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KINEMATIC AND KINETIC EVALUATION OF JUMP-LANDING TASK IN VOLLEYBALL DEFENSE: IMPLICATIONS FOR ACL INJURY RISK ASSESSMENT

KINEMATIČNA IN KINETIČNA OCENA SKAKALNEGA PRISTANKA V ODBOJKI: OCENA TVEGANJA ZA POŠKODBE ACL

ABSTRACT

The aim of this study was to evaluate the biomechanics of jumping and landing in defense between beginner and professional volleyball players. 10 professional volleyball players from Iranian leagues and 10 beginners with less than 2 years of training experience participated in this study. Selected kinetic and kinematic variables in jump and landing movement in 5 tasks of volleyball defense was analyzed. There were no significant differences between beginners and professional groups in different types of jumping and landing in the phase of preparation, jumping and landing in the variables of ground reaction force in different directions except the variable YP1 in the side stepping to the left (P = 0.029) and loading rate. The results also showed that the knee flexion angle at the moment of landing in all jumps was significantly higher in professional volleyball players than in the beginner group. The difference between the groups in maximum knee flexion in the landing phase was also significant in all jumps except the side stepping to the left (p <0.05). Professional volleyball players have a lower risk of ACL injury than beginner volleyball players. As a result, to reduce the risk of ACL injury in beginners, it is necessary to pay attention to landing exercises and focus on increasing the flexion angle.

Keywords: Anterior cruciate ligament, Injury prevention, Jump, Kinetics, Kinematics

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IZVLEČEK

Namen te študije je bil ovrednotiti biomehaniko skokov in doskokov v obrambi med začetniki in profesionalnimi odbojkarji. V raziskavi je sodelovalo 10 profesionalnih odbojkarjev iz iranskih lig in 10 začetnikov z manj kot 2 leti izkušenj Z ODBOJKARSKIM treningom. Analizirane so bile izbrane kinetične in kinematične spremenljivke pri skoku in doskoku pri 5 nalogah odbojkarske obrambe. Med začetniškimi in profesionalnimi skupinami pri različnih vrstah skokov in doskokov v fazi priprav, skokov in doskokov v spremenljivkah sile reakcije tal v različnih smereh ni bilo UGOTOVLJENIH ZNAČILNIH razlik (P = 0,029). Rezultati so tudi pokazali, da je bil kot upogiba kolena v trenutku doskoka pri vseh skokih bistveno večji pri profesionalnih odbojkarjih kot v začetni skupini. Razlika med skupinama v maksimalni fleksiji kolena v fazi doskoka je bila pomembna tudi pri vseh skokih razen pri bočnem koraku v levo (p <0,05). Profesionalni odbojkarji imajo manjše tveganje za poškodbe ACL kot odbojkarji začetniki. zA zmanjšanje tveganja za poškodbe ACL pri začetnikih posvetiti pozornost pristajalnim vajam in se osredotočiti na povečanje upogibnega kota.

Ključne besede: sprednja križna vez, preprečevanje poškodb, skok, kinetika, kinematika

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INTRODUCTION

Anterior cruciate ligament (ACL) injury is one of the most common injuries among athletes (Johnson et al., 2020). It takes 6 to 12 months for the injured athlete to return to play conditions after the injury (Ardern, Webster, Taylor, & Feller, 2011; Chijimatsu et al., 2020). Approximately 72% of ACL injuries occur in non-contact conditions, such as jumping, landing, and spinning (Agel, Arendt, & Bershadsky, 2005). Excessive knee abduction and internal rotation in low knee flexion during landing (Hewett et al., 2005; Kiapour et al., 2016), especially high knee abduction moment (Levine et al., 2013) are known as biomechanical risk factors for in non-contact ACL injuries. Numerous studies have examined the factors influencing the incidence of ACL injury, including kinematic variables such as decreased knee flexion, increased knee abduction, and also bending the trunk towards the side of the supporting limb that may occur during single-leg landing maneuvers (Larson, Vannatta, Rutherford, & Kernozek, 2021). In this regard, Leppänen et al. (2017) showed that with every 10 degrees increase in knee flexion peak during vertical jump, the risk of ACL injury is reduced by 0.55 times, while every 100 N increase in ground reaction force (GRF) will increase this ratio by 1.26 times (Leppänen et al., 2017).

