players. We hypothesized that including RST in volleyball training sessions would lead to greater increases in CMJ, RVJA, and aerobic power performance in comparison to the regular skill-based volleyball training sessions.

METHODS

Participants

A priori sample size estimation was done before the commencement of the study, using the G∗Power version 3.0.10 (Heinrich-Heine-Universitat Dusseldorf, Germany). The results estimated a minimum sample size of 18 participants to be included in the study (1-β > 0.80) based on moderate effect size (ES = 0.63) (44). Twenty-one (*n* = 21) collegiate male volleyball players of the same team, competing at regional and national college-level tournaments participated in this study. All participants had more than three years of competitive volleyball experience and had no history of muscular or joint injury in the last six months. The volleyball team performed three training sessions per week. During the training program, two players from CG were excluded from the study (i.e. attendance < 85% of training sessions). Therefore, nineteen (*n* = 19) players completed the experimental sessions (CG = 09 and RST = 10).

The study was approved by the institutional Ethics and Research Committee (CAAE: 58886816.2.0000.5537; protocol number: 1.812.430), followed the ethical principles contained in the Declaration of Helsinki, and this research was carried out fully following the ethical standards of the International Journal of Exercise Science (36). All players participated voluntarily in this study and a written consent form was signed before entering the study.

Protocol

A randomized, controlled, and parallel-group design was conducted to assess the study's hypothesis. The current study lasted 6-weeks during the pre-season and included three specific volleyball training sessions per week (~120min each session), which were designed to develop specifics and general technical-tactical performance according to playing position (i.e., setter, hitters, or libero). One week before the commencement of the study protocol, all players were familiarized with the functional tests. The baseline assessment was done in the next week, including body composition, maximal graded treadmill test, CMJ, and RVJA, in three evaluation sessions with a 48-72hr interval between them. At the end of the 6-weeks training program, a one-week recovery microcycle preceded the post-training assessments (i.e., 30min reduction in daily training duration) to allow an adequate recovery period for the players (i.e., tapper) (28).

Training sessions started with ~15min of skill-based volleyball drills warm-up, jogging, full-body stretching, and submaximal jumps. Then, the players in the RST group performed all-out repeated-sprints bouts in addition to the regular volleyball training, twice per week. The training progression was based on the number of sets performed per week; two sets of 6×30m in the first week, three sets of 6×30m from the second to the fifth week, and two sets of 6×30m in the sixth week. Training volume was reduced in the last week to minimize the residual effect of neuromuscular fatigue. The sprints were interspersed by 20s passive recovery, and each set was separated by 5min of active recovery at low intensity (self-paced). The players in the CG underwent their regular skill-based volleyball training sessions (i.e. technical-tactical). The technical training involved, service, spike, receive, defensive, setting, and block drills. The tactical training included small-sided games to work offensive and defensive strategies. Both groups performed similar technical-tactical training routines.

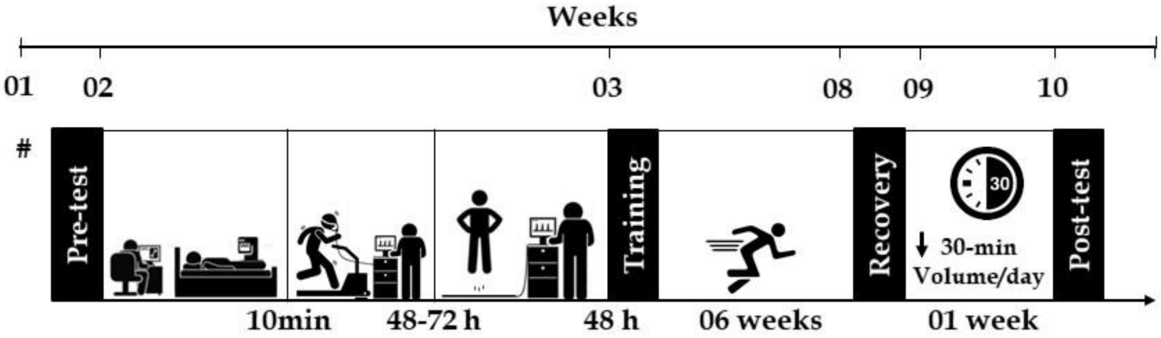

Figure 1. Experimental design
Note: # = familiarization sessions; the vertical line represents recovery between procedures

