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Differences in ground reaction forces during landing between volleyball spikes

JAROSŁAW KABACIŃSKI[1], MICHAŁ MURAWA[1], LECHOSŁAW BOGDAN DWORAK[2], JACEK MĄCZYŃSKI[1]

Abstract

Introduction. **The peak values of the vertical ground reaction force in the landing phase of attacks suggest a external loads of volleyball player. The high dynamic loads during landing in volleyball jumps may cause lower extremity injuries.** Aim of Study. **The main purpose of this study was to compare the impact forces between three different volleyball attack techniques.** Material and Methods. **Twelve female volleyball players (mean±standard deviation: age 22.3±4.2 years, body height 183.0±8.7 cm, body mass 74.4±10.9 kg) participated in the laboratory tests. A force platform was used to measure the ground reaction forces (GRFs) during landing in volleyball spikes. The vertical (v) component of GRF and horizontal (h) components (resultant) of GRFs, buildup index of these forces (vBIF, hBIF) and time to peak GRF (Tv, Th) were analyzed.** Results. **No significant differences in Tv and Th (from 0.05±0.01 s to 0.06±0.01 s) between the three volleyball jumps were demonstrated ($p<0.05$). Significant differences in the peak vGRF, hGRF, vBIF and hBIF between the back row attack and front row attack (23.7%, 18.2%, 38.2% and 29.7%, respectively), and between the back row attack and slide attack (21.1%, 27.3%, 28.7% and 26.4%, respectively) were found ($p<0.05$). The highest values of peak vGRF (3.8±0.3 $BW \cdot m^{-1}$), peak hGRF (1.1±0.2 $BW \cdot m^{-1}$), vBIF (79.4±14.6 $BW \cdot m^{-1} \cdot s^{-1}$) and hBIF (21.2±7.2 $BW \cdot m^{-1} \cdot s^{-1}$) were obtained during landing in the back row attack ($p<0.05$).** Conclusions. **The peak vGRF and vBIF during landing in volleyball spikes ranged: from approximately 3 to 4 $BW \cdot m^{-1}$ (vGRF) and from approximately 50 to 80 $BW \cdot m^{-1} \cdot s^{-1}$ (vBIF), and were several times higher than hGRF and hBIF. Increased impact forces in spikes indicate higher external loads during landings and a greater risk of lower extremity injuries in female volleyball players.**

KEYWORDS: ground reaction force, landing, spike, knee injuries, volleyball.

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Corresponding author: biomechanika@awf.poznan.pl

[1] Poznan University of Physical Education, Department of Biomechanics, Poznań, Poland
[2] University of Arts, Department of Bionics, Poznań, Poland

Introduction

Blocks and attacks performed repeatedly at high performance lead to serious overuse of the musculoskeletal system of volleyball players [5, 9, 20, 22, 24]. Ferretti et al. [9] reported that a large number of this jumps and the likelihood of losing balance due to deviations in jumping technique are the primary causes of injury in volleyball. The inherent risk of injury in volleyball athletes is a result of the sport's dynamic and ballistic nature during the jumping-landing sequence [24]. In particular, landing after a block and spike increases the incidence of lower extremity injuries in volleyball players.

Maximum values of the ground reaction force (GRF) during the landing phase of volleyball jumps exceed several times athlete's body weight [1]. The peak GRF during landings may increase the internal loads that may cause injury if not sufficiently distributed or attenuated by the musculoskeletal system [16, 22]. The high impact forces suggest a greater risk of knee injury risk among volleyball players [8, 9, 18]. The deleterious effects of these forces may be compounded for an