Some biomechanical variables of vertical jumps including the evaluation of the ground reaction force (Hewett et al., 2005) in the 30 cm box jump have been investigated to measure the risk factors associated with ACL injury. The results showed that the maximum ground reaction force was normally four times to the athlete's body weight(McNair & Prapavessis, 1999). The results also indicated that increasing the ground reaction force would cause instability of the knee and could impose more load on the knee joint and ACL (Yu & Garrett, 2007). Numerous factors such as increasing jump height, gaining weight, reducing the ratio of quadriceps to hamstring muscle activity and increasing loading rate could increase the ground reaction force and increase the risk of knee injury during landing (Bates, Ford, Myer, & Hewett, 2013; Zahradnik, Jandacka, Uchytil, Farana, & Hamill, 2015). A possible explanation is that as the ground reaction force propagates through a closed kinetic chain and torsional moments are transmitted to the knee (Boden, Dean, Feagin, & Garrett, 2000), increasing it creates a larger moment that can enhance knee joint instability and thus the risk of ACL injury (Cronström, Creaby, & Ageberg, 2020).

Volleyball, despite being one of the most popular sports in the world, is associated with a high risk of musculoskeletal injuries (Gouttebarge, Barboza, Zwerver, & Verhagen, 2020). While defending, the player needs to reach the player to the right or left by moving their step side or long cross. Moreover, there are unpredictable situations in volleyball in which an athlete has to block by changing directions quickly. In this sport, ACL injury usually occurs when landing from a jump while defending (Mercado-Palomino, Richards, Molina-Molina, Benítez, & Espa, 2020; Salci, Kentel, Heycan, Akin, & Korkusuz, 2004).

Research to date on ACL risk factors has mostly been limited to controlling movements and performing a task such as jumping from a box and then performing the second jump (Bates et al., 2013), side jump (Sinsurin, Vachalathiti, Srisangboriboon, & Richards, 2018), asymmetry in the lower limb (McPherson, Dowling, Tubbs, & Paci, 2016). ACL injury prevention programs currently consist of a variety of exercises, but finding safe ways to jump and land and managing risk factors for ACL injury should be carefully considered. However, even with increasing awareness of the biomechanical factors associated with the risk of ACL injury, but joints mechanics during landing in each type of block and the incidence of ACL injury in these positions are still unclear. The main purpose of this study is to investigate the ground reaction force and the angle of flexion of the knee in jumping and landing movements for different types of block on the net in volleyball. Despite numerous studies on the biomechanical aspects of jumping and landing in athletes, the focus of the present study is on performing jumping and landing in different conditions of block on the net. This study tries to answer these questions: Can a person's initial position before jumping for block affect the ground reaction force, and thus increase the risk of ACL injury? Is there a difference between professionals and beginners in the amount of ground reaction force in different block situations on the net? In this study, it is assumed that the amount of ground reaction force and knee flexion angle in different jumps for block on the net are different in professional and beginner volleyball players.

METHODS

Participants

This cross-sectional and descriptive study was performed in the Sports Biomechanics Laboratory. In order to determine the number of participants in each study sample, G * Power software with $\alpha = 0.05$ was used the results of which suggested sample sizes of at least 8 people to ensure a statistical power of 80% (Faul, Erdfelder, Lang, & Buchner, 2007). Hence, 10 professional volleyball players from **.....** professional leagues and 10 beginner volleyball players who had at least 2 years of experience in volleyball training, participated in this study voluntarily. None of the subjects had a history of serious lower and upper limb injuries such as joint dislocations and muscle strain or fractures in the past year and had undergone any medication treatment program in the past month leading up to the test. The subjects also completed the consent form to participate in the test. The participants were briefed on the purpose of the study, testing procedures and the working methods. All procedures performed in this study were approved by research council (code number: 1.324.925) and institutional review board (code number: 1399.1421.9) of the Hamedan branch of Islamic Azad University, Iran and followed the ethical guidelines of the Declaration of Helsinki.