The sample characteristics were determined through anthropometric and body composition assessments. Body mass and height were measured using an electronic scale with a stadiometer (Welmy®, São Paulo, Brazil), with a precision of 0.1 cm to stadiometer and 50 g on an electronic scale, respectively (35). A total body scan was performed using dual-energy radiological absorptiometry (DEXA) (Lunar®/G.E PRODIGY - LNR41.990, United States).

Maximal graded treadmill test: The aerobic power was assessed by a maximal graded treadmill test (Centurion 200®, Micromed, Brasilia, Brazil). The test began with an initial velocity of 8 $km \cdot h^{-1}$ and keep constant during the first 3min, increasing 1 $km \cdot h^{-1}$ every 1min until subjective exhaustion (2). Heart rate (RS800cx monitor, Polar Electro®, Finland) and breath-by-breath air expired (Metalyzer 3B®, Cortex, Germany) were continuously measured during the test. At least two of the following criteria adopted must be met to consider the incremental test as maximum effort: (a) respiratory exchange ratio, $R > 1.1$; (b) $> 90\%$ of predicted maximum heart rate ($HRmax = 220 - age$); and (c) $RPE \geq 19$ reported by the Borg scale (7). All the trials were preceded by a flow, volume, and gases of the metabolic chart calibration according to the manufacturer's recommendations and the laboratory temperature was similar across the visits (~24°C). The final velocity reached in the incremental protocol (Vmax) and the highest 20s average value of oxygen uptake (VO_{2max}) were retained for analysis. All players were previously asked to abstain from vigorous physical activity on the last day before the test, not to eat heavy meals, and not to drink caffeinated beverages in the three hours preceding the test. Finally, all participants received strong verbal encouragement during the test.

Countermovement jump (CMJ) and repeated vertical jump ability (RVJA): The CMJ and RVJA assessment was performed on the same day with 3min rest between tests. CMJ height was determined on a contact platform connected to the Jump System 1.0 software (CEFISE®, São Paulo, Brazil). The procedures adopted in the current investigation followed previously well-established recommendations (24). All players performed two CMJs trials with a 1min of passive recovery between them as valid criteria for the RVJA test. The best CMJ height was retained for analysis. Before the RVJA test, all players were asked to achieve a jump height of at least 90% of their best individual CMJ and encouraged to perform a maximum effort and "jump as high as possible" during the test. The RVJA consisted of four sets of *all-out* continuous 15s jumps with 10s of passive recovery between trials (19).

The following measures were obtained during the RVJA test: best 15s average repeated-jump ($RVJA_{peak}$); 60s average repeated-jump ($RVJA_{mean}$); and repeated-jump performance decrement ($RVJA_{Dec}$). The latter was calculated as follows: $RVJA_{Dec} = 100 \times \{(RVJA_{peak} - RVJA_{worst})/RVJA_{peak}\}$; where the worst RVJA was considered as the worst 15s average jump. Good reliability was previously reported for those variables (20).

Internal training load: The internal training load was daily monitored through the session rating of perceived exertion method (s-RPE), determined using the CR-10 Borg's scale (13). The CR-10 scale is a category ranging from (0 = nothing at all to 10 = extremely strong). To determine s-RPE, players were asked ("how hard was your training session?") about their perceived exertion within 15min after the training session (43). All players were submitted to a familiarization process with the scale 2-weeks before the commencement of the study.

