

Dynamic load indicators for take-off–landing sequence in blocks and attacks of elite female volleyball players

JAROSŁAW KABACIŃSKI^{1*}, LECHOSŁAW BOGDAN DWORAK²,
MICHAŁ MURAWA¹, AGATA RZEPNICKA¹

¹ Department of Biomechanics, University School of Physical Education, Poznań, Poland.

² Department of Physiotherapy and Biological Renovation, Stanisław Wojciechowski Higher Vocational State School, Kalisz, Poland.

Purpose: Dynamic loads during landings determined by the ground reaction forces (GRFs) may elaborate internal loads and increase the risk of overload knee injuries as a result of performing volleyball jumps many times. The study dealt with a biomechanical assessment of dynamic load indicators in female volleyball players for the motion sequence of take-off–landing in blocks and attacks. *Methods:* Twelve professional female volleyball players participated in the study. Blocks and attacks were filmed by two cameras. GRFs vs. time graphs were recorded with the use of a force platform. Values of dynamic load indicators in terms of the relations of peak of vertical component of GRF, build-up index of this force (BIF), and power output (P) during landing to the vGRF, BIF and P during take-off (L/T) were calculated. *Results:* The statistically significant ($p < 0.05$) highest values of L/T indicators were found for back row attack spikes: 2.4 (vGRF), 12.2 (BIF) and 3.1 (P). In the case of blocks, slide attack spikes and attack line spikes, results of these variables were in range: $1.8 \div 2.1$, $5.9 \div 7.6$ and $2.1 \div 2.9$, respectively. *Conclusions:* The reduction of GRFs during landings contributes to decreasing the level of the load indicators L/T which should minimize the incidence of anterior cruciate ligament and patellar tendon injuries in female volleyball players.

Key words: ground reaction forces, take-off–landing, dynamic loads, blocks and attacks, volleyball, biomechanics

1. Introduction

Dynamic loads for take-off–landing motion sequence in blocks and attacks are often the cause of injuries in volleyball players [3], [10], [24]. In particular, during landings the high external loads determined by the ground reaction forces (GRFs) may elaborate internal loads that may cause injury if not sufficiently distributed or attenuated by the musculo-skeletal system [14], [21]. The peak values of GRFs during landings from a volleyball jumps exceed several times the body weight (BW), approximately 4 BW (blocks) and $5 \div 7$ BW (attacks) [10]. Furthermore, Stacoff et al. reported that in landing phase after volleyball block the first peak of the vertical component of GRF appeared at forefoot touchdown and ranged from 1 BW to 2 BW, whereas the second peak, which was recorded for heel contact, ranged between 1 BW

to 7 BW [23]. Accumulation of large impact forces leads to greater risk of injuries to lower extremities (LEs) among volleyball athletes [6], [8], [17]. Especially, in female volleyball players there was observed high susceptibility to non-contact anterior cruciate ligament (ACL) injuries [3], [8] and patellar tendinopathy (jumper's knee) [11], [13], [15], [20].

The potential force-velocity capabilities of a player affect the level of take-off dynamics in volleyball jump [2], [5]. Increasing the LEs strength and muscle power in specialized training, which includes, e.g., plyometric exercises that employ the stretch–shortening cycle (S-SC) effect, and proper jumping technique, allow greater vertical jump height to be achieved [12], [16], [18], [19], [22]. On the other hand, the appropriate level of LEs strength enables one to safely absorb impact forces during the eccentric contraction of LEs muscles [9], [24]. Moreover, high external loads may be considerably reduced by use of the proper volley-

* Corresponding author: Jarosław Kabaciński, University School of Physical Education, Department of Biomechanics, ul. Królowej Jadwigi 27/39, 61-871 Poznań, Poland. E-mail: biomechanika@awf.poznan.pl, phone number: +48-61-8355392.

Received: December 6th, 2014

Accepted for publication: March 26th, 2015

ball jump landing technique [3], [7], [21], [23], [25]. The decreasing of GRFs during landings may reduce the risk of overload injuries in female volleyball players that result from repeated jumps.

The purpose of this study was to assess the magnitude of dynamic load indicators in female volleyball players for the motion sequence of take-off–landing in blocks and attacks.