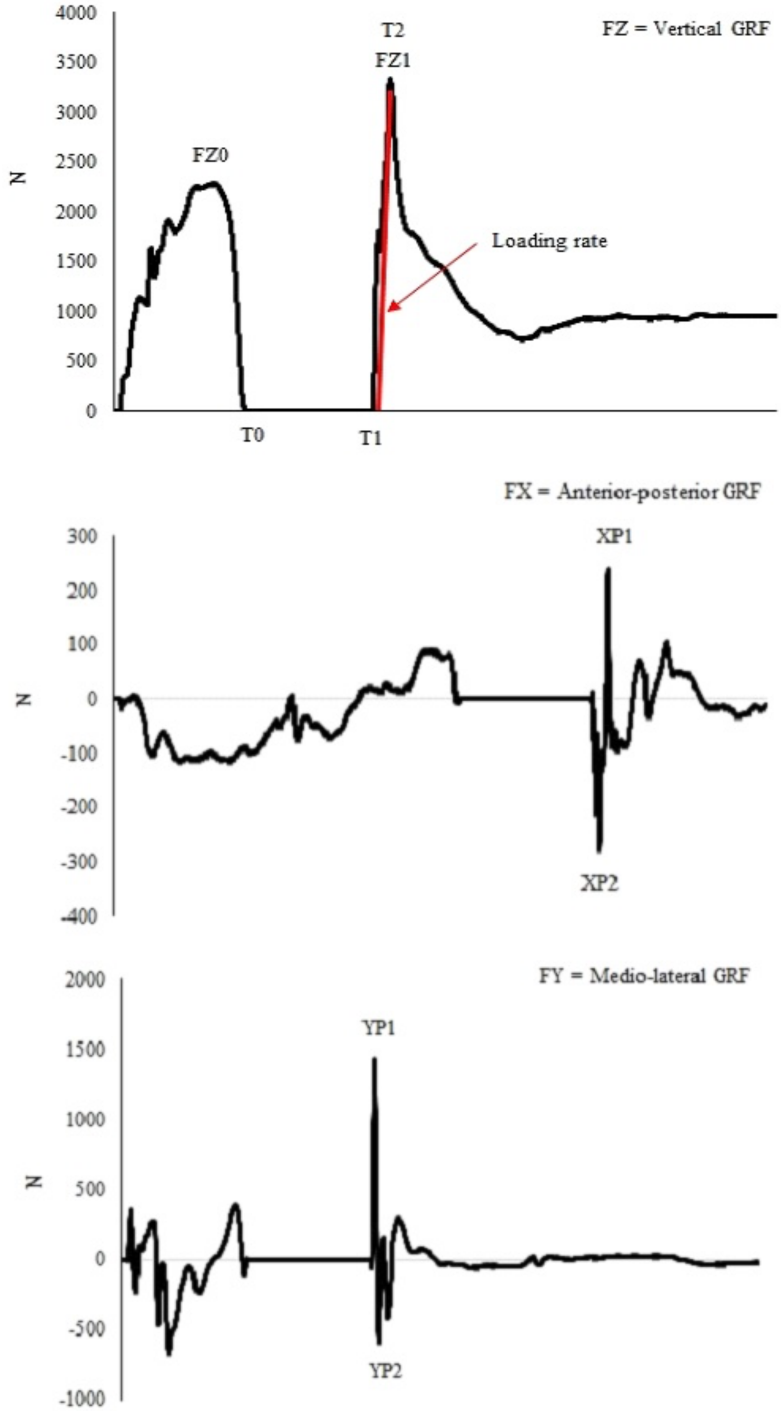
Instrumentation and procedure

The Vicon 3D motion analyzer (Vicon Peak, Oxford, UK) was used with six T20 series cameras at 200 Hz and markers attached to the subjects' lower limbs while performing the tasks. The markers used were spherical and 14 mm in diameter, and were attached to specific anatomical landmarks of both legs of the participants based on the Plug-In Gait model (Ferrari et al., 2008). Simultaneously, for recording kinetic data, two Kistler (Type 9281, Kistler Instrument AG, Winterthur, Switzerland) force plates synchronized with the cameras were used at a sampling frequency of 1000 Hz. Kinematic and kinetic data were analyzed using software Nexus 1.8.5 and Polygon 4.3 (Vicon Motion Systems, Oxford, UK).