Statistical Analysis

Data were reported as mean and standard deviation after the assumption of normality was confirmed using the Shapiro–Wilk test. The independent *t*-test was used to compare variables at baseline. The 2-way mixed-model repeated-measures ANOVA test was used to verify the main effects and interactions (group x time) for dependent variables. Bonferroni's post hoc test was used to find the significant differences. The assumption of sphericity of the data was verified by the Mauchly test, and the Greenhouse–Geisser correction was adopted when this assumption was violated. Besides, within- and between-subjects effect sizes (ES) and magnitude based-inference (MBI) were calculated for practical significance. ES was interpreted according to Cohen as 0.2 (small), 0.5 (moderate), and 0.8 (large) (11). The MBI was used to determine whether the observed changes were considered harmful, trivial, or beneficial. The smallest worthwhile change was calculated as 0.2 of the pooled between-group standard deviation at baseline (4). The following thresholds were used: 1% = almost certainly not; 1%–5% = very unlikely; 5%–25% = unlikely; 25%–75% = possibly; 75%–95% = likely; 95%–99% = very likely; and >99% = almost certain (21). If the chance of having beneficial/better or harmful/poorer performances were both >5%, the true difference was considered unclear. The significance level was set as $p < 0.05$ and the analyses were performed using the Statistical Package for Social Sciences software version 20.0 (Chicago, IL, USA).

RESULTS

There were no statistical differences in the physical performance and anthropometric characteristics of the volleyball players at baseline ($p > 0.05$).

Table 1. Baseline characteristics of male college volleyball players.

Variables	RST ($n = 10$)	CG ($n = 9$)	p
Age (years)	21.6 ± 3.34	21.33 ± 2.91	0.856
Weight (kg)	81.81 ± 15.52	80.37 ± 14.52	0.837
Height (cm)	180.80 ± 6.68	181.44 ± 7.71	0.485
Body fat (%)	23.23 ± 5.35	24.62 ± 8.63	0.674
Fat-free mass (kg)	59.13 ± 6.31	58.03 ± 8.23	0.538
CMJ (cm)	36.31 ± 5.66	37.33 ± 7.10	0.317
VO_{2max} (ml ·min^{-1} ·kg^{-1})	50.39 ± 4.30	48.84 ± 5.89	0.293

Note: CG = control group; RST = repeated-sprint training group; CMJ = countermovement jump; VO_{2max} = maximum oxygen uptake

Figure 2 shows the weekly internal training load across the study intervention. No differences were observed between groups ($F_{(5,50)} = 1.11$; $p = 0.36$; $\eta^2 = 0.10$). The main time effect was found between the sixth week and the firsts training weeks ($F_{(5,50)} = 24.70$; $p = 0.01$; $\eta^2 = 0.71$) in both groups.

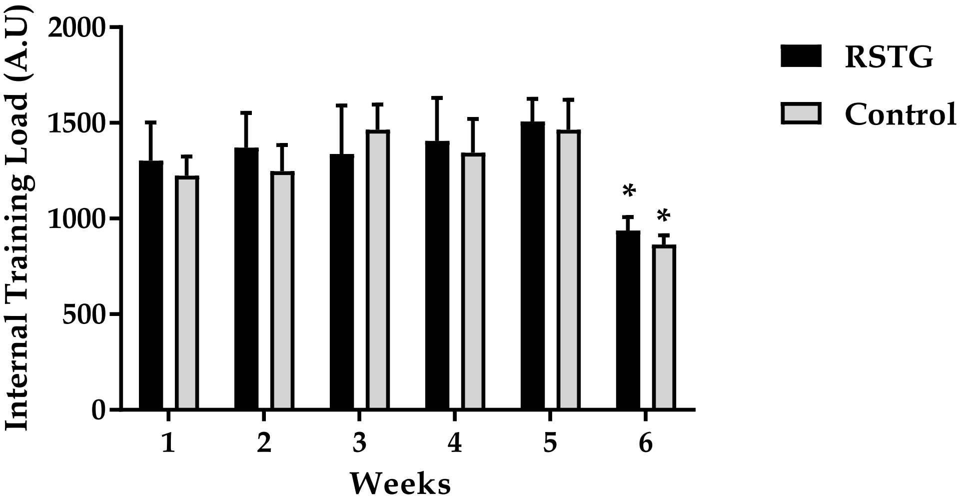

Figure 2. Weekly internal training load assessed using the session ratings of perceived exertion method. RST= repeated sprint training group; * = significant difference from week one to five ($p = 0.01$).

