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The effects of skill-based volleyball training program on running economy in male volleyball players

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ABSTRACT

The purpose of this study was to examine the effects of a 6-week skill-based volleyball training program on the running economy (RE) of male competitive volleyball players. Ten male amateur volleyball players (age 21.1 ± 1.5 years) participated in a 6-week skill-based volleyball training program three times a week in the pre-season preparatory period. Before and after the training period, the following tests were completed: (i) incremental treadmill test to determine maximal oxygen uptake (VO_{2max}), ventilator threshold (VT), and running velocity associated with VO_{2max} (*v*VO2max); (ii) submaximal constant-intensity test to determine RE. RE was determined by measuring steady-state VO_2 (ml/kg/min) for 6 min at speed corresponding to 90% of the VT. The training program caused a significant improvement in RE by 5.3 ± 4.1% (p = 0.01). VO_{2max}, VT and vVO_{2max} were not significantly affected by the training program (p> 0.05). There were no significant changes in respiratory exchange ratio (RER) and minute ventilation (VE) measured during the submaximal constant-intensity test (p > 0.05). There were no significant changes in maximal RER and VE values measured during the incremental treadmill test (p> 0.05). The absence of significant changes in VO_{2max} as well as VE and RER suggests that the improved RE after a skill-based volleyball training may not be the result of an increase in the delivery and utilization capacity of oxygen or a change in substrate utilization. The improvement in RE may be related to more effective storage and release of elastic energy with the skill-based volleyball training.

Keywords: Oxygen cost of running, maximal oxygen uptake, running efficiency, stretch-shortening cycle.

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INTRODUCTION

Inter-individual variances in aerobic endurance performance are explained by maximal oxygen uptake (VO_{2max}), lactate threshold and running economy (RE) (Helgerud, 1994; Helgerud et al., 2001). Although VO_{2max} was previously well accepted as a good predictor of endurance performance, RE has been considered as a better predictor of distance running performance in trained athletes (Morgan et al., 1989; Paavolainen et al., 1999). Running economy is typically defined as the energy cost of running at a constant running velocity and assessed by measuring the steady-state oxygen uptake (VO_2) at a given running velocity (Conley and Krahenbuhl, 1980; Daniels, 1985; Barnes and Kilding, 2015). Lower oxygen consumption means better RE during submaximal steady-state running. RE is expressed in terms of relative to body mass per minute (ml $kg^{-1} min^{-1}$) or the total oxygen volume needed to run one kilometer relative to body mass (ml kg^{-1} km^{-1}) (Foster and Lucia, 2007; Barnes and Kilding, 2015). It has been observed that distance runners had significant differences in oxygen consumption rates while running at the same velocity (Williams and Cavanagh, 1987; Daniels and Daniels, 1992).

RE may have high variability (>15 %) among highly trained athletes with similar VO_{2max} (Conley and Krahenbuhl, 1980; Morgan and Craib, 1992). There is a strong relationship between RE and distance running performance (Di Prampero et al., 1993). However, RE is a multi-factor concept that represents the functioning of metabolic, cardiopulmonary, biomechanical and neuromuscular systems during submaximal running (Barnes and Kilding, 2015). Runners with the best RE have been shown to have higher contractile strength and higher tendon stiffness (Arampatzis et al., 2006).

Various training strategies have the potential to increase the individual's RE by enhancing cardiovascular, metabolic, neuromuscular and biomechanical adaptations (Barnes and Kilding, 2015). Improvements in RE have traditionally been demonstrated by continuous or interval running (endurance) training (Sjödin et al., 1982; Svedenhag and Sjodin, 1985; Barnes et al., 2013). Endurance training leads to central and peripheral adaptations that improve oxygen delivery and utilization, mechanisms that could potentially enhance RE (Barnes and Kilding, 2015). On the other hand, when plyometric training or resistance training is added to the endurance training program, it seems to improve run-specific neuromuscular and mechanical factors and induce changes in muscle recruitment, improving RE even in well-trained runners (Arampatzis et al., 2006; Denadai et al., 2017). The explanations suggested for improvements in RE with plyometric and resistance training program include increased lower limb muscle-tendon stiffness and elastic energy return, enhanced running mechanics, muscle strength and power (Barnes and Kilding, 2015). Musculoskeletal elastic components of the leg, such as muscles, tendons and ligaments, have been shown to be used to minimize metabolic costs while running (Cavagna et al., 1977; Kerdok et al., 2002).

