The effect of 4-week of barefoot and shod plyometric training on jump height, reactive strength index, and stiffness on female volleyball athletes

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Abstract: The majority of technical skills performed by volleyball players during a volleyball match are jump actions, such as serving, attacking, blocking, all of which require significant lower-limb explosive power. Plyometric exercises (PE) such as drop jumps (DJs) are used to develop muscle strength, lower extremity stiffness and RSI. The purpose of the study was to compare the effect of 4-week plyometric training on jump height (JH), reactive strength index (RSI**)**, and stiffness of the lower limbs, in female volleyball. Twenty-eight volleyball players aged 17 to 25 years volunteered to participate in the present study and were randomly divided into two equal groups (experimental group [EG] and control group [CG]). The EG trained bared by performing a specific plyometric training program lasting 4 weeks with a frequency of twice a week, while the CG performed the same program but wearing their athletics shoes. The evaluation was done with the application "MyJump2" one day before the start of the intervention program and one day after the end of the intervention program. The results showed no statistically significant interaction between time and group in none of the examined variables on shoes and bared. However, a significant main effect was found for time on shod (p = .001) and barefoot group (p = .001) on jump height (JH), reactive strength index (RSI**)**, and stiffness. Conclusively, plyometric training produced significant improvement in stiffness, RSI and Tc after 7 weeks of intervention either in shod either in barefoot group. However, EG revealed further improvement in JH in shod condition.
Keywords: Plyometric training, reactive strength index, barefoot, stiffness, volleyball

1. Introduction

Two of the most basic human skills are running and jumping. The theoretical basis for barefoot running has recently been argued, concluding that man has evolved to adapt himself to running without shoes (Lieberman, 2012). The cushion of the foot gives feedback, which the shoe deforms and due to which the runners change movement's mechanism to reduce the landing vibration. Depending on the surface and the cushion the ankle joint is more automatically engaged as the surface stiffness, whether it is a shoe cushion or a soft floor (Willwacher et al., 2012). Several studies have been conducted to investigate barefoot activity during running (Bonacci, Saunders, Hicks, 2013; De Wit, De Clercq, Aerts, 2000; Divert et al., 2008; Hamill et al., 2011; Hein, Grau, 2014; Lieberman, 2010; Mullen et al., 2014). So, the body has to adapt by involving additional mechanisms of shock absorption due to the speed at which the foot lands on the ground before turning it into a take-off. Therefore, the time spent on the ground increases due to the extra neuromuscular requirements.

The majority of technical skills performed by volleyball players during a volleyball match are jump actions, such as serving, attacking, blocking, all of which require significant lower-limb explosive power (Dopsaj, Copić, Nešić, Sikimić, 2012). The plethora of research studies that has been done regarding barefoot training, is related on balance and proprioception and mechanisms of running at different speeds. There is little literature on other forms of exercise and footwear. De Wit, Clercq, Aerts (2000) found that for shock absorption the contact time (Tc) with the ground increases, the knee angles become sharper, the stride length decreases and the stride frequency increases.

Plyometric training (PT) has beneficial effect of lower limb stiffness (Brazier, Bishop, Simons, Antrobus, Read, Turner, 2014; Hobara, Inoue, Muraoka, Omuro, Sakamoto, Kanosue, 2010) improving jump ability by storing more elastic energy during eccentric phase which in turn reuse on the following propulsive phase generating more concentric force (Brazier et al., 2014) allowing a faster and more effective transfer of force from muscle to bone (Legerlotz, Marzilger, Bohm, Arampatzis, 2016). Mullen, Cotton, Bechtold, Toby (2014) examining lower limb stiffness through 8-weeks of running training, with and without shoes revealed significantly different joint stiffnesses. Usually, plyometric exercises (PE) such as drop jumps (DJs) are used to develop muscle strength, lower extremity stiffness and RSI (Barker, Harry, Mercer, 2018; Kubo, Ishigaki, Ikebukuro, 2017; Lloyd, Oliver, Hughes, Williams, 2012; Meylan, & Malatesta, 2009). A method to quantify stretch-shortening cycle (SSC) is RSI which define subject's ability to be change quickly from an eccentric to concentric contraction (Young, 1995). Although there are data on the effect of PE on RSI (Lloyd, Oliver, Hughes, Williams, 2012), nothing similar has been done in relation to barefoot training.