To perform the desired tasks in the laboratory, a volleyball net at a height of 2.43 meters was placed in the middle of the calibrated environment of the laboratory. The volleyball net was positioned so that the longitudinal edges of the two force plates were along the net. Before the tests, the participants warmed up their upper and lower limbs for about 15 minutes by running and doing stretching exercises, as is the usual warm-up program in volleyball exercises. Following this, the subjects first performed 5 defense moves on the net to get acquainted with the laboratory environment. In addition, before performing the desired tasks, a static test was taken from each subject to determine the position of the joint centers and the coordinates of the limbs. Subjects were asked to complete the tasks for block, including static block, step right side and block on the net, step left side and block on the net, long cross-step to the right, and block on the net, and run a long cross to the left and block on the net. The order of execution of the tasks was random and the execution of the defense was accepted only if at the time of landing, each subject's foot was placed inside a force plate. 6 repetitions were done for each task and two minutes of rest were allowed between consecutive tasks.

After initial processing, a low-pass zero-lag fourth-order Butterworth filter with cut-off frequencies of 6 Hz and 20 Hz was used to filter the kinematics and GRF data, respectively (Azadian, Majlesi, & Jafarnezhadgero, 2018). The GRF variables were normalized with respect to the body weight (BW) (Sorkheh, Majlesi, & Jafarnezhadgero, 2018). In this study, the ground reaction force in three axes and vertical loading rate were measured in different jump and landing tasks while blocking on defense (Briani, Pazzinatto, Waiteman, de Oliveira Silva, & de Azevedo, 2018). Moreover, the ground reaction force was evaluated in two phases. The initial jump phase (preparation phase for the jump) and the main jump for block immediately after the initial jump (Fig. 1). The variables measured included: Maximum ground reaction force in preparation for jump (FZ0); Maximum ground reaction force at subject's main landing phase (FZ1); Moment of foot separation from the ground after the preparation phase (T0); The moment the foot contact the ground when landing (T1); Moment of force peak at landing phase (T2), maximum ground reaction force to the right after subject’s landing (YP1); Maximum ground reaction force to the left after subject’s landing (YP2); Maximum ground reaction force posterior after landing (XP1); maximum ground reaction force anterior after landing (XP2) and the knee flexion angle in the initial contact after the main jump for defense and the maximum knee flexion angle after the main jump for block. Also, jump height was defined as the difference in anterior superior iliac spine marker position at the highest point of the jump and the height in upright standing position (De Ruiter, Van Leeuwen, Heijblom, Bobbert, & De Haan, 2006). From the moment the subject's foot detached from the ground at the end of the preparation phase until the foot contact again at the end of the main phase of the jump, it was considered as the duration of the jump.

Figure 1. Variables of ground reaction force and loading rate in different directions in jump-landing movement in defense.



Note: FZ0: Maximum ground reaction force in preparation phase for jump; FZ1: Maximum ground reaction force in landing phase; T0: moment of foot separation from the ground after the preparation phase; T1: The moment the foot contact when landing; T2: Moment of peak force at landing phase; red line: loading rate. YP1: Maximum ground reaction force to the right after the subject lands; YP2: Maximum ground reaction force to the left after the subject lands. XP1: Maximum ground reaction force to backwards after the subject lands; XP2: Maximum ground reaction force to forward after the subject lands.

Statistical analysis

In this study, Shapiro-Wilk test was used to test the normality of the distribution of the data. databased on the results, parametric statistical tests were used. Independent t-test was run to examine the differences between the two groups in different tasks. All the statistical analyses were performed using SPSS software version 21 with a significance level of P <0.05.