attacker as a result of performing landings many times during a match [24].
Landing in volleyball jump is one of the primary non-contact mechanisms that lead to anterior cruciate ligament (ACL) injury [6, 9]. Non-contact situations could potentially occur near the foot strike when the quadriceps is eccentrically contracting to resist flexion [6]. In female athletes in particular, increased strain on the passive support structures of the knee could contribute to the greater incidence of non-contact ACL injury [12]. Colby et al. [6] explained that the ACL of females is predisposed to greater loads as a result of a more extended knee position when making ground contact. Furthermore, Salci et al. [22] demonstrated the different biomechanics of the lower extremities in terms of the kinematic and kinetic parameters of the knee, hip and ankle joints during landing between female and male volleyball players.
Overloading the knee extensor mechanism beyond the capacity of the patellar tendon (PT) to regenerate will precipitate jumper's knee development [20]. In volleyball, an increased incidence of jumper's knee may occur as a result of high loads on the PT during block and spike landings [2, 13, 23]. Furthermore, valgus knee strain during eccentric loading in the landing phase after a spike may contribute to the asymmetric onset of jumper's knee in female volleyball athletes [14]. Apart from the dynamic loads, landing technique (LT) [17], jump height [13] and volume of jump training [26, 27] are important risk extrinsic factors for patellar tendinopathy in volleyball.
The purpose of this study was to compare the impact forces during landing between three different volleyball spike techniques. A secondary purpose was to examine the biomechanical factors associated with ACL injury and patellar tendinopathy as well as strategies for preventing knee injuries in volleyball.

Material and Methods

Subjects
Twelve female volleyball players of the 1st team (mean ± standard deviation: age 22.3 ± 4.2 years, body height 183.0 ± 8.7 cm, body mass 74.4 ± 10.9 kg), representing the highest volleyball league in Poland were recruited for this study. The study was approved by the Bioethical Committee of the Poznan University of Medical Sciences. All female athletes provided written informed consent to participate in research and were fully informed of the aims of this study and the experimental procedures. Prior to testing, each participant performed ten minutes of total body warm-up exercises by running on a treadmill and followed by five minutes of muscles stretching.

Procedures
The measurements of GRFs were performed using piezoelectric force platform Kistler type 9261A 1000Hz (Winterthur, Switzerland). GRF vs. time graphs: the vertical component (vGRF), the anterior-posterior of the horizontal component (hGRFy) and the lateral of the horizontal component (hGRFx) were recorded.
Blocks and attacks were filmed by two Canon cameras at 25 Hz placed in the lateral and frontal planes (Figure 1). Based on video screening, three representative attempts of each technique for all female volleyball players were selected for analysis.

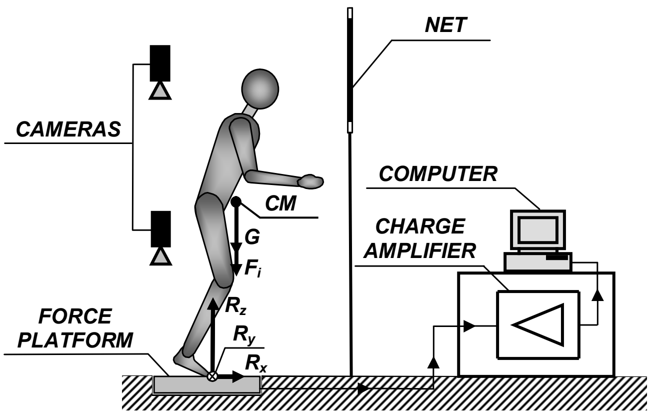

Figure 1. Biomechanical model during landing in volleyball jump (R_z – the vertical component of GRF, R_y – the anterior-posterior of the horizontal component of GRF, R_x – the lateral of the horizontal component of GRF, G – gravitational force, F_i – inertial force, CM – center of mass)

The female athletes performed the three volleyball spikes at a net suspended in the laboratory:
(1) Slide attack – take-off from a single lower extremity after running around the setter along the net,
(2) Front row attack – jump from attack area after a 1-2 steps run-up,
(3) Back row attack – jump from beyond the attack line after a 2-3 steps run-up.
Each action consisted of setting and hitting the ball, and blocking on the opponent's side.
The following parameters were analyzed in this study:
a) maximal values of the force (peak vGRF and peak hGRF), where:

$$\text{peak hGRF} = \sqrt{\text{peak hGRFx}^2 + \text{peak hGRFy}^2},$$

b) time to peak vGRF (Tv) and time to peak hGRF (Th),
c) build-up index of peak vGRF (vBIF) and build-up index of peak hGRF (hBIF), where BIF = peak GRF/T.