2. Materials and methods

Participants

Twelve female volleyball players of the 1st team, representing the highest volleyball league in Poland, participated in this study. All female athletes provided written informed consent to participate in the experiment. The tests were performed after participants had been acquainted with the experimental procedures. The study received approval from the Bioethical Committee of the Poznań University of Medical Sciences. Mean \pm SD values of age and competitive experience as well as somatic parameters of height and weight, body mass index (BMI) and Rohrer's index (RI) are presented in Table 1.

Table 1. Characteristics of the female volleyball players ($N = 12$)

Parameters	Mean \pm SD
Age [years]	25.7 \pm 6.4
Volleyball experience [years]	13.3 \pm 6.0
Body height [cm]	182.6 \pm 6.7
Body weight [kg]	74.9 \pm 7.3
BMI [kg/m ²]	22.5 \pm 1.7
RI [g/cm ³]	1.2 \pm 0.1

Experimental procedures

The measurements of GRFs were performed using the piezoelectric force platform Kistler type 9261A 1000 Hz (Winterthur, Switzerland). Blocks and attacks were filmed by two Canon video cameras (25 Hz), placed on the sides at heights of 50 cm and 220 cm. Furthermore, the volleyball net was suspended in the laboratory at the level of 224 cm. For each volleyball technique the net was moved to the appropriate distance from the platform (Fig. 1). The GRFs = $f(t)$ were recorded separately for the take-offs and during landings on a stationary platform and were analyzed using a computerized data acquisition and analysis program. Unsmoothed graphs of GRFs vs. time were normalized to body weight (BW).

Prior to the tests, each participant performed ten minutes of total body warm-up based on running on

the treadmill and cycling stationary bike followed by five minutes of muscle stretching. Female athletes performed the following volleyball techniques: block from a run-up, attack line spike, back row attack spike and slide attack spike. While one of the players attacked the ball played by a setter the other blocked it. Three successful trials respectively for each technique were selected for the final analysis based on video recordings. Using the computer program the peak values of the following parameters were determined:

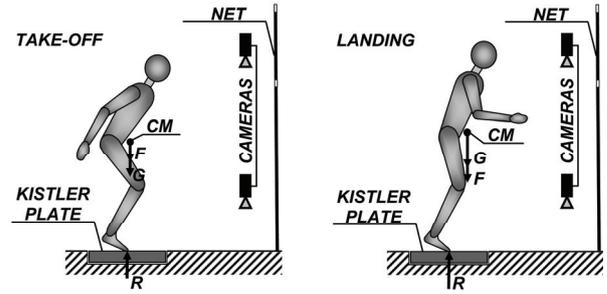


Fig. 1. Biomechanical models during take-off and landing in volleyball jump (R – ground reaction force, G – gravitational force, F – inertial force)

- vertical component ground reaction force (vGRF) during take-off (R_{zT}) and landing (R_{zL}),
- buildup index of GRF (BIF), during take-off (I_{zT}) and landing (I_{zL})

$$I_{zT} = \frac{R_{zT}}{t_{zT}}, \quad (1)$$

$$I_{zL} = \frac{R_{zL}}{t_{zL}}, \quad (2)$$

- power output (P), during take-off (P_{zT}) and landing (P_{zL})

$$P_{zT} = R_{zT} \cdot v_{zT}, \quad (3)$$

$$P_{zL} = R_{zL} \cdot v_{zL}, \quad (4)$$

where m – mass of the female athlete, v_z – velocity of CM

$$v_z = \frac{1}{m} \int_{t_1}^{t_2} R_z(t) dt. \quad (5)$$

On the basis of the results of these dynamic parameters, the following values of load indicators in take-off–landing sequence (L/T) were calculated

$$L/T_{GRF} = \frac{R_{zL}}{R_{zT}}, \quad (6)$$

$$L/T_{BIF} = \frac{I_{zL}}{I_{zT}}, \quad (7)$$

$$L/T_P = \frac{P_{zL}}{P_{zT}} \quad (8)$$

Statistics

The results were submitted to statistical analysis with the use of Statistica 10.0 and PQStat 1.6.0 computer programs. The means and standard deviations of age, somatic and dynamic load indicators were calculated. The results of the Shapiro–Wilk test ($p < 0.05$) indicated that the data was not normally distributed. Consequently, nonparametric Friedman

ANOVA test ($p < 0.05$) and post hoc Dunn test ($p < 0.05$) were used to indicate significant differences between four volleyball jumps for the mean values: L/T_{GRF} , L/T_{BIF} and L/T_P .