RESULTS

The mean and standard deviation (SD) of the demographic characteristics of the subjects are presented in Table1.

Table 1. Participant characteristics per groups, mean (SD)

	Groups		
Variables	Professional	Beginner	Sig.
Age (y)	25.49 (3.75)	24.56 (2.14)	0.104
Weight (kg)	86.60 (8.99)	84.60 (8.30)	0.083
Height (m)	1.96 (0.06)	1.91 (0.05)	0.090
BMI	22.54 (2.10)	23.32 (2.19)	0.427

*Note. Abbreviations; y: year; kg: kilogram; m: meter; BMI: body mass index

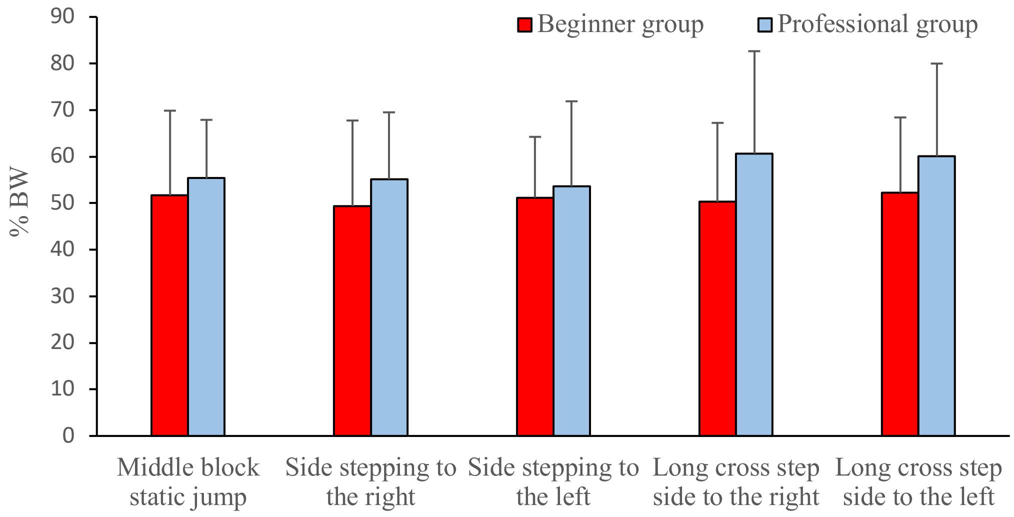
The results of independent samples t-test for XP2, XP1, YP2, YP1, ZP1, ZP0 variables showed that except for the YP1 variable in the Step side left jump (P = 0.029), there was not a significant difference between beginners and professionals in different types of jump-landing tasks in the preparation phase and the main jump-landing tasks (Table 2). Also, no significant difference was observed between the two groups of beginners and professionals in the variable of loading rate in different tasks (Fig. 2).

Table 2. Mean and standard deviation of ground reaction force variables in different jumps (normalized based on subjects' weight)