Volleyball is an intermittent sport that combines explosive movements in both vertical and horizontal directions with short periods of recovery (Polglaze and Dawson, 1992; Silva et al., 2019). The ability of the neuromuscular system to repeatedly produce rapid force during intense exercises such as various sprints, jumps and high-intensity court movement and the ability to store and utilize elastic energy are the most important factors that determine athletic performance in the volleyball (Hakkinen, 1993). Although volleyball is not an endurance sport in itself, an optimum level of aerobic capacity is essential to maintaining high-intensity exercises over an extended period of time (~ 90 minutes) during volleyball match (Polglaze and Dawson, 1992; Vittasalo et al., 1987). In order to ensure the success of the volleyball team, it is important to optimize the skill development as well as the conditioning development of the volleyball players (Kukić et al., 2020). Numerous coaches use exercises such as digs, attacks, transitions from defense to attack and blocking in order to improve conditioning level as well as the skill development of volleyball players in training sessions. Using skill-based conditioning games in training sessions allows simulation of movement patterns of volleyball, while providing a competitive environment for players to perform under pressure and fatigue (Gabbett, 2008).

Only one study has investigated the effect of beach volleyball training and competition on running economy of the indoor volleyball players (Balasas et al., 2013). However, no study to our knowledge has examined the effect of a skill-based volleyball training on RE in volleyball players. The purpose of this study was to examine the effects of a 6-week preseason skill-based volleyball training program on the RE of male competitive volleyball players. We hypothesized that skill-based volleyball training program would improve RE.

MATERIALS AND METHODS

Participants and experimental design

Ten male amateur volleyball players (mean ± SD; age 21.1 ± 1.5 years, height 183.9 ± 4 cm, body mass 73.6 ± 7.9 kg) volunteered to participate in the present study. All of the participants were members of the Erciyes University volleyball team. All players had trained and competed regularly in volleyball for at least 4 years. The study was explained to all participants in detail, and informed consent forms were acquired. Measurements were performed following the approval of the Ethics Committee and carried out in accordance with the Declaration of Helsinki. All testing and training procedures were fully explained, and written informed consent was obtained for each participant. During the study, the players were not allowed to perform any additional strength and conditioning training that would affect the results of the study.

The experimental protocol consisted of baseline testing, a 6-week training intervention, and post-testing. Players performed a skill-based volleyball training program three times per week for 6 weeks at the beginning of the pre-season preparatory period. All training sessions were conducted at the same time of day on Monday, Wednesday and Friday of each consecutive week. All players performed two tests with an interval of 48 hours between each test. The two tests consisted of an incremental treadmill test and the submaximal constant-intensity test. Baseline and post-testing began with an incremental treadmill test to determine their maximal oxygen uptake (VO_{2max}), ventilatory threshold (VT), running velocity associated with VO_{2max} (vVO_{2max}). After at least two days, participants performed a submaximal constant-intensity test to determine RE. The players were not allowed to perform any training the day before each testing.

Data collection

Incremental running test and submaximal running test were performed on a motorized treadmill (h/p/Cosmos Quasar med, Nussdorf-Traunstein, Germany). Throughout all tests, expired air was measured online using a breath-by-breath cardiopulmonary exercise testing system (Quark PFT Ergo, Cosmed Srl, Rome, Italy). Breath-by-breath data was smoothed using a five-step average filter and then reduced to 15 s stationary averages. During the incremental testing period, heart rate (HR) was monitored continuously using a wireless HR monitor (S610i, Polar, Finland) and was synchronized to ventilatory signals. Before each test, ambient conditions were measured, and the gas analyzers and turbine flowmeter were calibrated with known certified gas concentrations (16% O_2, 5% CO_2, and balanced N_2) and a 3 L calibration syringe, respectively, following the manufacturer's instructions. Before each test, the players performed a standardized warm-up consisting of a 5 min run at their own pace followed by about 3 min of stretching.

Incremental treadmill test

Following the warm-up, players started running at 7 km/h with speed increments of 1 km/h every minute until they could no longer keep pace. All players were given strong verbal encouragement throughout the test to elicit their best performance. Achievement of VO_{2max} was considered as the attainment of at least two of the following criteria: 1) a plateau in VO_2 despite increasing speed, 2) a respiratory exchange ratio (VCO_2/VO_2) above 1.10, and 3) a HR within 10 beats per minute of age-predicted maximum HR (220 – age). The VO_{2max} was defined as the highest 15 s VO_2 value reached during the incremental test and expressed as a relative value (milliliters per minute per body mass; ml/kg/min). Running velocity associated with VO_{2max} (vVO_{2max}) was determined as the minimal velocity at which VO_{2max} occurred. Maximal minute ventilation (VE_{max}) and maximal respiratory exchange ratio (RER_{max}) were expressed as the highest 15 s average value obtained during the last stage of the incremental exercise test.