3. Results

Figures 2 and 3 illustrate mean graphs for take-offs $R_{zT}(t)$ and for landings $R_{zL}(t)$ in block from a run-up and attacks.

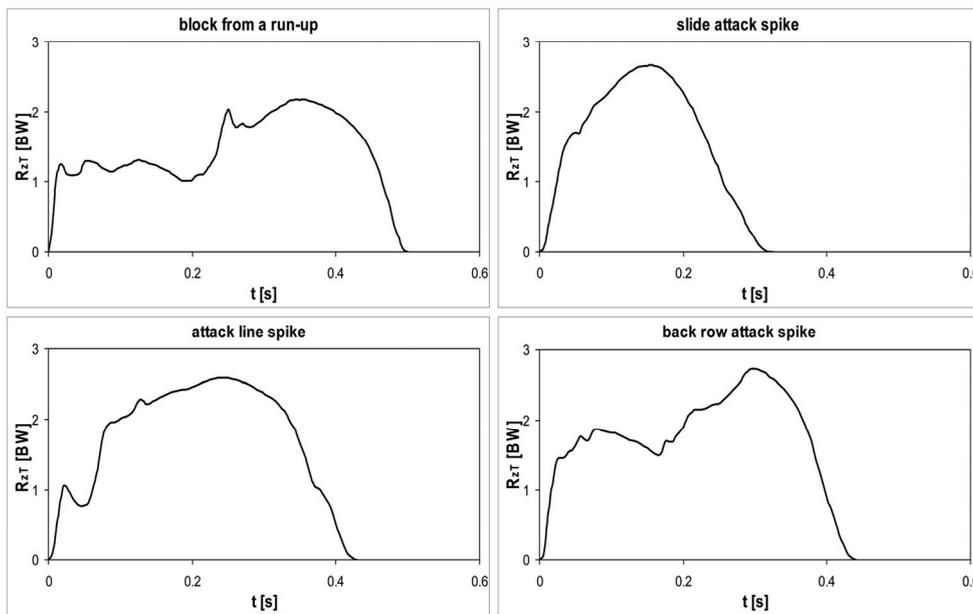


Fig. 2. VGRF vs. time graphs during take-offs in blocks and attacks

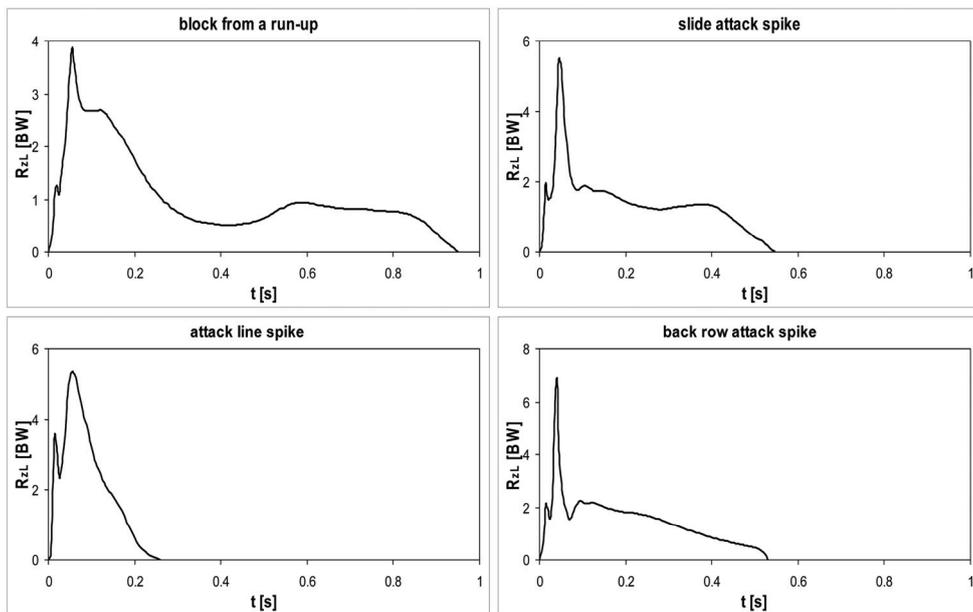


Fig. 3. VGRF vs. time graphs during landings in blocks and attacks

The values of L/T indicators for block from a run-up and attacks are presented in Table 2. Furthermore, based on ANOVA Friedman test ($p < 0.05$) and post hoc Dunn test ($p < 0.05$) statistically significant differences in the mean values of the L/T indicators (Δ [%]) respectively between the block from a run-up, slide attack spike, attack line spike and back row attack spike were obtained (Table 3).