Jump-landing	Variables	Groups: professional	Groups: beginner	T	Sig.
Middle block static jump	ZP0	2.81 (0.34)	2.76 (0.54)	1.02	0.317
	ZP1	4.60 (0.70)	5.05 (0.70)	1.41	0.174
	YP1	0.30 (0.24)	0.32 (0.13)	0.25	0.805
	YP2	0.24 (0.13)	0.22 (0.13)	0.29	0.772
	XP1	1.10 (0.37)	1.43 (1.01)	0.96	0.348
	XP2	1.23 (0.62)	1.54 (0.63)	1.07	0.298
Side stepping to the right	ZP0	3.03 (0.39)	3.02 (0.60)	0.03	0.974
	ZP1	4.75 (0.82)	4.49 (0.79)	-0.71	0.484
	YP1	0.17 (0.08)	0.30 (0.20)	1.95	0.066
	YP2	0.31 (0.15)	0.42 (0.20)	1.35	0.192
	XP1	1.05 (0.37)	1.28 (1.19)	0.58	0.565
	XP2	1.28 (0.55)	1.13 (0.48)	-0.61	0.545
Side stepping to the left	ZP0	3.01 (0.36)	2.91 (0.42)	-0.60	0.556
	ZP1	4.67 (1.17)	4.59 (0.77)	-0.18	0.859
	YP1	0.29 (0.12)	0.44 (0.16)	2.37	**0.029**
	YP2	0.17 (0.14)	0.28 (0.22)	1.32	0.201
	XP1	1.00 (0.32)	1.05 (0.32)	0.32	0.746
	XP2	1.35 (0.68)	1.32 (0.54)	-0.10	0.917
Long cross step side to the right	ZP0	3.16 (0.50)	2.98 (0.63)	-0.68	0.503
	ZP1	4.87 (1.04)	4.62 (1.06)	-0.53	0.597
	YP1	0.20 (0.11)	0.26 (0.13)	1.10	0.285
	YP2	0.45 (0.19)	0.42 (0.21)	-0.37	0.711
	XP1	1.13 (0.54)	1.00 (0.36)	-0.61	0.545
	XP2	1.53 (0.69)	1.79 (1.62)	0.46	0.648
Long cross step side to the left	ZP0	3.12 (0.45)	3.02 (0.60)	-0.41	0.683
	ZP1	4.92 (1.11)	4.69 (0.97)	-0.50	0.621
	YP1	0.55 (0.26)	0.47 (0.27)	-0.65	0.519
	YP2	0.16 (0.08)	0.22 (0.17)	0.91	0.376
	XP1	1.20 (0.63)	1.10 (0.40)	-0.44	0.661
	XP2	1.46 (0.39)	1.47 (0.93)	0.03	0.977

*Note: Bolded p-values indicate significance ($p < 0.05$).

Figure 2. The loading rate in different jumps in both groups of professional and beginner volleyball players.



Regarding the variables of jump duration and jump height in different tasks, the results of independent samples t-test showed a significant difference between the beginner and professional groups in these variables ($p < 0.05$) (Fig. 3 and 4).

Figure 3. Duration of jumping in different tasks in both professional and beginner groups.

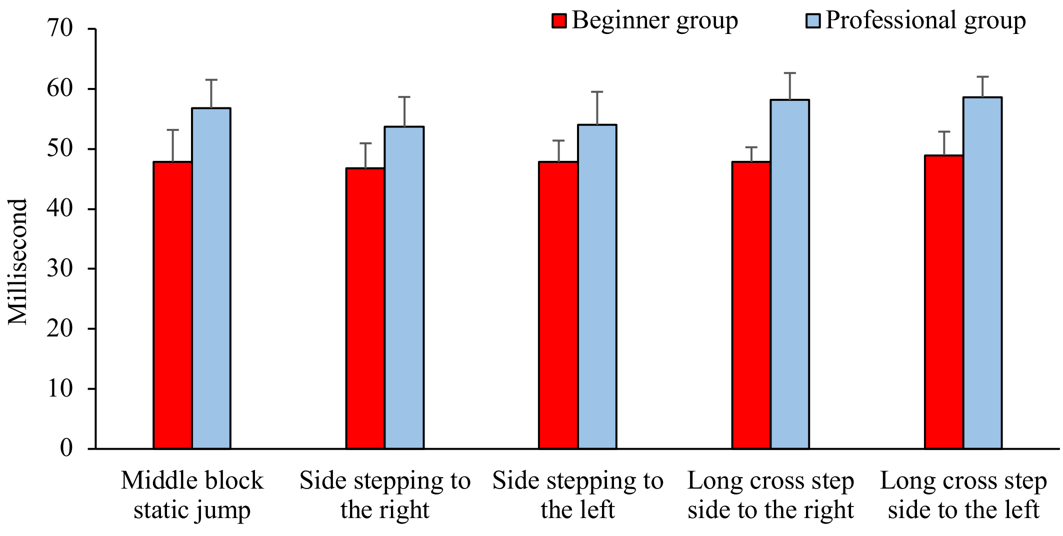
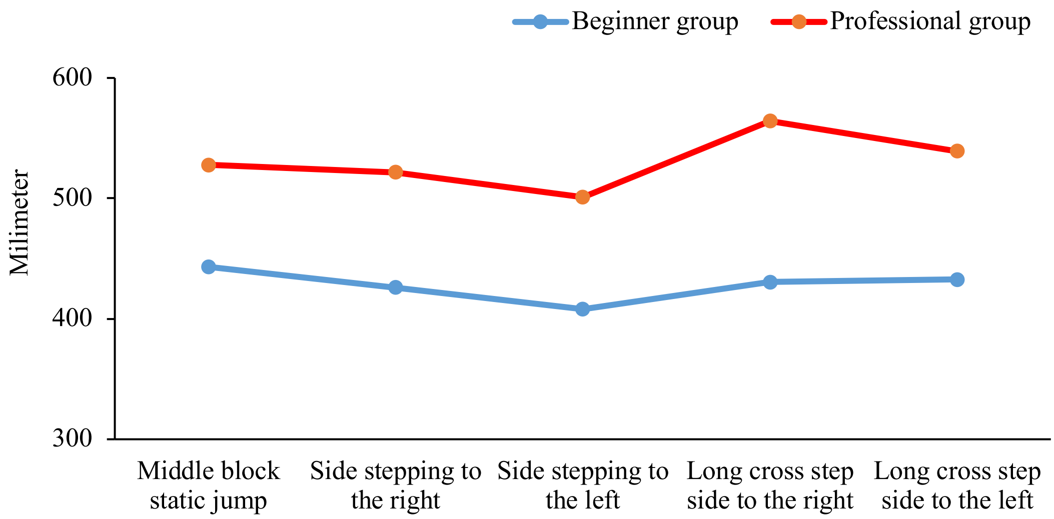


