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Associated ACL risk factors differences during an unanticipated volleyball blocking movement

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ABSTRACT

The lateral tilt of the arms accompanied by trunk lateral tilt is a typical blocking manoeuvre in volleyball. However, during this unanticipated blocking movement, an associated risk of ACL injury may result. The aim of the present study was to compare associative ACL risk factors at the initial contact and the first and second peak of VGRF during an unanticipated blocking movement with different arm positions. Synchronized kinematic and kinetic data were collected for each trial of each condition. Student paired t-tests and effect size were used to determine differences between two conditions (S – with arms straight up from the body) and (T – with the arms and trunk laterally tilted). The results showed that the T condition significantly decreases knee flexion, increases VGRF at the foot contact, first peak force and increases the valgus moment at the first peak force. The values of the associated risk factors for a non-contact ACL injury appear to be related to the tilted arm position accompanied by trunk tilt towards to right lower limb during landing. The players should be taught to land with greater knee flexion and, if possible, a double-leg landing to decrease right lower limb loading during the blocking manoeuvre.

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KEYWORDS
Leg injuries; knee; arms and trunk tilt; kinematics; kinetics

Introduction

Non-contact anterior cruciate ligament (ACL) injury in team sports usually occurs during movements with sudden change of speed and direction as cutting manoeuvres and landing from a jump (Koga et al., 2010; Krosshaug et al., 2007). Although the volleyball may be considered a low-risk sport rather than a high-risk sport (Prodromos et al., 2007), ACL rupture is an injury that may influence an individual's sporting career and quality of life. The incidence of knee injury in volleyball is 0.27 injury per 10,000 hours of exposure to sport of which 16% were ACL/PCL rupture (De Loës et al. 2000). ACL injury occurs in a volleyball more in spikers and blockers during landing from a jump attack and a block jump (Devetag et al., 2018). A blocking movement represents a basic volleyball skill which is very frequently used during training sessions and competition matches (Zahradnik et al., 2018). The main goal of the defensive player is to jump to block the ball coming from an attacker behind the edge of the net on the opponent's side of the court. If the block is to be successful, the defensive player has to position themselves in front of the attacker's shoulder and to place their arms and hands on the opponent's side of the court. Based on the expected direction of the attack, the defensive players can hold their arms straight or use a lateral tilt of the arms above the net. The defensive players commonly use the lateral tilt of the arms above the net during block movement to decrease potential space for successful completion of an attack.

The mechanisms of ACL injuries are multifactorial, resulting from the interplay of neuromuscular, biomechanical, anatomical, genetic, hormonal and other factors (Schultz et al., 2015). However, ACL strain appears to be significantly increased during landing due to: 1) low knee flexion (0–30° of knee flexion) (Dürselen et al., 1995), p. 2) tibialis anterior shear force as results of excessive quadriceps contraction and insufficient activation of hamstrings (Berns et al., 1992; DeMorat et al., 2004; Lipps et al., 2012), p. 3) increases in axial compression load (Wall et al., 2012; Yeow et al., 2009), p. 4) increases in internal tibial rotation (Levine et al., 2012; Markolf et al., 2004), p. 5) increases in valgus loading (moment of force and angle) of the knee joint (Kristianslund & Krosshaug, 2013; Krosshaug et al., 2007); and, p. 6) combinations of above-listed mechanisms (Berns et al., 1992). From ages 11–12, both males and females showed an increased frequency of ACL injury claims with the risk increasing to age 18 years (Shea et al., 2004).

The results of video observational studies (Koga et al., 2010; Krosshaug et al., 2007), in vitro studies (Meyer & Haut, 2005; Withrow et al., 2006a, 2006b) and simulated studies (Laughlin et al., 2011; Pflum et al., 2004; Shin et al., 2007) suggest that ACL injury occurs shortly after initial contact with ground (in a range of 17–60 ms after touch down). Donnelly et al. (2012) suggest that greatest risk of non-contact ACL injury is during the weight acceptance phase (first 20–30% of stance) of single-leg landing or sidestepping movements. Moreover, ACL injury appears most often during passive loading when first peak of VGRF occurs (Boden et al., 2000; Hughes et al., 2010; Olsen et al., 2004).