VT was evaluated in the incremental treadmill test to determine the subjects' running speed during the RE test. The VT was determined using the V-slope method described by Beaver et al. (1986) The VT was defined as the VO_2 value corresponding to the intersection of two linear regression lines derived separately from the data points below and above the breakpoint in the VCO_2 versus the VO_2 relationships (Sigma Plot 12.0, Systat Software Inc., Chicago, USA).

Submaximal constant-intensity test

RE was determined by measuring steady-state VO_2 (ml/kg/min) for 6 min at speed corresponding to 90% of the VT (9.6 ± 1.9 km/h), after a standardized warm-up. The average of four consecutive 15 s measurements in the final minute of the 6 min submaximal constant-intensity test was used for the analyses of RE, VE and respiratory exchange ratio (RER_{submax}) values.

Skill-based volleyball training program

A single training session lasted approximately 120 min (comprising warm-up, main and cool-down periods). The warm-up period consisted of jogging, different types of running and accelerations, submaximal jumps, mobility exercises, full body stretching and specific volleyball warm-up drills with the ball, and lasted 20-25 minutes. Each training session ended with a 10-15 minutes cool-down consisting of walking and stretching. The main part of the volleyball session consisted of: 1) on-court skills training including low-intensity and medium- and high-intensity activities and 2) the game-based drills including small-sided games and real-game volleyball drills. Low-intensity activities included serving, passing, and setting in small groups. Medium- and high-intensity activities included spiking, blocking and digging drills, as well as skills-based conditioning drills such as lateral movement and blocking, lateral movement and dig drill, moving off of the net and retrieving a ball. Training sessions concluded with high-intensity game-based drills to work on offensive and defensive strategies and individual tactics. The game-based drills included small-sided games such as 3 vs. 3 and 4 vs. 4, where the volleyball court was divided into two smaller courts, and 6 vs. 6 real-game volleyball drills.

Statistical analysis

Data are reported as mean ± standard deviation (SD). Statistical significance was accepted at $p < 0.05$. The normality distribution of the data was checked with the Shapiro-Wilk test. All data met the assumption of normal distribution with the exception of the vVO_{2max}. Within-group changes before and after the 6-week training period was compared using paired t-test for normally distributed data, and Wilcoxon matched-pair signed-rank test for non-normally distributed data. To allow a better interpretation of the results, effect sizes were also calculated using Cohen's d (Thalheimer and Cook, 2002). Effect sizes were interpreted as negligible (d ≥ 0.2), small (0.2 ≤ d ≤ 0.5), medium (0.5 ≤ d ≤ 0.8) or large (0.8 ≥ d). SPSS version 21 was used for all analyses (SPSS Inc., Chicago, IL).

RESULTS

The skills-based volleyball training program caused a significant improvement in RE by 5.3 ± 4.1% (p = 0.01). There were no significant changes in RER_{submax} and VE (p > 0.05) measured during the submaximal constant-intensity test. There were no significant changes in

Table 1. Results of the incremental treadmill test and submaximal constant-intensity test of the volleyball players before (pre) and after (post) the 6-week training period.

Variables	Pre-training	Post-training	p	d
RE (ml/kg/min)	38.6 ± 7.5	36.5 ± 6.6*	0.01	0.30
RER_{submax}	0.94 ± 0.03	0.94 ± 0.04	0.72	0
VE_{submax} (L/min)	92.1 ± 18.1	85.9 ± 23.7	0.13	0.3
VO_{2max} (ml/kg/min)	50.2 ± 3.5	50.6 ± 3.6	0.20	0.12
VO_{2VT} (ml/kg/min)	37.7 ± 4.6	38.9 ± 5.3	0.08	0.25
vVO_{2max} (km/h)	15.6 ± 1.1	16 ± 1.4	0.1	0.33
RER_{max}	1.17 ± 0.06	1.2 ± 0.06	0.18	0.88
VE_{max} (L/min)	151.5 ± 18.3	155.8 ± 10.2	0.25	0.31

Values are mean ± standard deviation. * Significantly different from pre-training (baseline) values. RE = running economy, RER_{submax} = submaximal respiratory exchange ratio, VE_{submax} = submaximal minute ventilation during the submaximal constant-intensity test, VO_{2max} = maximal oxygen uptake, VO_{2VT} = VO_2 at ventilatory threshold, vVO_{2max} = velocity associated with VO_{2max}, RER_{max} = maximal respiratory exchange ratio, VE_{max} = maximal minute ventilation.