The values of GRF were normalized to subjects' body weight (BW) and body height (m) ($BW \cdot m^{-1}$).

Statistical analysis

The results were submitted to statistical analysis using Statistica 12.0. The means and standard deviations of age, somatic parameters, T, GRF and BIF were calculated. The normal distribution of the data was verified by the Shapiro-Wilk test ($p < 0.05$). The nonparametric Friedman ANOVA test ($p < 0.05$) and post hoc Dunn test ($p<0.05$) were used to determine the significant differences between three volleyball techniques for the mean values: Tv and Th, vGRF and hGRF, and vBIF and hBIF.

Results

Figures 2 and 3 illustrate time graphs of the vGRFs and hGRFs during landing in volleyball spikes. The values of the biomechanical parameters calculated from the recorded GRF vs. time graphs are shown in Table 1. No significant differences in the time to peak GRF between the three volleyball jumps were found, and values ranged from 50 to 60 ms (ANOVA Friedman test, $p < 0.05$). Moreover, using the ANOVA Friedman test ($p < 0.05$) and post hoc Dunn test ($p < 0.05$), the significant differences in the peak GRF and BIF between the back row attack and front row attack, and between the back row attack and slide attack were demonstrated. The values obtained for these variables ranged from approximately 2.9 to 3.8 $BW \cdot m^{-1}$ (vGRF), from 0.8 to 1.1 $BW \cdot m^{-1}$ (hGRF), from 49.1 to 79.4 $BW \cdot m^{-1} \cdot s^{-1}$ (vBIF) and from 14.9 to 21.2 $BW \cdot m^{-1} \cdot s^{-1}$ (hGRF). Table 2 presents the differences in peak GRF and BIF between the three volleyball jumps.

Discussion

This study determined the magnitude of GRFs during landing in the slide attack, front row attack and back row attack. Moreover, differences in GRFs between these three volleyball spike jumps were found. The highest peak vGRF and hGRF values of approximately 4 $BW \cdot m^{-1}$ and 1 $BW \cdot m^{-1}$, respectively, were recorded during landing after the back row attack spike. The increase in peak GRF in this technique may results from the high take-off dynamics and maximum jump height indispensable to successfully spike the ball over the opponent's block. Considering slide attack

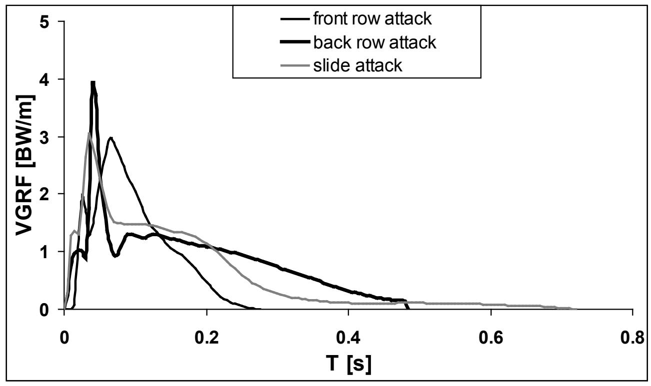

Figure 2. Vertical ground reaction force (vGRF) vs. time (T) graphs during landing in volleyball spikes

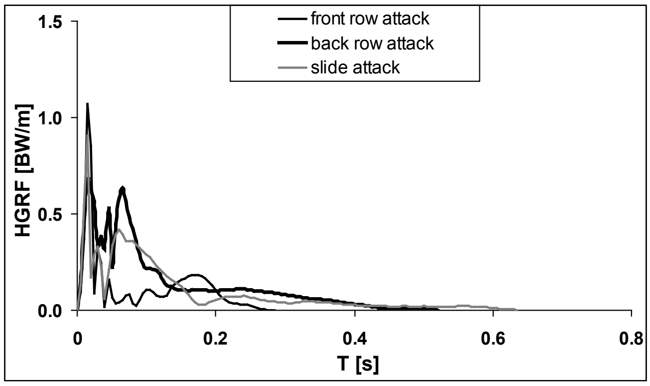

Figure 3. Horizontal ground reaction force (hGRF) vs. time (T) graphs during landing in volleyball spikes