The lateral tilt of the arms tends to be accompanied with a tilted frontal plane trunk movement (i.e., lateral trunk flexion). This would place the centre of mass movement over the stance

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limb during the landing manoeuvre that could increase the valgus moment at the knee (Hewett et al., 2009; Powers, 2010). Moreover, the lateral tilt of the arms accompanied by lateral trunk tilt during an unanticipated blocking movement could change the associated risk factors of ACL injury. ACL injury is a common problem in volleyball (Lobietti et al., 2010). Therefore, the aim of the present study was to compare associative ACL risk factors at the initial contact and the first and second peak of VGRF during an unanticipated blocking movement with different arm positions. We hypothesized that the associative risk factors of non-contact ACL injury will increase ACL load and will be related to the lateral tilt of the arms during the blocking movement. We expected that lateral tilt of the arm and the trunk during landing would decrease knee flexion, increase valgus moment, vertical ground reaction force and lean the trunk towards the right lower landing limb thus increasing the risk of ACL injury.

Methods

Twelve junior female volleyball players (age 17.6 ± 1. years; height 178.3 ± 6.0 cm; mass 70.1 ± 9.5 kg) were recruited as participants in this study. All of the participants were right-handed centre blockers, receiver-hitters, right side hitters and setters with (7.3 ± 1.6) years of experience playing in the highest cadet and junior leagues in the Czech Republic. Participants had no history of hip, knee, or ankle surgery or injury within the previous six months and had no history of ACL injury. At the time of testing, the participants had no injuries that would prevent their participation in physical activity. Prior to testing, the aims and experimental procedures were explained to the participants. All procedures in this study were approved by the Research Ethics Committee of the University and informed consent was given by each participant.

One force plate (Kistler, 9286 AA, Switzerland), embedded in the floor, was used to collect ground reaction force data at a sampling rate of 1200 Hz. Simultaneously, a motion-capture system (Qualisys Oqus, Gothenberg, Sweden) consisting of eight infrared cameras was employed to collect the kinematic data at a sampling rate of 240 Hz. The experimental setting was based on a simulated game scenario of a volleyball attack and block during a match. The upper edge of the net was at the height of 2.24 m above the floor. To normalize the height of the jump and the position of the hands above the edge of the net, two static volleyballs were suspended in the space above the net. The centre of the first ball was located 0.15 m above the edge of the net and 0.1 m behind the edge of the net on the opponent's side of the court. The centre of the second ball was located 0.3 m to the right, next to the first ball, in the same position above and behind the edge of the net on the opponent's side of the court. A 22-inch television display was used to show a visualization of the stimulus (a recording of a real, quick tempo attack from the middle of the court) before the blocking jumping and landing tasks. The centre of the display was located 0.11 m above the edge of the net and 0.33 m behind the edge of the net and the middle plane of the display corresponded with middle plane of the first suspended ball (Figure 1). The visualization of the stimulus and blocking jumping and landing tasks included in the present study were made as realistic as possible in order to increase the ecological validity of the study.

The participants visited the laboratory for one day of testing. Retro-reflective markers were placed on each participant prior to the initiation of data collection. Calibration markers were placed bilaterally on the lateral and medial malleolus, medial and lateral femoral condyles, greater trochanter of the femur, and on the shoe over the first and fifth metatarsal heads. Tracking markers were securely positioned to define the trunk (acromion), pelvis (iliac crests, posterior superior iliac spines), thighs and shanks (four light-weight rigid plates with four markers per plate) and shoe (a triad of markers on the heel over the calcaneus).

At the start of each trial, the participant performed a jump and block of a static ball suspended above the net based on two different real situations projected on the display. If the player in the recording attacked the ball in the direction of the middle of the court, the participant had to block the first suspended ball without tilt of the arms above the net (S). If the player in the recording attacked the ball, from the participant's perspective, to the right side of the court, the participant had to block second suspended ball with tilt of the arms above the net (T). The participants were instructed to perform takeoff and landing in the vertical direction only without movement in lateral direction (Figure 1). Before data collection, all participants performed a 10-minute warm-up consisting of stretching the lower and upper extremities as well as running on a treadmill at self-determined speeds. After the warm-up, three acclimatization attempts followed in each situation. A standing calibration trial was carried out, after which the participants had to perform seven successful attempts in the random order in each situation (S, T). The participants were instructed to land with their right limb on the force platform. A trial was repeated when the participant failed to land on the force plate with the required foot or when the participant poorly reacted to the attack direction.