VO_{2max}, VT, vVO_{2max}, RER_{max} and VE_{max} measured during the incremental treadmill test ($p > 0.05$) (Table 1).

DISCUSSION

This study investigated the effects of 6-week skill-based volleyball training program on RE of male competitive volleyball players. The lack of a control group for comparison in interpreting the results is the limitation of our study. The major finding was that the skills-based volleyball training program improved the RE without significant changes in VO_{2max}, VT and vVO_{2max}. The improved RE occurred independent of a change in RER_{submax} and VE during submaximal steady-state running. The improvement in RE with skill-based volleyball training may be attributed to more effective storage and release of elastic energy rather than changes in skeletal muscle oxidative capacity or substrate utilization.

Skill-based volleyball training significantly improved the RE as evidenced by the decrease in VO_2 (5.3 ± 4.1%) during submaximal steady-state running. Likewise, previous investigators reported improvements in RE ranged from 2 to 8% using various training models such as plyometric (Turner et al., 2003; Saunders et al., 2006), resistance (Johnston et al., 1997; Storen et al., 2008), interval (Barnes et al., 2013) and endurance running (Sjödin et al., 1982; Svedenhag and Sjodin, 1985). RE is measured as steady-state oxygen uptake at intensities below the VT, because above this intensity, the slow component of VO_2 indicates that steady-state conditions are unlikely to be achieved (Foster and Lucia, 2007). In our study, the steady-state condition during RE measurements both before and after training was verified by RER <1 (Conley and Krahenbuhl, 1980; Saunders et al., 2004; Barnes and Kilding, 2015). Skills-based volleyball training improved RE, without concurrent change in RER_{submax} and VE during submaximal constant-intensity test. Moreover, VO_{2max}, VE_{max} and RER_{max} were not affected by the skill-based volleyball training program.

RE has been shown to improve in endurance training as well as strength and/or plyometric training (Svedenhag and Sjodin, 1985; Barnes et al., 2013; Johnston et al., 1997; Paavolainen et al., 1999). Endurance training probably increases the capacity of the metabolic and cardiovascular systems associated with RE (Sjödin et al., 1982; Svedenhag and Sjodin, 1985; Denadai et al., 2017; Barnes and Kilding, 2015). Thus, endurance training leads to an increase in oxidative muscle capacity, which allows athletes to use less oxygen per mitochondrial respiratory chain during submaximal running (Saunders et al., 2004; Barnes and Kilding, 2015). The absence of significant changes in VO_{2max} as well as VE and RER in our study suggests that the improved RE may not be the result of an increase in the delivery and utilization capacity of oxygen or a change in substrate utilization. Previous studies have shown an improvement in RE without change in VO_{2max} after plyometric or resistance training in endurance athletes (Johnston et al., 1997; Paavolainen et al., 1999; Turner et al., 2003; Saunders et al., 2006). For example, heavy-resistance strength training has been reported to improve RE of female distance runners without changes in VO_{2max} (Johnston et al., 1997) Turner et al. (2003) demonstrated that a 6-week plyometric training program improved RE in regular trained distance runners without significant changes in VO_{2max}. Paavolainen et al. (1999) reported an enhancement in RE accompanied improvement in sprint and jump performance in well-trained endurance athletes after 9-week explosive-strength training program involving various sprints and plyometric (jumping) exercises. In addition, significant improvements in 5-km run performance with no changes in VO_{2max} were observed. The authors suggested that 5-km running performance was due to the enhanced neuromuscular characteristics that were transferred into improved muscle power and RE. In addition, Saunders et al. (2006) reported an improvement in RE with no changes in VO_{2max}, cardiorespiratory variables and substrate utilization after 9-week plyometric training program. The mechanisms underlying the enhancement in the RE may be the improvement of muscle power and the better use of stored elastic energy (Saunders et al., 2006). Unlike our study findings, 12-week of beach volleyball training and competition has been shown to lead to the improvement in the RE concurrent with VO_{2max} of the indoor volleyball players (Balasas et al., 2013). However, besides playing outdoors, volleyball performance on the sand makes beach volleyball more challenging than indoor volleyball. For this reason, it is possible for the beach volleyball training and competition to improve the aerobic capacity of the players.