Table 2. The values of L/T loads indicators in block from a run-up and attacks

Parameters		Block from a run-up	Slide attack spike	Attack line spike	Back row attack spike
L/T_{GRF}	[-]	1.8 ± 0.1	2.1 ± 0.1	2.0 ± 0.1	2.4 ± 0.1
L/T_{BIF}	[-]	7.6 ± 2.1	5.9 ± 1.6	7.4 ± 1.7	12.2 ± 1.9
L/T_P	[-]	2.6 ± 0.4	2.9 ± 0.5	2.1 ± 0.2	3.1 ± 0.4

Table 3. The significant differences in the values of the L/T indicators between the four volleyball jumps * $p < 0.05$, ANOVA Friedman test and post hoc Dunn test

Parameters		Block from a run-up	Slide attack spike	Attack line spike	Back row attack spike
$\Delta L/T_{GRF}$ [%]	Block from a run-up	–	17*	11*	33*
	Slide attack spike	17*	–	5	14*
	Attack line spike	11*	5	–	20*
	Back row attack spike	33*	14*	20*	–
$\Delta L/T_{BIF}$ [%]	Block from a run-up	–	29*	3	61*
	Slide attack spike	29*	–	25*	107*
	Attack line spike	3	25*	–	65*
	Back row attack spike	61*	107*	65*	–
$\Delta L/T_P$ [%]	Block from a run-up	–	12*	24*	19*
	Slide attack spike	12*	–	38*	7
	Attack line spike	24*	38*	–	48*
	Back row attack spike	19*	7	48*	–

Statistically insignificant differences occurred in the mean values of L/T load indicators (ANOVA Friedman test, $p < 0.05$ and post hoc Dunn test, $p < 0.05$) only between:

- slide attack spike and attack line spike for GRF,
- block from a run-up and attack line spike for BIF,
- slide attack spike and back row attack spike for P.

4. Discussion

This study determined the magnitude of dynamic load indicators in female volleyball players for take-off–landing motion sequence in blocks and attacks. Significantly greater L/T load indicator values as 2.3 (vGRF), 12.2 (BIF) and 3.1 (P) were recorded in back row attack spike. The high level of L/T in these techniques is caused by very large vGRF and P values during landing phase. In the back row attack spike, it is recommended to increase vGRFs and P during take-off to develop higher vertical velocity of players' center of mass (CM). Greater take-off dynamics enables one to obtain the maximum height of player CM during the flight phase of the back row attack and successfully spike the ball over the opponent's block. Thus, volleyball jump height influences the level of impact forces and mechanical power output during landing. Furthermore, relatively large values of L/T_{GRF} for slide attack spike (2.1) and attack line spike (2.0) were observed. In turn, high results L/T_{BIF} and L/T_P indicators were obtained for the block from a run-up in comparison with attacks (line spike and slide). It was mainly due to the greater values of both parameters during landing in relation to take-off. However, the lowest values of L/T_{BIF} were observed for slide attack spike. The BIF represents the rate of change of peak GRF and increases with the growth of force generated in the shortest period of time. Out of the four volleyball jumps the highest value of the BIF during take-off was determined for slide attack mainly as a result of the dynamic take-off (high peak vGRF as well as horizontal GRF). Secondly, due to the shortest duration of take-off phase, associated with sports technique of this attack. In slide attack, spiker after running around the setter across the net performs a take-off from a single LE.