A key parameter that has been associated with the various types of injuries is RSI and leg stiffness. The RSI shows the quality of the contact of the lower extremities with the ground and can be evaluated by performing plyometric exercises. A low RSI has been associated with soft tissue injuries, while a very high one has been associated with joint injuries due to bone compressive forces (Tam, Divekar, Lamberts, Tucker, Hill, 2016). In the present study, an attempt was made to address these difficulties by replacing running with PE. During the process of a jump, the human-shoe-ground system is more or less deformed, even on the side of the shoe or the ground (Butler et al., 2003). Previous study stated that lower limb stiffness affects power production during an SSC (Arampatzis, Schade, Walsh, Brϋggemann, 2001), and that muscle stiffness significantly increased in the tibialis anterior, after 6-week with these increments being observed during the last 2 weeks of PE application (Dariusz et al., 2019). PEs involve exercises such as vertical jumps or depth jumps to train the slow fast SSC, respectively. To the best of our knowledge only two previous studies examined the effect of footwear training on jumping performance (Harry, Paquette, Caia, Townsend, Weiss, Schilling, 2015; La Porta et al., 2013). More specifically, La Porta et al. (2013) investigated the effect of different footwear on jumping performance and found that barefoot (BF) resulted in greater JH during the single VJ compared to other footwear conditions. However, Harry, Paquette, Caia, Townsend, Weiss, Schilling (2015) investigated the effects of different footwear conditions on jump performance, during the vertical and standing long jump (SLJ) and found no difference on vertical jump displacements between footwear conditions. There is not enough research to investigate the RSI and lower extremity stiffness without involving running in their method. This study applied PE, which have not been found to be governed by a change in the way of contact with the ground either in barefoot or in the shoes condition. The main purpose of the study was to investigate the effects of barefoot DJs on RSI and vertical stiffness. It was hypothesized that barefoot DJs would produce different amount on stiffness, RSI, height, Tc, and height than DJs with shoes.

2. Methodology

2.1 Participants

The study involved 28 volleyball athletes, aged 17-25 years, with training experience of more than four years. The athletes were randomly divided into two equal groups, the experimental (EG: n = 14) and control group (CG: n = 14). None of these athletes had previous experience with a plyometric training program. Before the inception of the program and after being notified the purpose of the study, all the participants filled an informed concept having the right to leave whenever they wished. Baseline measurements were done via drop jump test from an elevated surface by 30 cm. Initially, they made two familiarization attempts and then each participant performed randomly 4 DJ, two with shoes and 2 barefoot which were recorded using video at 120 frames per second. It was understood by all participants that the goal is the minimum duration of contact with the ground while achieving maximum jump, as defined by the international guidelines for the deep jump test. The videos were introduced in the My Jump 2 program and analyzed according to the instructions set by its creators. The average of 2 jumps was kept from each situation, barefoot or barefoot.

2.2 Training procedure

The intervention program lasted 7 weeks, 2 sessions per week separated by 72 hours, and consisted of 11 exercises. The participants continued to carry out their club's training program, which did not include additional organized plyometric exercises, but nevertheless included some jumping efforts for block-pass-nail. The intervention program took place after the formal warm-up of participants, lasting 10 minutes. Each session contained 5 exercises, with a gradual increase of contacts. The exercises were performed only with the use of body weight but in some cases were performed from a bench height of 30 cm. Before each exercise there was an explanation, test and supervision of the necessary safety rules. The verbal guidance was aimed at the safe completion of the exercises. Three days (next availability) after the last training the final measurements were made with the same procedure as in the first ones. The exercises and their dosage selected for the training program were based on previous literature (Lloyd, Oliver, Hughes, Williams, 2012).

Table 1: 4-week intervention plyometric training program

Exercise	**Week 1**		**Week 2**		**Week 3**		**Week 4**	
	S 1	**S 2**	**S 3**	**S 4**	**S 5**	**S 6**	**S 7**	**S 8**
Squat jumps	2x6					2x5	4x4	4x5
Tuck jumps	2x6	2x8					3x5	3x5
Lateral jumps	2x8	2x8	3x8	2x10	2x10	4x8	4x10	4x10
Triple long jump	2x8	4x4	2x3					
One-legged side jumps	2x8	4x8	4x8					
One-legged jumps			3x4					
One-legged cross jumps			4x3					
Drop jumps [Drop height 30 cm]				3x5	3x5			
Bounces with outstretched legs				3x8	3x8	3x8		
Jumps with a 30 cm bench climb				2x10	2x10	2x8	2x10	2x10
Counter movement jumps				3x5	3x5	4x5	3x5	3x5
Total contact	**72**	**80**	**86**	**94**	**94**	**102**	**106**	**110**