An increase in the muscle power and muscle-tendon stiffness from plyometric training could improve RE by producing more force from the muscles without an increase in the metabolic energy requirement (Saunders et al., 2004). Indeed, Spurrs et al. (2003) indicated that the enhancement in the RE associated with the improvement of lower leg muscle-tendon stiffness in response to 6-week of plyometric training. The stiffness of the muscle-tendon system allows the body to store and utilize elastic energy more effectively (Spurrs et al., 2003). The energy cost of running has been shown to be significantly related to the stiffness of the propulsive leg (Dalleau et al., 1998). It has been suggested that the storage and release of elastic energy in muscles may have the potential to explain a considerable portion of the interindividual differences in the running economy, as it is one of the important factors contributing to the running economy (Anderson, 1996). The balance between eccentric and concentric contractions during the stretch shortening cycle (SSC) activities can potentially affect RE because eccentric contractions where elastic energy is stored are less costly than concentric contractions where energy is released (Williams, 1985; Barnes and Kilding, 2015). Mechanical energy is stored in the tendons, muscles and ligaments during the eccentric phase of contact with the ground, while the recovery of the stored elastic energy during the concentric phase reduces energy consumption (Saunders et al., 2004). VO_2 during running has been reported to be 30 to 40% higher without contributions from elastic energy storage and return (Cavagna et al., 1964). Based on this information, our study findings suggest that improvement in RE with skill-based volleyball training may be related to more effective storage and release of elastic energy rather than improved metabolic or cardiorespiratory efficiency.

Skill-based volleyball training includes plyometric exercises such as jumping and spikes, which are also included in different plyometric training programs (Gjinovci et al., 2017). It has been reported that elite male volleyball players performed 250-300 high-power activities during a volleyball match of five sets, most of these power activities consisted of jumps (Hasegawa et al., 2002). Volleyball players repeatedly perform SSC actions such as bounding, jumping, and hopping during the volleyball training session. Plyometric training using these types of actions has the potential to increase the muscle’s ability to produce power (Turner et al., 2003) and muscle-tendon stiffness (Spurrs et al., 2003). Plyometric training is performed to increase the ability of the muscles to produce power by exaggerating the SSC (Turner et al., 2003). Skill-based volleyball training requires the SSC such as blocking, spiking, jump serving, digging, diving, and changes-in-direction to be repeatedly exaggerated, like plyometric training. Therefore, volleyball skill conditioning may result in training effects similar to those seen in plyometric training, as volleyball skills includes activities involving SSC (Trajkovic et al., 2012). Skill-based volleyball training, like plyometric training, is likely to improve the RE by improving the ability of muscle to store and return elastic energy during SSC (Turner et al., 2003). Lower leg muscle-tendon stiffness may be improved due to the repetitive nature of explosive volleyball skills (i.e., spiking, blocking, diving and digging). However, lower body explosive power or muscle-tendon stiffness was not measured in the present study. On the other hand, the skill-based conditioning program has been shown to improve the jumping capacity of volleyball players (Gabbett, 2008; Gjinovci et al., 2017; Idrizovic et al., 2018; Pekas et al., 2019). It is assumed that the greatest improvement in performance occurs when the training stimulus mimics the metabolic and technical demands of the actual game (Gabbett, 2008; Trajkovic et al., 2012). In our study, skill-based volleyball training is likely to improve lower leg muscle-tendon stiffness due to the characteristics of the game that include repetitive jumping, diving, and lateral movement. The increase in muscle-tendon stiffness, which allows the lower body to store and utilize elastic energy more efficiently, might have reduced the energy cost during submaximal running. These adaptations may explain the increase in RE without a proportional increase in metabolic profiles within muscles (Saunders et al., 2006).

In conclusion, the results of this study indicated that 6-week skill-based volleyball training may improve the RE of volleyball player. Due to the absence of significant changes in VO_{2max}, VE and RER_{submax}, the mechanisms underlying the improved RE after skill-based volleyball training program appear to be unrelated to changes in skeletal muscle oxidative capacity or substrate utilization. A possible explanation for this finding may be that the improvement in the RE has occurred by a mechanism involving enhanced in storage and return of elastic energy. The increase in lower body muscle-tendon stiffness provided by plyometric exercises included in the skill-based volleyball training might have reduced the energy cost during submaximal running. Although RE is an important determinant of endurance performance, it can also be used to determining and monitoring physical fitness in anaerobic sports, as there are numerous different mechanisms affecting RE. Further research is needed to investigate the effects of skill-based volleyball training on RE together with lower body muscle-tendon stiffness.

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