Table 2 presents the effect of RST on the vertical jump ability and aerobic power. An interaction effect was observed for CMJ ($F_{(1,17)} = 6.92$; $p = 0.018$; $\eta^2 = 0.289$), $RVJA_{peak}$ ($F_{(1,17)} = 4.92$; $p = 0.040$; $\eta^2 = 0.225$), VO_{2max} ($F_{(1,17)} = 9.29$; $p = 0.007$; $\eta^2 = 0.353$) and Vmax ($F_{(1,17)} = 8.66$; $p = 0.009$; $\eta^2 = 0.337$). Post hoc analysis indicated that only the RST improved performance.

Table 2. Effect of six weeks of repeated-sprint training on vertical jump ability and aerobic power of college volleyball players (mean ± SD).

Variables	RST Group		Control Group		ES (90% CI)	ES magnitude	Qualitative change
	Pre	Post	Pre	Post			% chance to be Beneficial / trivial / harmful
CMJ (cm)	36.31 ± 5.66	38.34 ± 5.90^{a}	37.33 ± 7.10	37.61 ± 7.34	0.53 (0.15 to 0.71)	Moderate	92 / 08 / 0
RVJA$_{peak}$ (cm)	31.04 ± 5.33	33.43 ± 4.85^{a}	31.97 ± 5.30	31.93 ± 5.55	0.47 (0.10 to 0.84)	Small	89 / 11 / 0
RVJA$_{mean}$ (cm)	28.66 ± 4.84	31,52 ± 5.07	28.96 ± 5.23	29.99 ± 5.75	0.37 (-0.10 to 0.85)	Small	73 / 24 / 03
RVJA$_{DEC}$ (%)	8.19 ± 5.03	5.34 ± 3.28	9.57 ± 5.12	6.22 ± 4.88	0.10 (-0.55 to 0.76)	Trivial	40 / 39 / 21
VO$_{2max}$ (ml ·min^{-1} ·kg^{-1})	50.39 ± 4.30	52.30 ± 4.92^{a,b}	48.84 ± 5.89	47.87 ± 5.13	0.53 (0.16 to 0.90)	Moderate	93 / 07 / 0
Vmax (km ·h^{-1})	15.70 ± 1.34	16.60 ± 1.78^{a}	15.33 ± 1.22	15.44 ± 1.43	0.62 (0.26 to 0.93)	Moderate	97 / 03 / 0

Note: ES = Cohen' standardized differences; CMJ = countermovement jump; RVJA$_{peak}$ = repeated-vertical jump ability best 15-s; RVJA$_{mean}$ = 60-s average repeated-jump; RVJA$_{Dec}$ = repeated jump performance decrement; VO$_{2max}$ = maximum oxygen uptake; Vmax = final speed achieved in incremental treadmill test. a = post hoc compared with pre-test; b = significant different from control group at same time point

Figure 3 displays the qualitative chance of the intervention being beneficial, trivial, or harmful. Accordingly, RST improved CMJ, RVJA$_{peak}$, and aerobic power with a positive chance to have a practical beneficial "possibly" effect on RVJA$_{mean}$ compared to the control group.