Marker data were processed using Visual 3D software (C-motion, Rockville, MD, USA). Each trial was determined by the first occurrence of the vertical ground reaction force above 20 N for each force plate (Schot et al., 1994). All force plate data were filtered using a fourth-order low-pass Butterworth filter with a 50 Hz cut-off frequency. The motion capture coordinate data were low-pass filtered using a fourth-order Butterworth filter with a 12 Hz cut-off frequency. In order to determine the local coordinate system of the segment, all segments were modelled as a frustra of right circular cones, while the pelvis and trunk were modelled as cylinders (C-motion, Rockville, MD, USA). The local coordinate systems were defined using the standing calibration trial for each participant.

All analyses focused on the right lower limb and were performed at the instant of the first contact with ground (FC), at the instant of the first (FP1) and second peak (FP2) of the vertical ground reaction force (VGRF). The knee flexion joint angle was determined as the angle between the local coordinate systems of the thigh and shank in the sagittal plane (0° indicates full extension). The knee valgus (-) and varus (+) joint angles were determined as the angle between the local coordinate systems of the thigh and shank in the

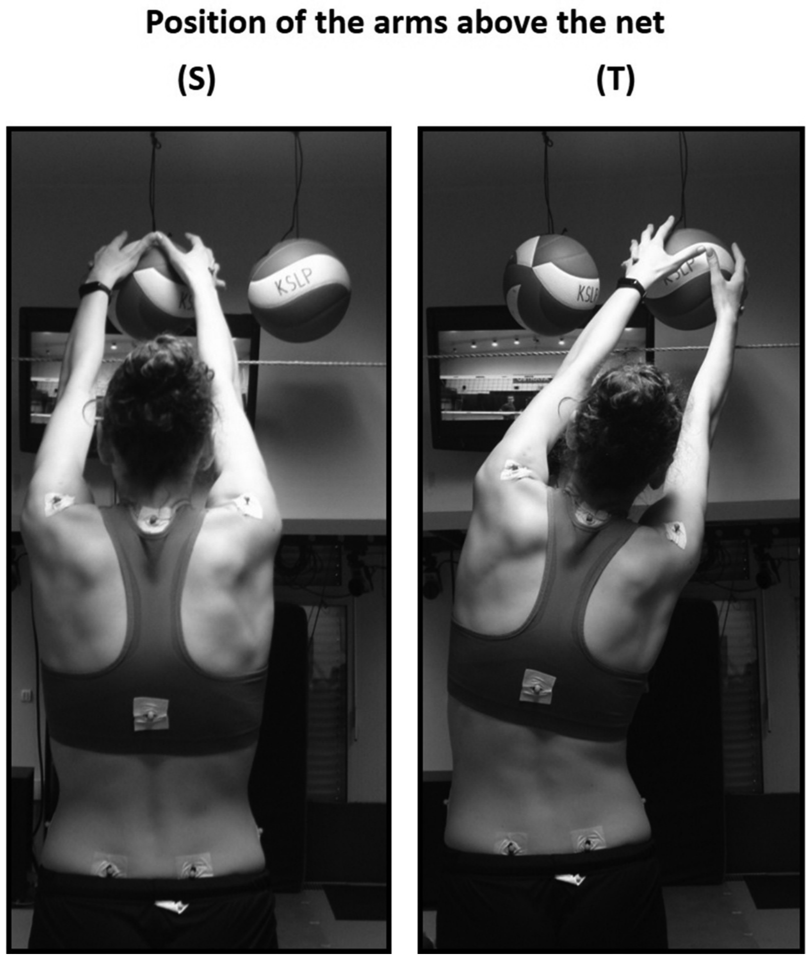

Figure 1. Experimental setup of unanticipated block movement with different position of the arms above the net.

frontal plane. The trunk angle was determined as the angle between the local coordinate systems of the trunk and the global reference frame in the frontal plane. The knee valgus (+) and varus (-) joint moments of force in the frontal plane were calculated using a Newton-Euler inverse dynamics technique. The net knee moment of force was expressed in the local coordinate system of the thigh segment (Hamill & Selbie, 2004).