Table 1. Time (Tv, Th), and peak values of the ground reaction force (vGRF, hGRF) and build-up index of force (vBIF, hBIF) during landing in volleyball jumps (mean ± standard deviation)

Parameters	Slide attack	Front row attack	Back row attack
		Vertical	
Tv [s]	0.06 ± 0.01	0.06 ± 0.01	0.05±0.01
vGRF [$BW \cdot m^{-1}$]	3.0 ± 0.2*	2.9 ± 0.2*	3.8 ± 0.3*
vBIF [$BW \cdot m^{-1} \cdot s^{-1}$]	56.6 ± 12.6*	49.1 ± 9.1*	79.4 ± 14.6*
		Horizontal	
Th [s]	0.06 ± 0.01	0.06 ± 0.01	0.05 ± 0.01
hGRF [$BW \cdot m^{-1}$]	0.8 ± 0.2*	0.9 ± 0.2*	1.1 ± 0.2*
hBIF [$BW \cdot m^{-1} \cdot s^{-1}$]	15.6 ± 5.6*	14.9 ± 5.8*	21.2 ± 7.2*

*$p < 0.05$, ANOVA Friedman test

Table 2. The differences in values of peak ground reaction force (vGRF; hGRF) and build-up index of force (vBIF; hBIF) between front row attack, slide attack and back row attack

	vGRF [%]; hGRF [%]			vBIF [%]; hBIF [%]		
	Slide attack	Front row attack	Back row attack	Slide attack	Front row attack	Back row attack
Slide attack	–	3.3; 11.1	21.1*; 27.3*	–	13.3; 4.5	28.7*; 26.4*
Front row attack	3.3; 11.1	–	23.7*; 18.2*	13.3; 4.5	–	38.2*; 29.7*
Back row attack	21.1*; 27.3*	23.7*; 18.2*	–	28.7*; 26.4*	38.2*; 29.7*	–

*Significant differences between the three volleyball spikes (post hoc Dunn test, $p < 0.05$)

and front row attack, the values of vGRF and hGRF were 3 $BW \cdot m^{-1}$ and 0.8 $BW \cdot m^{-1}$, and 2.9 $BW \cdot m^{-1}$ and 0.9 $BW \cdot m^{-1}$, respectively. Thus, the peak vGRF was several times greater than hGRF because the main movement that occurs during landing after spike is performed in the vertical direction.

The peak values of vGRF were generated after only 50-60 of milliseconds. Short-lasting movements of the lower extremities during landing have ballistic characteristics and are controlled in the open loop of the neuromuscular process according to the ante-post factum rule. The information reception period is too short to produce feedback and introduce a regulating signal (correcting stimulus) to consciously control the follow-up movement aimed at reducing GRF. Therefore, Fu et al. [10] suggested that if the neuromuscular system fails to prepare properly for an impact during landing, a shoe intervention may be an effective method for minimizing the impact force and reducing soft tissue resonance.

Findings revealed high vBIF values (in the range of approximately 50 - 80 $BW \cdot m^{-1} \cdot s^{-1}$) for the three different volleyball spike techniques. The BIF indicates the rate of the peak GRF change and increases with increasing force generated in the shortest period of time. The high peak GRF and BIF values in the landing phase after a spike suggest significant external loads. Furthermore, the improper LT (e.g., stiff landing when the maximal knee flexion angle is less than 90°) entails greater dynamic loads of the musculoskeletal system in athletes [20]. Increased landing stiffness may lead to higher loading rates and peak forces on the PT [26]. The knee extensor moment loading rate and the knee angular velocity also represent important risk factors related to patellar tendinopathy [2]. In addition, increasing knee adduction moment loading can potentially place a higher strain on the ACL [7]. Moreover, Withrow et al. [28] demonstrated the effect of valgus knee moment loading on ACL strain during landing.