S: Session

For the assessment of RSI, the most common method is DJ (Rogers et al., 2019) and for its evaluation My Jump 2 was used in the present study which is a reliable and valid analysis through video recording on Android and iOS platform (Haynes, Bishop, Antrobus, Brazier, 2019). The following somatometrics characteristics were collected for each participant. Ankle length, pelvic-toe length, athlete height in a semi-sitting position of 90 degrees (required by MyJump2 for measurement accuracy), athlete height, athlete weight. The data were collected and entered into the tool which extracted the RSI, the stiffness of the lower limbs, the contact time (Tc) and finally the JH.

2.3 Statistical analysis

Statistical analyses were performed using SPSS version 24 (IBM, New York, USA). A two-way (group x time) ANOVA with repeated measures on the second factor was used for the statistical analysis. Sphericity was checked using Mauchly's test, and the Greenhouse-Geisser's correction on degrees of freedom was applied when necessary. Levene's test of equality of error variances was used to check the assumption of homogeneity of variances. In cases where interaction between time and group was detected, the simple effects were investigated, and Bonferonni's correction was used. In the absence of interaction, the main effects of the two factors (time and group) on the dependent variables were investigated. All statistical significances were tested at $\alpha = 0.05$.

3. Results

No statistically significant interaction between time and group was found in none of the examined variables on shoes (RSI: $F_{(1)} = .014$, $p = .906$; stiffness: $F_{(1)} = .020$, $p = .887$; Tc: $F_{(1)} = .556$, $p = .462$; JH: $F_{(1)} = .793$, $p = .381$); and bared (RSI: $F_{(1)} = .191$, $p = .665$; stiffness: $F_{(1)} = .089$, $p = .768$; Tc: $F_{(1)} = 3.191$, $p = .085$; JH: $F_{(1)} = .611$, $p = .441$). However, a significant main effect was found for time on shoes group (RSI: $F_{(1)} = 51.994$, $p = .001$; stiffness: $F_{(1)} = 40.476$, $p = .001$; Tc: $F_{(1)} = 42.855$, $p = .001$; JH: $F_{(1)} = 12.968$, $p = .001$); and bared group (RSI: $F_{(1)} = 48.180$, $p = .001$; stiffness: $F_{(1)} = 85.178$, $p = .001$; Tc: $F_{(1)} = 65.050$, $p = .001$). The mean values of the examined DVs are presented in table 2.

Table 2: Descriptive statistics (X ± SD) on dependent variables

Time contact (Tc) (msec)

GROUP	PRE - TEST		POST TEST	
	Shod	Barefoot	Shod	Barefoot
EG	0.309 ± 0.06	0.357 ± 0.07	0.222 ± 0.05 ↑	0.239 ± 0.04 ↑
CG	0.289 ± 0.06	0.298 ± 0.07	0.220 ± 0.06 ↑	0.224 ± 0.05 ↑

Jump height (cm)

GROUP	PRE-TEST		POST TEST	
	Shod	Barefoot	Shod	Barefoot
EG	12.977 ± 1.41	12.988 ±1.23	14.054± 1.36 ↑	13.521 ± 1.93
CG	14.528 ± 2.51	14.647 ± 2.93	15.178 ± 2.01	14.770 ± 2.26

Stiffness (KN/m)

GROUP	Pre test		Post test	
	Shod	Barefoot	Shod	Barefoot
EG	13.20 ± 5.57	10.14 ± 3.31	22.36 ± 7.20 ↑	19.49 ± 5.64 ↑
CG	14.32 ± 5.15	14.22 ± 6.36	23.91 ± 9.11 ↑	22.99 ± 9.47 ↑