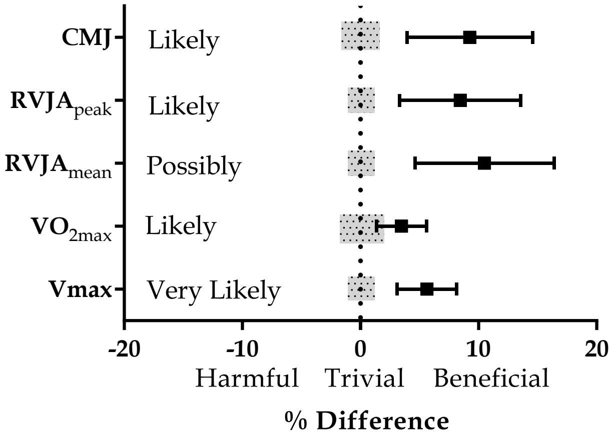

Figure 3. Effects of the repeated-sprint training compared to conventional volleyball training to improve vertical jump ability and aerobic power of volleyball players.
Note: RVJA indexes and aerobic power. Bars indicate uncertainty in the true mean changes with 90% confidence intervals. Trivial areas (shaded) were calculated from the smallest worthwhile change (see methods). CMJ = countermovement jump; RVJA$_{peak}$ = repeated-vertical jump ability best 15-s; RVJA$_{mean}$ = repeated-vertical jump ability 60-s; Vmax = final velocity achieved in incremental treadmill test.

DISCUSSION

The main findings of this study were that RST resulted in a "likely" to "very likely" positive practical effect compared to specific skill-based volleyball training sessions for improving CMJ, $RVJA_{peak}$, VO_{2max}, and Vmax, despite the similar weekly perceived internal training load between groups. Similarly, the practical significance analysis suggested that RST was "possibly" more effective than regular volleyball training for improving $RVJA_{mean}$. To the best of our knowledge, this is the first study to assess the effect of RST on RVJA performance in volleyball players during the preseason period. As our participants were college volleyball players, jump height is a crucial factor in overall performance (42).

The improvement in CMJ with RST is in line with studies that recruited samples of athletes from different team sports (3, 9, 22). For instance, Buchheit et al. (9) showed that CMJ improved in football players, after 10 weeks of RST with one change of direction (COD 180°) once a week. Likewise, Attene et al. (3) showed that CMJ improved in basketball players after two RST protocols (COD 180° and multiple CODs) performed twice a week during 4-weeks. Moreover, Iacono et al. (22) reported improvement in CMJ in elite handball players after eight weeks of RST (COD 180°) and jump shots, with a twice-week training frequency. Conversely, Soares-Caldeira et al. (43) did not find an effect of additional RST (during 4-weeks in the preseason) on CMJ, repeated sprint ability, and aerobic power in elite futsal players.

Some studies are contradictory about the effect of RST on CMJ performance (3, 18, 22, 43). While the reasons for the different results are unclear, it is possible to suggest that the improvements found in the present study may be related to the sports characteristics and/or players' competitive level. For instance, the fact that participants of the present study have not been previously exposed to RST may have induced greater adaptations. Indeed, studies involving elite adults (43), or highly trained youth soccer or futsal players (18) often fail to find positive responses to RST. Furthermore, it is also possible that the recovery microcycle (i.e. reduced training volume) included in our study design may have reduced the residual fatigue during RST and favored the training-induced changes in performance (28).

Although the underlying mechanism is far beyond the scope of the current investigation, it has been well-established that improvements in CMJ are related to, but not exclusively, the increase in recruitment and firing rate of large motor units and more efficient use of elastic energy produced by the knee flexor muscles (i.e. SSC) (10, 16, 27). This statement is supported by the correlations found between CMJ height and running speed (≥ 30 m) in elite players (1, 25, 40). These correlational data are reinforced by the results of a meta-analysis study showing that RST resulted in an improvement in CMJ with a moderate effect size (ES = 0.63) (44). Furthermore, a possible explanation for this transference effect might be related to the SSC and higher vertical ground reaction force required in both the CMJ and sprints actions (> 20 m) (10, 40).