Numerous authors have indicated improper landing as an essential factor increasing the risk of knee injuries. For example, van der Worp et al. [26] reported that LT including small post-touchdown range of motion is associated with the onset of patellar tendinopathy. Malliaras et al. [17] observed a greater likelihood of PT injury among volleyball players performing landing with a reduced range of ankle dorsiflexion. Other biomechanical studies have revealed an increased incidence of jumper's knee due to the development of a deep knee flexion angle during landing in spike jumps [13, 21]. In turn, Boden et al. [4] have found that ankle in a dorsiflexed position at initial ground contact predisposes the ACL to injury. The ACL's susceptibility to injury may also result from insufficient knee flexion (0-30°) during landing [19]. Additionally, Salci et al. [22] reported that landing with lower hip flexion may contribute to the higher incidence of ACL injury in female volleyball players.

The position of the lower extremity joints at ground contact determines the magnitude of the GRF in the landing phase. Some authors showed a positive effect of soft landing, i.e., with an increased range of motion for the lower extremity joints and forefoot landing, on impact forces dissipation [3, 5, 20, 22]. The use of this LT may also lead to a reduction of vGRFs during landing in volleyball jumps. Decreasing the vGRFs observed during block and spike landings by implementing a correct LT can help reduce the risk of lower extremity injuries among volleyball players [5, 9, 15, 20, 22, 25].

The strategies for preventing knee injuries are also associated with the strength training of the thigh muscles. For example, strengthening of knee extensors in eccentric exercises is an effective strategy for preventing patellar tendinopathy [29]. Repeated eccentric contractions during drop jumps may produce a stronger protective effect against injuries related to landing from a jump [11, 20]. Furthermore, plyometric training incorporating dynamic stabilization exercises could reduce the impact forces and incidence of knee injury in female athletes [11].

Conclusions

This study demonstrated the significantly highest peak vGRFs and BIFs during landing after the back row attack spike. Furthermore, the findings revealed several times greater values of vGRF than athlete's body weight which were generated after only tens of milliseconds. Increased impact forces during landing in spikes indicate that female volleyball players sustain high dynamic loads. The accumulation of these loads as a result of repeated jumps leads to an increase in mechanical stress on the knee ligament structures and an greater risk of ACL injury or patellar tendinopathy. Therefore, mechanisms of PT and ACL injuries, and strategies for preventing knee injuries in volleyball players were described.