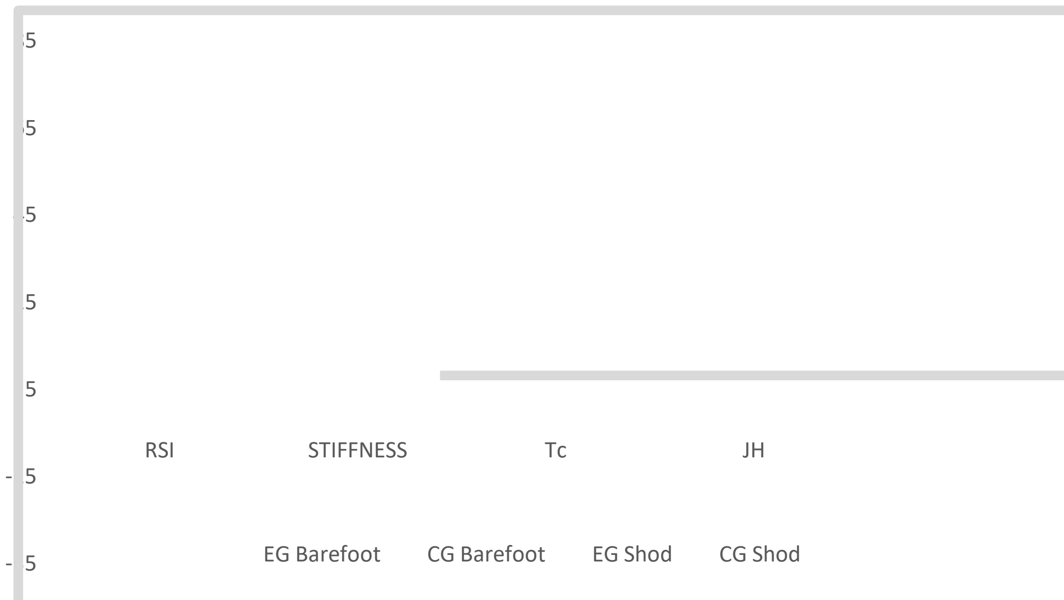
Reactive strength index (RSI) (mm/ms)

GROUP	Pre test		Post test	
	Shod	Barefoot	Shod	Barefoot
EG	1.10 ± 0.28	0.95 ± 0.22	1.58 ± 0.36 ↑	1.44 ± 0.33 ↑
CG	1.23 ± 0.29	1.08 ± 0.52	1.70 ± 0.44 ↑	1.64 ± 0.46 ↑

↑ Significant improvement compared to pre-test ($p < .001$)
EG: Experimental Group
CG: Control group

Percentage differentiation on the examined variables are shown in figure 1.

Figure 1: Percentage differentiation on Barefoot and shod on the examined variables



4. Discussion

This is the first study that examines the effect of barefoot training by performing PE in contrast to the related literature that refers to the effect of barefoot training during running. Therefore, the comparison of the results of our study with those of the related literature are not directly comparable. The results of the study firstly showed that the 4-week intervention program of PE in volleyball athletes, significantly affect RSI, stiffness and Tc ($p < .001$). Secondly, EG showed an additional improvement in JH in shoes condition ($p < .001$) and lastly that barefoot condition in EG revealed greater improvement in all the examined variables compared to CG. Our results are in agreement with the results of Lloyd, Oliver, Hughes, Williams (2012) who found a significant improvement in RSI after a 4-week plyometric training in male youths and those of Maylan and Malatesta (2009) who found, albeit nonsignificant, an improvement in RSI after an 8-week plyometric training program. However, it is noted that the per cent improvements in our study were greater in EG (51.58% and 43.63%) compared to the CG values (51.85% and 38.21%) in barefoot and shod, respectively (figure 1). On the contrary, our findings opposed to those of Guo et al. (2021) who stated that PE alone not enough to bring significant improvement in RSI after a 6-week training. However, our results showed that there was an increase in RSI and stiffness, a finding which contradict what Jaén-Carrillo, Cartón-Llorente, Lozano-Jarque, Rubio-Peirotén, Roche-Seruendo, García-Pinillos (2021) invoke, that is no significant correlations exist between lower-limb stiffness and RSI. In our study, stiffness was increased in both condition in EG, whoever barefoot showed significant higher percentage improvement compared to shod (94.9% and 69.39%, respectively) (figure 1). In addition, our results revealed that stiffness improvement was almost equivalent in EG and CG in shod condition (69.39% and 68.02%, respectively), whereas these values amounting to 92.01% and 61.04% respectively, in barefoot condition. This finding suggest that PE positively affect leg stiffness and that the percentage improvement is significantly higher in barefoot condition. In addition, our data partially support previous data by Dariusz et al. (2019) who showed that PT significantly increase stiffness in the tibial anterior especially during the last 2 weeks of PT application and those of Kubo, Ishigaki, Ikebukuro (2017) although this study had a longer training program duration (12 weeks, 3 times a week) and this may be responsible for the statistically significant difference in the examined variable. Furthermore, our results reinforce previous data by Brazier et al who revealed that PT increase lower extremity stiffness enhancing jumping performance by storing more elastic energy at landing which in turn generate more concentric force during the propulsive (Brazier, Bishop, Simons, Antrobus, Read, Turner, 2014).