All data were normally distributed according to the Shapiro–Wilk test. Student paired t-tests were used to determine differences between two conditions (S) and (T) with a criterion alpha level of 0.05. Effect size (ES) was used to assess the biological relevance of the differences between the two conditions (S) and (T). The ES was interpreted as <0.2 trivial; 0.2–0.5 small; 0.51–0.8 medium and >0.8 large (Cohen, 1988). IBM SPSS Statistics 19 software was used to perform all statistical tests (SPSS, Inc. and IBM Company, Chicago, IL).

Results

Means, standard deviations and statistical analyses for all parameters in two conditions at the instant of FC, FP1 and FP2 are presented in Table 1. At the instant of FC, there was a statistically significantly lower knee flexion angle ($p = 0.007$, difference 1.7°) with a small ES and statistically significantly greater VGRF ($p = 0.007$, difference 0.1 BW) with small ES in the (T) condition. No statistically significant difference, but a large ES, was found for trunk tilt ($p = 0.070$, difference 2.9°).

At the instant of the FP1, the results indicated a statistically significant lower knee flexion angle ($p = 0.007$, difference 1.9°) with small ES, a statistically significant greater knee valgus moment ($p = 0.040$, difference 0.8 Nm/kg) with a large ES and a statistically significant greater VGRF ($p = 0.001$, difference 0.13 BW) with a medium ES in the (T) condition. No significant difference, but large ES was found for trunk tilt ($p = 0.068$, difference 2.9°). No significant difference and trivial ES was found for time of occurrence of FP1.

At the instant of the FP2, the results indicated statistically significantly greater VGRF ($p = 0.003$, difference 0.37 BW) with a large ES in the (T) situation. No significant difference, but large ESs were found for trunk tilt ($p = 0.068$, difference 2.7°). No significant difference and a trivial ES was found for to the time of occurrence of FP2.

Discussion

The aim of the present study was to compare associative ACL risk factors during two types of unanticipated blocking movements in volleyball: 1) with the arms and trunk straight; and 2) with the arms and trunk laterally tilted. We hypothesized that