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References

1. Adrian MJ, Lauglin CK. Magnitude of ground reaction forces while performing volleyball skills. In: Matsui H, Kobayashi K, eds., Biomechanics VIII-B, Champaign, IL: Human Kinetics; 1983. pp. 903-914.
2. Bisseling RW, Hof AL, Bredeweg SW, et al. Relationship between landing strategy and patellar tendinopathy in volleyball. Br J Sports Med. 2007; 41: 264-268.
3. Blackburn JT, Padua DA. Sagittal-plane trunk position, landing forces, and quadriceps electromyographic activity. J Athl Tr. 2009; 44: 174-179.
4. Boden BP, Torg JS, Knowles SB, et al. Video analysis of anterior cruciate ligament injury: abnormalities in hip and ankle kinematics. Am J Sports Med. 2009; 37: 252-259.
5. Briner WW Jr, Kacmar L. Common injuries in volleyball. Mechanisms of injury, prevention and rehabilitation. Sports Med. 1997; 24: 65-71.
6. Colby S, Francisco A, Yu B, et al. Electromyographic and kinematic analysis of cutting maneuvers. Implications for anterior cruciate ligament injury. Am J Sports Med. 2000; 28: 234-240.
7. Cortes N, Morrison S, van Lunen BL, et al. Landing technique affects knee loading and position during athletic tasks. J Sci Med Sport. 2012; 15: 175-181.
8. Dufek JT, Bates BT. The evaluation and prediction of impact forces during landings. Med Sci Sports Exerc. 1990; 22: 370-377.
9. Ferretti A, Papandrea P, Conteduca F, et al. Knee ligament injuries in volleyball players. Am J Sports Med. 1992; 20: 203-207.
10. Fu W, Liu Y, Zhang S. Effects of footwear on impact forces and soft tissue vibrations during drop jumps and unanticipated drop landings. Int J Sports Med. 2013; 34: 477-483.
11. Hewett TE, Stroupe AL, Nance TA, et al. Plyometric training in female athletes. Decreased impact forces and increased hamstring torques. Am J Sports Med. 1996; 24: 765-773.
12. Hughes G, Watkins J, Owen N. Differences between the sexes in knee kinetics during landing from volleyball block jumps. Eur J Sport Sci. 2010; 10: 1-11.
13. Lian O, Engebretsen L, Ovrebo RV, et al. Characteristics of the leg extensors in male volleyball players with jumper's knee. Am J Sports Med. 1996; 24: 380-385.
14. Lian O, Refsnes PE, Engebretsen L, et al. Performance characteristics of volleyball players with patellar tendinopathy. Am J Sports Med. 2003; 31: 408-413.
15. Lobietti R, Coleman S, Pizzichillo E, et al. Landing technique in volleyball. J Sports Sci. 2010; 28: 1469--1476.
16. Madigan LM, Pidcoe PE. Changes in landing biomechanics during a fatiguing landing activity. J Electromyogr Kines. 2003; 13: 491-498.
17. Malliaras P, Cook JL, Kent P. Reduced ankle dorsiflexion range may increase the risk of patellar tendon injury among volleyball players. J Sci Med Sport. 2006; 9: 304--309.
18. Mills C, Pain MTG, Yeadon MR. Reducing ground reaction forces in gymnastics' landings may increase internal loading. J Biomech. 2009; 42: 671-678.
19. Olsen OE, Mykelbust G, Engebretsen L, et al. Injury mechanisms for anterior cruciate ligament injuries in team handball: a systematic video analysis. Am J Sports Med. 2004; 32: 1002-1012.
20. Reeser JC, Verhagen E, Briner WW, et al. Strategies for the prevention of volleyball related injuries. Br J Sports Med. 2006; 40: 594-600.
21. Richards DP, Ajemian SV, Wiley JP, et al. Relation between ankle joint dynamics and patellar tendinopathy in elite volleyball players. Clin J Sport Med. 2002; 12: 266-272.
22. Salci Y, Kentel BB, Heycan C, et al. Comparison of landing maneuvers between male and female college volleyball players. Clin Biomech. 2004; 19: 622-628.
23. Sorenson SC, Arya S, Souza RB, et al. Knee extensor dynamics in the volleyball approach jump: the influence of patellar tendinopathy. J Orthop Sports Phys Ther. 2010; 40: 568-576.

24. Tillman MD, Hass CJ, Brunt D, et al. Jumping and landing techniques in elite women's volleyball. J Sports Sci Med. 2004; 3: 30-36.
25. Tokuyama M, Ohashi H, Iwamoto H, et al. Individuality and reproducibility in high-speed motion of volleyball spike jumps by phase-matchingand averaging. J Biomech. 2005; 38: 2050-2057.
26. Van der Worp H, de Poel HJ, Diercks RL, et al. Jumper's Knee or Lander's Knee? A Systematic Review of the Relation between Jump Biomechanics and Patellar Tendinopathy. Int J Sports Med. 2014; 35: 714-722.
27. Visnes H, Bahr R. Training volume and body composition as risk factors for developing jumper's knee among young elite volleyball players. Scand J Med Sci Sports. 2013; 23: 607-613.
28. Withrow TJ, Huston LJ, Wojtys EM, et al. The effect of an impulsive knee valgus moment on in vitro relative ACL strain during a simulated jump landing. Clin Biomech. 2006; 21: 977-983.
29. Young MA, Cook JL, Purdam CR, et al. Eccentric decline squat protocol offers superior results at 12 months compared with traditional eccentric protocol for patellar tendinopathy in volleyball players. Br J Sports Med. 2005; 39: 102-105.