Figure 4. Jumping heights in different tasks in both professional and beginner groups.



The results of comparisons on knee flexion angles in the beginner and professional groups are shown in Table 3. Based on the results of analyses, the knee flexion angle at the moment of landing in all jumps in professional volleyball players was significantly higher than that in the beginner group. Furthermore, the difference between groups in maximum knee flexion in the landing phase in all jumps was significant (p <0.05) except for Step side left jump**.**

Table 3. Knee flexion angle in initial foot contact and maximum knee flexion angle in different jumps.

Jump-landing	Variables	**Groups** professional	beginner	T	Sig.
Middle block static jump	Knee flexion angle at initial contact (°)	22.55 (4.16)	10.70 (1.37)	8.55	**0.001**
	Maximum knee flexion angle (°)	61.05 (7.02)	46.70 (2.24)	3.43	**0.003**
Side stepping to the right	Knee flexion angle at initial contact (°)	22.75 (0.57)	18.95 (0.05)	8.94	**0.001**
	Maximum knee flexion angle (°)	61.30 (8.57)	45.75 (1.32)	3.37	**0.003**
Side stepping to the left	Knee flexion angle at initial contact (°)	22.05 (1.53)	15.80 (0.21)	7.11	**0.001**
	Maximum knee flexion angle (°)	60.85 (6.07)	55.15 (3.32)	1.25	0.23
Long cross step side to the right	Knee flexion angle at initial contact (°)	22.30 (2.74)	12.35 (0.37)	10.24	**0.001**
	Maximum knee flexion angle (°)	62.80 (7.38)	49.10 (0.95)	5.82	**0.02**
Long cross step side to the left	Knee flexion angle at initial contact (°)	19.25 (5.11)	11.45 (0.57)	4.79	**0.03**
	Maximum knee flexion angle (°)	61.30 (7.80)	47.40 (0.63)	5.62	**0.02**

*Note: Bolded p-values indicate significance (p < 0.05).