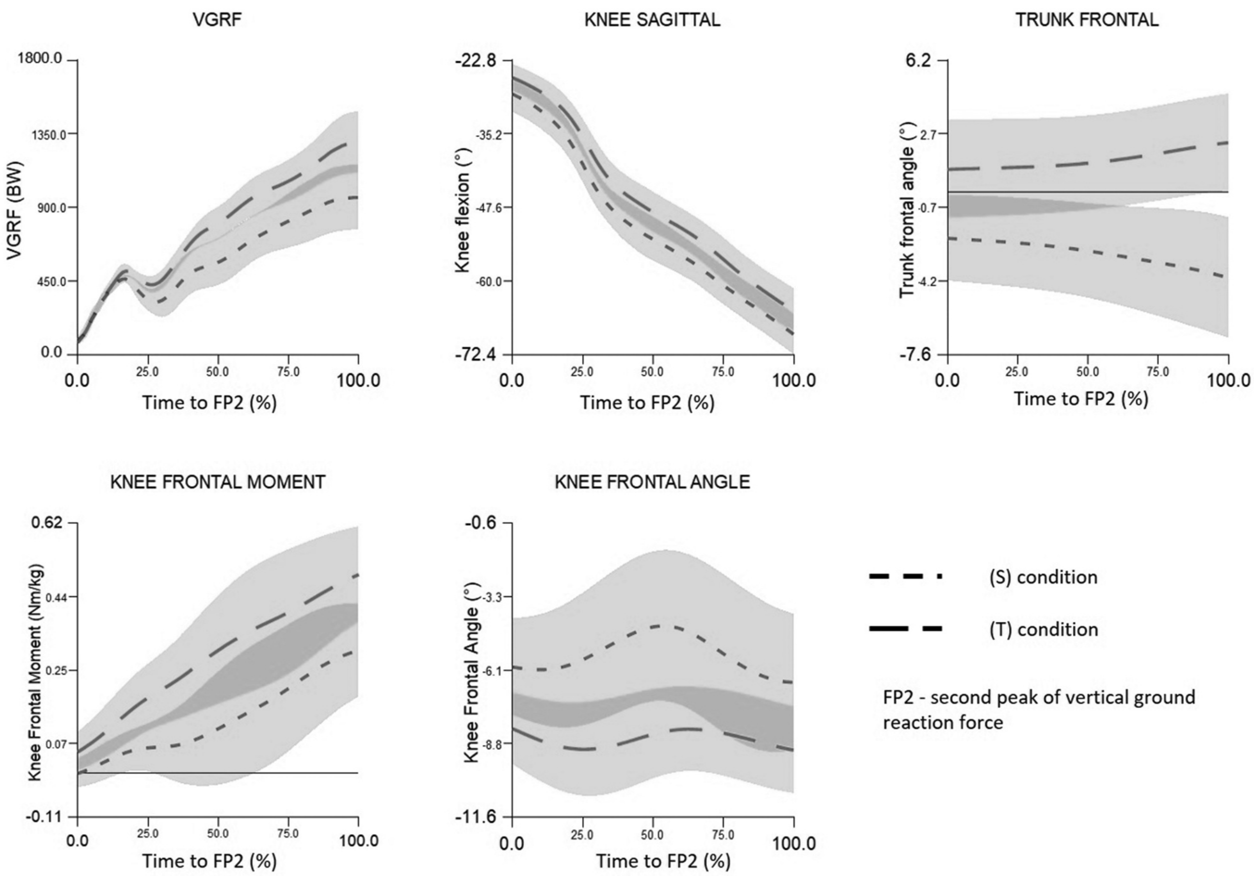

Figure 2. Representative time-history graph of the depended variables.

the values of the associative risk factors for non-contact ACL injury would be related to the lateral tilt of the arms during the blocking movement. The results of the current study generally supported the hypothesis. The main finding of this study confirmed that lateral tilt of the arms significantly decreases knee flexion at the instants FC, FP1, increases VGRF at the instant of FC, FP1, FP2 and increases valgus moment at the instant FP1. Moreover, lateral tilt of the arms clinically increases lateral trunk tilt and shifts the centre of mass over right lower limb.

The mechanisms of ACL injuries are multifactorial, resulting from the interplay of neuromuscular, biomechanical, anatomical, genetic, hormonal and other factors (Schultz et al., 2015). Authors of cadaver studies (Berns et al., 1992; Dürselen et al., 1995) and in vivo studies (Beynnon et al., 1995; Hosseini et al., 2009) indicate that low knee flexion (0–30°) may be a critical value in terms of determining ACL peak loading particularly if a single-leg landing is used. Single-leg landings decrease knee flexion and may increase the risk of ACL injury compared with double-leg landings (Nagano et al., 2009; Yeow et al., 2011). In the current study, the participants used their natural landing in both conditions with a mixture of single-leg and double-leg landings. Although the single-leg landings were less frequent (1% in S condition and 31% in T condition), the results of the study revealed lower knee flexion angles of 30° at the instants FC and FP1 in both conditions (S, T). Significantly lower knee flexion was found in the (T) condition at the instants FC and FP1. A video observational study by Koga et al. (2010) presented knee joint kinematics in ACL injury situation in female handball and basketball. Results showed mean knee flexion (23°) at the initial contact which increased by one degree during first 40 ms. Similarly, the study by Krosshaug et al. (2007) showed a mean knee flexion (15°) at the initial contact which increased to 27° during first 50 ms in ACL injury situations. The current values of the knee flexion in both conditions corresponded with the Koga study at the instant of the initial contact (22.6° in T and 24.3 in S conditions) and our values well corresponded with the Krosshaug study at the instant of FP1 (27.1° in T and 29° in S conditions). Therefore, the arms tilt accompanied by trunk tilt during landing with low knee flexion could put the players in a greater risk of ACL injury during single-leg landing more than during double-leg landings. Similarly, the arms tilt accompanied by trunk tilt during double-leg landing with low knee flexion could increase knee loading more than double-leg landings without tilt of the arms above the net.