During a volleyball match, it is likely that the highest jump height may provide some advantages in technical skills performance that predicts the final match's outcomes (e.g., block, spike, counterattack) (26, 45). In this regard, improving CMJ height, $RVJA_{peak}$, and $RVJA_{mean}$ represent an important adaptation through RST sessions due to the high demand for jump performance in volleyball training and competitive matches. In the present study, performing RST sessions resulted in improvements in $RVJA_{peak}$ and $RVJA_{mean}$, demonstrating that regular skill-based volleyball training did not provide sufficient stimuli to improve RVJA. Therefore, physical conditioning training sessions along with skill-based volleyball training are required to improve physical performance in volleyball players during the preseason. During repeated-sprints efforts, the major energetic demand is derived from phosphocreatine (PCr) hydrolysis and anaerobic glycolysis (12, 30). In addition, there is also an increase in aerobic contribution when sprints are repeated (29). Hence, it is possible to assume that training-induced adaptations in RVJA might be related, in part, due to similar metabolic and physiological determinants (e.g., muscle metabolites, energetic demands, and neural drive pattern) when sprints and jumps are repeated (8). However, futures studies are warranted to investigate the main physiological determinants of RVJA performance.

High-intensity efforts are performed repeatedly during a volleyball match over 60 to 90 minutes, which suggests that athletes must not only have a well-developed anaerobic capacity but also the aerobic capacity to cope with the game's physiological demand (39). Previous studies have suggested the importance of aerobic fitness in high-intensities intermittent efforts due to its role in providing adenosine triphosphate (ATP) for restoring PCr and buffering metabolic byproducts during the rest period (17, 29, 32). Our findings demonstrated that RST improved VO_{2max} and Vmax with qualitative beneficial practical effects from "likely" to "very likely", respectively. Therefore, the present study provides some data that could be considered by strength and conditioning coaches aiming to improve the RVJA and aerobic power in volleyball players. Also, we found an increase in Vmax, which represents an aerobic adaptation to RST. Similar results were found in volleyball players who improved VO_{2max} and time to exhaustion in an incremental test on a treadmill after 6-weeks (18 sessions) of RST (23). However, in the present study, a lower training volume was used (i.e. 12 sessions), which may allow more time for skill-based volleyball training (i.e. technical and tactical drills).

From a practical perspective, RST could be considered an efficient strategy for improving different components of athletic performance such as single-, repeated-jump, and aerobic power in college volleyball players. Despite the improvements observed in our study, they cannot be generalized to high-level or elite volleyball players. Thus, future investigations should investigate the effects of RST on jump performance and aerobic power, considering the competitive level of volleyball players.

In conclusion, our findings support the efficacy of 6-weeks of RST for improving single- and repeated-jump performance and aerobic power of volleyball players during the preseason when compared to their regular skill-based volleyball training sessions in college volleyball players.

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REFERENCES

1. Alemdaroglu U. The relationship between muscle strength, anaerobic performance, agility, sprint ability and vertical jump performance in professional basketball players. J Hum Kinet 31(3): 149–58, 2012.

2. Alvarez JC, D'Ottavio S, Vera JG, Castagna C. Aerobic fitness in futsal players of different competitive level. J Strength Cond Res 23(7): 2163–6, 2009.

3. Attene G, Laffaye G, Chaouachi A, Pizzolato F, Migliaccio GM, Padulo J. Repeated sprint ability in young basketball players: one vs. two changes of direction (Part 2). J Sports Sci 33(15): 1553–63, 2015.

4. Batterham AM, Hopkins WG. Making meaningful inferences about magnitudes. Int J Sports Physiol Perform 1(1): 50–7, 2006.

5. Bishop D, Edge J, Goodman C. Muscle buffer capacity and aerobic fitness are associated with repeated-sprint ability in women. Eur J Appl Physiol 92(4–5): 540–7, 2004.

6. Bishop D, Girard O, Mendez-Villanueva A. Repeated-sprint ability - Part II: recommendations for training. Sports Med 41(9): 741–56, 2011.

7. Borg G. Borg's perceived exertion and pain scales. Champaign. IL: Human Kinetics: 1998.

8. Buchheit M. Performance and physiological responses to repeated-sprint and jump sequences. Eur J Appl Physiol 110(5): 1007–18, 2010.