DISCUSSION

The aim of this study was to investigate the changes in the ground reaction force in three axes as well as the flexion angles of the knee joint during the performance of different jump and landing in block on the net tasks in professional and beginner volleyball players. The results of the data analyses showed that there were no statistically significant differences between beginners and professionals in the GRF peak variables in static block movement, step side to the right and left of the block on the net and long cross step to the right and left and block on the net. The level of GRF in the preparation phase (ZP0) in all tasks was less than its level in the main jump for defense. On the other hand, the average ground reaction force in both anterior-posterior (XP1 and XP2) and medial-lateral (YP1 and YP2) directions was lower in the professional group than it was in the beginner group. But the difference was not statistically significant except for the YP1 in the step side left jump. Previous studies have reported that volleyball players make 300 to 400 jump moves for attack or block in a four-hour game, or jump to a maximum height about 60 times per hour (Bahr & Bahr, 2014). Therefore, although impact forces have a positive effect on the health of the skeletal system, if the applied forces are very frequent and are exerted in large amounts, the risk of joint damage decreases.

On the other hand, the results of the present study showed that there was a significant difference between the beginner and professional groups in terms of the height and duration of jumping and that the average jump height in static block movement, step side to the right and left block on the net and long cross step to Right and left and block on the net were 24% higher in professional athletes than they were in novice athletes. Jump time in all movements by the professional athletes including static block, step side to the right and left block on the net and long cross step to the right and left and block on the net were respectively 19, 15, 13, 22 and 20% more than those by the beginner athlete.

As the results of the study indicated while the height and duration of the jump in professionals were significantly higher than those of beginners, professionals experienced less or sometimes similar reaction force than that of beginner athletes in all types of jumps. According to previous studies on the intensity of the ground reaction force and its relationship with ACL damage, it can be concluded that skilled people perform better in all jumps with different initial conditions, with less or similar reaction force to beginners. As a result, it may be concluded that the risk of ACL injury in professionals is lower than it is in beginners. In this study, if the jump height was controlled, the reaction force in professionals could be less than that in beginners.

The results on the maximum flexion angle at the moment of landing also showed that the amount of knee flexion angle in all jumps in professional volleyball players was significantly higher than that in beginners. These results implied a reduction in ACL risk in professionals. As the review of the related literature indicated, every 10 degrees increase in peak knee flexion during vertical jump would reduce the risk of ACL injury by 0.55 (Leppänen et al., 2017). Findings in the present study showed that the difference in knee flexion angles in skilled and beginners was about 4 degrees in the minimum and about 12 degrees in the maximum, which can imply a better performance of professional athletes.

In this study, no statistically significant difference was observed between the study groups concerning the variable of vertical loading rate in different tasks. Increased loading rates of more than 70 and 72 N/kg/s have been reported to be associated with the risk of pressure fractures as well as patellar pain (Cheung & Rainbow, 2014). Runners with compression fractures in the tibia had high loading rates. Therefore, by reducing the vertical loading rate, the possibility of injury to the lower limb can be minimized (Jafarnezhadgero, Ghorbanlou, & Majlesi, 2019). In this study, professionals had higher loading rates, but as shown in the results, the loading rate in both groups was less than 70 N/kg/s.

In line with the results of the studies reported in the literature, the findings of the present study showed that landing is one of the most dangerous movements in sports activities, especially when the landing ends with an immediate stop. Higher GRF has been shown to be associated with increased ACL strain (Bakker et al., 2016), and the risk of ACL injury increases with lower knee flexion and peak GRF (Larson et al., 2021). It also seems that the significant difference observed in the height and duration of the jump depends on the neuromuscular coordination and proper use of the upper limbs to increase joint moment in the professional group (Floria, Gómez-Landero, & Harrison, 2014; Preatoni et al., 2013).

The limitation which could have affected the generalizability of the findings may be due to the fact that female participants were not represented in the study as there were few of them willing to participate.

CONCLUSION

Based on the findings of the present study, professional volleyball players have a lower risk of ACL injury than novice volleyball players do, which is due to landing with a greater angle of flexion in the knee joint and thus better control of landing torque. As a result, to reduce the risk of ACL injury in beginners, paying attention to landing exercises and focusing on increasing the flexion angle need to be considered. It is also recommended to control the jump height in future studies in order to achieve more accurate results in terms of reaction force and joint moment.

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Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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