For the take-off–landing motion sequence in the volleyball jumps it is necessary to combine the ability to develop maximum force and power in the take-off phase (effective jump) with the proper LT (safe landing). However, during so-called stiff landing significant vGRFs are often generated and must be absorbed primarily by the musculoskeletal components of the LEs. Then high vGRF adversely acting on the talocrural joints and the knee joints may cause internal loads that lead to LEs injuries [6], [8], [17]. It was observed that ACL injury is more frequent in female volleyball players [3] and occurs 2 to 8 times more often than for male volleyball players [8]. Females initiate though different LEs biomechanics during block and spike landings than that of males [21]. The female knee is in

a more extended position at ground contact, and thus predisposes the ACL to greater external loads in impact phase [4]. Furthermore, recurrent loads on female knee extensor mechanism during landings in volleyball jumps also cause the patellar tendinopathy [11], [15]. In addition, among female athletes, valgus knee strain during the eccentric phase of the landing may contribute to the asymmetric onset of jumper's knee [13].

Undoubtedly, lowering the values of load indicators in take-off–landing motion sequence in volleyball jumps as a result of decreased GRFs can reduce the risk of LEs injuries. Minimization of external loads during landings after blocks and spikes is possible due to specific volleyball jump approach and correct landing technique (LT). For example, LT with an increased hip flexion, slightly flexed knee and plantar flexed foot is very important in dissipating large GRFs during landing and may be a protective mechanism to the ACL [1], [3]. In turn, Reeser et al. suggested that in prevention of patellar tendinopathy in volleyball athletes to minimize valgus strain on the lead knee during the jump approach and to keep knee flexion to a minimum on landing respectively may help to reduce cumulative load on the PT [20]. Apart from proper LT, high level LEs strength allows large impact forces to be safely absorbed. Therefore, the physical training of strength may be an effective modality for preventing injuries related to landings. In particular, plyometric exercises aimed at increasing the eccentric strength of LEs muscles during drop jumps are very useful in the training process and reduce incidence of knee injury in athletes. These biomechanical factors are important preventing strategies for injuries of LEs joints loaded in the take-off–landing motion sequence.

5. Conclusion

This study determined the level of the L/T load indicators for vGRF, BIF and P of four technically different volleyball jumps. Statistically significant differences were observed in the results of the above variables between the blocks and attacks. The highest of the values of L/T were recorded for back row spikes – attacks characterized by very high take-off dynamics and significant values of vGRF during landing. The growth of the impact forces and of the L/T indicators in volleyball jumps may increase the risk of the LEs joint injuries of athletes. Adverse dynamic loads may be significantly reduced through prevention strategies mainly associated with proper LT in volley-

ball jumps and effective strength training. The use of these important factors minimizing the external load indicators may reduce the scale of knee injuries in female volleyball players.

Acknowledgements

The authors would like to thank all participating players as well as the Club's coaching team for their cooperation.