9. Buchheit M, Mendez-Villanueva A, Delhomel G, Brughelli M, Ahmaidi S. Improving repeated sprint ability in young elite soccer players: repeated shuttle sprints vs. explosive strength training. J Strength Cond Res 24(10): 2715–22, 2010.

10. Buchheit M, Samozino P, Glynn JA, Michael BS, Al Haddad H, Mendez-Villanueva A, et al. Mechanical determinants of acceleration and maximal sprinting speed in highly trained young soccer players. J Sports Sci 32(20): 1906–13, 2014.

11. Cohen J. Statistical power analysis for the behavioral sciences. Routledge, 1988.

12. Dawson B, Goodman C, Lawrence S, Preen D, Polglaze T, Fitzsimons M, et al. Muscle phosphocreatine repletion following single and repeated short sprint efforts. Scand J Med Sci Sports 7(4): 206–13, 1997.

13. Foster C, Florhaug J a, Franklin J, Gottschall L, Hrovatin L a, Parker S, et al. A new approach to monitoring exercise training. J Strength Cond Res 15(1): 109–15, 2001.

14. Freitas-Junior C, Gantois P, Fortes L, Correia G, Paes P. Effects of the improvement in vertical jump and repeated jumping ability on male volleyball athletes' internal load during a season. J Phys Educ Sport 20(supplement 5): 2924–31, 2020.

15. Girard O, Mendez-Villanueva A, Bishop D. Repeated-sprint ability part I: Factors contributing to fatigue. Sport Med 41(8): 673–94, 2011.

16. Harrison AJ, Keane SP, Coglan J. Force-velocity relationship and stretch-shortening cycle function in sprint and endurance athletes. J Strength Cond Res 18(3): 473, 2004.

17. Haseler LJ, Hogan MC, Richardson RS, Mccully KK, Mulcahy TK, Ryan TE, et al. Skeletal muscle phosphocreatine recovery in exercise-trained humans is dependent on O 2 availability. J Appl Physiol 2013–8, 1999.

18. Haugen T, Tonnessen E, Oksenholt Y, Haugen FL, Paulsen G, Enoksen E, et al. Sprint conditioning of junior soccer players: Effects of training intensity and technique supervision. PLoS One 10(3), 2015.

19. Hespanhol J, Silva Neto L, Arruda M, Dini C. Assessment of explosive strength-endurance in volleyball players through vertical jumping test. Rev Bras Med do Esporte 13(19): 181–4, 2007.

20. Hespanhol JE, Silva Neto LG, Arruda M. Reliability of the four series 15-second vertical jumping test. Rev Bras Med do Esporte 12(2), 2006.

21. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. Med Sci Sports Exerc 41(1): 3–12, 2009.

22. Dello Iacono A, Ardigò LP, Meckel Y, Padulo J. Effect of small-sided games and repeated shuffle sprint training on physical performance in elite handball players. J Strength Cond Res 30(3): 830–40, 2016.

23. Kaynak K, Eryılmaz SK, Aydoğan S, Mihailov D. The effects of 20-m repeated sprint training on aerobic capacity in college volleyball players. Biomed Hum Kinet 9(1): 43–50, 2017.

24. Komi P V. Stretch-shortening cycle: A powerful model to study normal and fatigued muscle. J Biomech 33(10): 1197–206, 2000.

25. López M, Marques M, Van den Tillaar R, González J. Relationships between vertical jump and full squat power outputs with sprint times in U21 soccer players. J Hum Kinet 30: 135–44, 2011.

26. Marelic N, Resetar T, Jankovic V. Discriminant analysis of the sets won and the sets lost by one team in A1 Italian volleyball league - a case study. Kinesiology 36: 75–82, 2004.

27. Markovic G, Mikulic P. Neuro-musculoskeletal and performance adaptations to lower-extremity plyometric training. Sport Med 40(10): 859–95, 2010.