In addition, the average values 23 (KN/m) that found in our study performing DJ are comparable to those of Arampatzis, Schade, Walsh, Brϋggemann (2001) (values between 32 and 78 kN/m) who stated that the stiffness of the lower extremities can be regulated by changing the contact time. The lower values on the barefoot condition compared to the hypothetical one reinforces previous findings of Tam, Divekar, Lamberts, Tucker, Hill (2016) stating that the ankle stiffness is greater in the shod condition (with shoes) which is likely related to the increase in the sagittal ankle range of motion (ROM) of the ankle for someone who runs barefoot and that barefoot running resulted in a decreased joint stiffness at the ankle. The view that participants with a stiffer musculotendinous system might benefit from a faster elastic recoil during the concentric phase of the jump (Arampatzis, Schade, Walsh, Brϋggemann, 2001) is confirmed by the results of our study since the higher values on barefoot condition by EG (compared to shod condition) are accompanied, although no significant, by higher values of JH (4.10% and 0.83% in EG and CG, respectively) (figure 1). This beneficial effect of barefoot condition is highlighted even by the highest per cent improvement in EG which showed almost twice the per cent improvement compared to the CG even in the shod condition (8.30% and 4.47%, respectively) (figure 1). Lower-limb stiffness (LLS) (Moore, 2016) and the stretch-shortening cycle (SSC) (Vogt, & Hoppeler, 2014) are the two most important neuromuscular elements linked to elastic energy use. The later (elastic energy) is released during the concentric phase of the muscles (Komi, 2000). Jaen-Carrillo, Cartón-Llorente, Lozano-Jarque, Rubio-Peirotén, Roche-Seruendo, García-Pinillos (2021) revealed that no significant correlations exist between lower-limb stiffness and RSI.

In terms of Tc, results showed an improvement in post measurements in both groups, decreasing average values by 27.48%. The corresponding percentages for the barefoot and shod condition for the EG were 33.05% and 28.15% respectively, while for the CG these percentages were 23.87% and 24.83%, respectively (figure 1). Finally, the JH increased significantly by 8.30% only for the shoes condition on EG (figure 1). This finding is in line with those of La Porta et al. (2013) who examined the effect of different footwear on jumping and found that barefoot resulted in greater JH compared to traditional tennis shoes and those of Harry, Paquette, Caia, Townsend, Weiss, Schilling (2015) who revealed that vertical jump displacements were not statistically different between footwear conditions. The non-statistically difference between footwear conditions may be attributed to the fact that the force cannot be directed directly upwards but is dispersed in the cushion of the shoe resulting in a negative effect on take-off velocity and JH. Further, our results are in line with those of Meylan and Malatesta (2009) who revealed significant improvement on jump height applying a program of plyometric exercises. Barefoot training results in greater activation of the tibial muscles resulting in reduced joint stiffness (Tam, Divekar, Lamberts, Tucker, Hill 2016) and a significantly larger loading during impact (De Wit, De Clercq, Aerts, 2000).

The gain in JH improvement may be attributed to the fact that barefoot strength training (BST) improves athletic performance by increasing the size and strength of the intrinsic musculature of the foot making the muscles stronger increasing force potential when participants strike the ground with their foot (Mullen, Cotton, Bechtold, Toby, 2014). In addition, BST improve performance by increasing ground reaction forces (GRF) allowing participants to apply more force directly into the ground, which led to greater average JH and average power because in the case of footwear the cushioning of a shoe dissipates the GRF, which could decrease JH (La Porta et al., 2013).

5. Conclusions

Barefoot training results in an improvement in vertical jump, vertical stiffness, RSI and Tc when performing DJs in female volleyball athletes after a period of 4 weeks, which were not statistically significant. Given the small sample size, the results of the study should not be generalized to the rest of the population as they may not fully correspond to the true picture. In addition, due to the use of PE it is recognized that the technical requirements (proper shock absorption, timely pre-activation before landing, balance both on the ground and in the air) are increased. The sample consisted of young volleyball players with no significant previous experience in deep jumps. The findings are recommended not to be applied to experienced professional athletes. The findings are mere indications and further research is needed to generalize to other populations - groups of three athletes.

Conflict of interest

No potential conflict of interest relevant to this article was reported.

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