References

- [1] BLACKBURN J.T., PADUA D.A., *Sagittal-plane trunk position, landing forces, and quadriceps electromyographic activity*, J. Ath. Training, 2009, 44(2), 175–181.
- [2] BOBBERT M.F., GERRITSEN K.G., LITJENS M.C., VAN SOEST A.J., *Why is countermovement jump height greater than squat jump height?* Med. Sci. Sport Exerc., 1996, 28(11), 1402–1412.
- [3] BRINER W.W., Jr., KACMAR L., *Common injuries in volleyball. Mechanisms of injury, prevention and rehabilitation*, Sports Med., 1997, 24(1), 65–71.
- [4] COLBY S., FRANCISCO A., YU B., KIRKENDALL D., FINCH M., GARRETT W. Jr., *Electromyographic and kinematic analysis of cutting maneuvers: Implications for anterior cruciate ligament injury*, Am. J. Sport Med., 2000, 28(2), 1234–1240.
- [5] DRISS T., VANDEWALLE H., QUIÈVRE J., MILLER C., MONOD H., *Effects of external loading on power output in a squat jump on a force platform: A comparison between strength and power athletes and sedentary individuals*, J. Sport Sci., 2001, 19(2), 99–105.
- [6] DUFEK J.S., BATES B.T., *The evaluation and prediction of impact forces during landings*, Med. Sci. Sport Exerc., 1990, 22(3), 370–377.
- [7] DUFEK J.S., ZHANG S., *Landing models for volleyball players: a longitudinal evaluation*, J. Sport Med. Phys. Fit., 1996, 36(1), 35–42.
- [8] FERRETTI A., *Knee ligament injuries in volleyball players*, Am. J. Sport Med., 1992, 20(2), 203–207.
- [9] HEWETT T.E., LINDENFELD T.N., RICCOBENE J.V., NOYES F.R., *The effect of neuromuscular training on the incidence of knee injury in female athletes. A prospective study*, Am. J. Sport Med., 1999, 27(6), 699–706.
- [10] KABACIŃSKI J., DWORAK L.B., KMIECIK K., MURAWA M., MAĆZYŃSKI J., *Loads acting on the locomotive system of professional female volleyball players during the landing phase of typical technical elements: spikes and blocks*, Port. J. Sport Sci., 2011, 11, Supl. 2, 97–100.
- [11] KUJALA U.M., AALTO T., OSTERMAN K., DAHLSTRÖM S., *The effect of volleyball playing on the knee extensor mechanism*, Am. J. Sport Med., 1989, 17(6), 766–769.
- [12] LEES A., GRAHAM-SMITH P., *Plyometric training: a review of principles and practice*, Sport Exerc. Inj., 1996, 2, 24–30.
- [13] LIAN O., REFSNES P.E., ENGBRETSSEN L., BAHR R., *Performance characteristics of volleyball players with patellar tendinopathy*, Am. J. Sport Med., 2003, 31(3), 408–413.
- [14] MADIGAN L.M., PIDCOE P.E., *Changes in landing biomechanics during a fatiguing landing activity*, J. Electromyogr. Kines., 2003, 13(5), 491–498.
- [15] MALLIARAS P., COOK J.L., KENT P., *Reduced ankle dorsiflexion range may increase the risk of patellar tendon injury among volleyball players*, J. Sci. Med. Sport, 2006, 9(4), 304–309.

- [16] MCBRIDE J.M., TRIPLETT-MCBRIDE T.N., DAVIE A., NEWTON R.U., *The effect heavy – vs. light-load jump squats on the development of strength, power, and speed*, J. Strength Cond. Res., 2002, 16(1), 75–82.
- [17] MILLS CH., PAIN M.T.G., YEADON M.R., *Reducing ground reaction forces in gymnastics' landings may increase internal loading*, J. Biomech., 2009, 42(6), 671–678.
- [18] MORAN K.A., WALLACE E.S., *Eccentric loading and range of knee joint motion effects on performance enhancement in vertical jumping*, Hum. Movement Sci., 2007, 26(6), 824–840.
- [19] NEWTON R.U., ROGERS R.A., VOLEK J.S., HÄKKINEN K., KRAEMER W.J., *Four weeks of optimal load ballistic resistance training at the end of season attenuates declining jump performance of women volleyball players*, J. Strength Cond. Res., 2006, 20(4), 955–961.
- [20] REESER J., VERHAGEN E., BRINER W.W., ASKELAND T.I., BAHR R., *Strategies for the prevention of volleyball related injuries*, Br. J. Sports Med., 2006, 40(7), 594–600.
- [21] SALCI Y., KENTEL B.B., HEYCAN C., AKIN S., KORKUSUZ F., *Comparison of landing maneuvers between male and female college volleyball players*, Clin. Biomech., 2004, 19(6), 622–628.
- [22] SHEPPARD J.M., DINGLEY A.A., JANSSEN I., SPRATFORD W., CHAPMAN D.W., NEWTON R.U., *The effect of assisted jumping on vertical jump height in height-performance volleyball players*, J. Sci. Med. Sport, 2011, 14(1), 85–89.
- [23] STACOFF A., KAELIN X., STUESSI E., *The impact in landing after a volleyball block*, [in:] G. De Groot, A.P. Hollander, P.A. Huijing, G.J. van Ingen Schenau (eds.), *Biomechanics XI-B*, Free University Press, Amsterdam, 1988, 694–700.
- [24] TILLMAN M.D., HASS C.J., BRUNT D., BENNETT G.R., *Jumping and landing techniques in elite women's volleyball*, J. Sport Sci. Med., 2004, 3(1), 30–36.
- [25] TOKUYAMA M., OHASHI H., IWAMOTO H., TAKAOKA K., OKUBO M., *Individuality and reproducibility in high-speed motion of volleyball spike jumps by phase – matching and averaging*, J. Biomech., 2005, 38(10), 2050–2057.