28. Marrier B, Robineau J, Piscione J, Lacome M, Peeters A, Hausswirth C, et al. Supercompensation kinetics of physical qualities during a taper in team sport athletes. Int J Sports Physiol Perform 12(9): 1163-69, 2017.

29. McGawley K, Bishop DJ. Oxygen uptake during repeated-sprint exercise. J Sci Med Sport 18(2): 214–8, 2015.

30. Mendez-Villanueva A, Edge J, Suriano R, Hamer P, Bishop D. The recovery of repeated-sprint exercise is associated with PCr resynthesis, while muscle pH and EMG amplitude remain depressed. PLoS One 7(12): e51977, 2012.

31. Milanez VF, Pedro RE, Moreira A, Boullosa DA, Salle-Neto F, Nakamura FY. The role of aerobic fitness on session rating of perceived exertion in futsal players. Int J Sports Physiol Perform 6(3): 358–66, 2011.

32. Milioni F, Zagatto AM, Barbieri RA, Andrade VL, Dos Santos JW, Gobatto CA, et al. Energy systems contribution in the running-based anaerobic sprint test. Int J Sports Med 38(2): 226–32, 2017.

33. Moreno SJ, Afonso J, Mesquita I, Ureña A. Dynamics between playing activities and rest time in high-level men's volleyball. Int J Perform Anal Sport 16(2): 317–31, 2016.

34. Mroczek D, Januszkiewicz A, Kawczyński AS, Borysiuk Z, Chmura J. Analysis of male volleyball players' motor activities during a top level match. J Strength Cond Res 28(8): 2297–305, 2014.

35. Naimo M, de Souza E, Wilson J, Carpenter A, Gilchrist P, Lowery R, et al. High-intensity interval training has positive effects on performance in ice hockey players. Int J Sports Med 36(01): 61–6, 2014.

36. Navalta JW, Stone WJ, Lyons TS. Ethical issues relating to scientific discovery in exercise science. Int J Exerc Sci 12(1): 1–8, 2019.

37. Purkhús E, Krustrup P, Mohr M. High intensity training improves exercise performance in elite women volleyball players during a competitive season. J Strength Cond Res , 2016.

38. Ribeiro F, Santos F, Gonçalves P, Oliveira J. Effects of volleyball match-induced fatigue on knee joint position sense. Eur J Sport Sci 8(6): 397–402, 2008.

39. Riggs MP, Sheppard JM. The relative importance of strength and power qualities to vertical jump height of elite beach volleyball players during the counter-movement and squat jump. J Hum Sport Exerc 4(3): 221–36, 2009.

40. Shalfawi S, Sabbah A, Kailani G, Tønnessen E, Enoksen E. The relationship between running speed and measures of vertical jump in professional basketball players: a field-test approach. J Strength Cond Res 25(11): 3088–92, 2011.

41. Sheppard JM, Gabbett T, Borgeaud R. Training repeated effort ability in national team male volleyball players. Int J Sports Physiol Perform 3(3): 397–400, 2008.

42. Sheppard JM, Gabbett T, Taylor KL, Dorman J, Lebedew AJ, Borgeaud R. Development of a repeated-effort test for elite men's volleyball. Int J Sports Physiol Perform 2(3): 292–304, 2007.

43. Soares-Caldeira LF, de Souza EA, de Freitas VH, de Moraes SMF, Leicht AS, Nakamura FY. Effects of additional repeated sprint training during preseason on performance, heart rate variability, and stress symptoms in futsal players. J Strength Cond Res 28(10): 2815–26, 2014.

44. Taylor J, Macpherson T, Spears I, Weston M. The effects of repeated-sprint training on field-based fitness measures: a meta-analysis of controlled and non-controlled trials. Sport Med 45(6): 881–91, 2015.

45. Ziv G, Lidor R. Vertical jump in female and male volleyball players: A review of observational and experimental studies. Scand J Med Sci Sport 20(4): 556–67, 2010.