Results of the current study showed significantly higher VGRF at the instants of FC, FP1 and FP2 in the (T) condition. Hewett et al. (2005) reported that greater peak vertical ground reaction force was associated with ACL injury. Volleyball studies that deal with landing after a block showed large range of VGRF values based on movement task, mass of participants and jump height. Hughes et al. (2010) showed lower maximal values VGRF (difference 0.3 BW) during block landing than present study. On the other hand, the studies by Peng et al. (2019) and

Table 1. Means, standard deviations and statistical analyses for all parameters in two conditions at the instant of first contact, first and second peak of vertical ground reaction force.

	Position of arms above the net		t-test	Effect Size
FC	Straight (S)	Tilt (T)	p-value	Cohen ´s d
Knee flexion (°)	24.3 ± 5.0	22.6 ± 4.8	0.007*	0.4
Knee valgus (-) varus (+) angle (°)	−3.3 ± 1.5	−3.5 ± 2.8	0.687	0.1
Knee valgus (+) varus (-) moment (Nm/kg)	0.1 ± 0.1	0.1 ± 0.1	0.887	0
Trunk tilt (°)	−0.1 ± 3.1	2.8 ± 2.9	0.070	1.0
VGRF (BW)	0.12 ± 0.04	0.13 ± 0.04	0.046*	0.3
FP1				
Knee flexion (°)	29.0 ± 5.3	27.1 ± 4.5	0.007*	0.4
Knee valgus (-) varus (+) angle (°)	−2.9 ± 1.7	−3.2 ± 2.7	0.501	0.1
Knee valgus (+) varus (-) moment (Nm/kg)	−0.1 ± 0.2	0.7 ± 0.2	0.040*	4.0
Trunk tilt (°)	−0.2 ± 2.7	2.7 ± 2.7	0.068	1.1
VGRF (BW)	0.63 ± 0.20	0.76 ± 0.24	0.001*	0.6
Time to FP1 (s)	0.014 ± 0.004	0.014 ± 0.004	0.455	0
FP2				
Knee flexion (°)	60.3 ± 8.1	59.4 ± 9.0	0.489	0.1
Knee valgus (-) varus (+) angle (°)	−4.1 ± 3.0	−5.1 ± 3.3	0.126	0.3
Knee valgus (+) varus (-) moment (Nm/kg)	0.2 ± 0.2	0.3 ± 0.3	0.127	0.4
Trunk tilt (°)	−0.4 ± 2.6	2.3 ± 3.2	0.062	0.9
VGRF (BW)	1.55 ± 0.28	1.92 ± 0.37	0.003*	1.1
Time to FP2 (s)	0.093 ± 0.018	0.094 ± 0.016	0.384	0.02

FC: first contact with ground, FP1: first peak of vertical ground reaction force, FP2: second peak of vertical ground reaction force, VGRF: vertical ground reaction force. *Significance (p ≤ 0.05).

Kabacinski et al. (2016) reported higher maximal values VGRF (difference 0.5 BW and 2.1 BW). The literature projects a relationship between knee flexion and VGRF. The knee flexion angle was negatively correlated with the magnitude of the peak vertical ground reaction force at the instant of peak ground reaction force (Ohji et al., 2019). Greater knee flexion during landing task reduces the VGRF and ground reaction force (DeVita & Skelly, 1992; Seymore et al., 2019). Therefore, significant differences in knee flexion between the (T) and (S) conditions could explain higher VGRF in the (T) condition. Moreover, there were no differences between conditions in the time when the FP1 and FP2 occurred.

Results of the "in vitro" studies suggested that anterior shear force as a result of excessive quadriceps contraction in combination with varus or valgus moment of force increase ACL strain (Berns et al., 1992; Markolf et al., 1995). The application of the tibiofemoral compression force with internal rotation and valgus moments together also increases the ACL force with increasing of knee flexion (Markolf et al., 2019). We found that the valgus moment at the instants of FC, FP1 and FP2 in both conditions was similar except for FP1 in the (S) condition. Results of the present study showed that the tilted arms condition significantly increased the valgus moment at the instant of FP1 only. The FP1 occurs during the weight acceptance phase (first 20–30% of stance) of landing (Donnelly et al., 2012) and during phase of passive loading (Hughes et al., 2010) which are suggested to be risk factors for a non-contact ACL injury. The valgus moment was found as a predictive factor (73%) of ACL injury (Hewett et al., 2005). Limited knee flexion during landing is associated with increased valgus moment (Pollard et al., 2010). Therefore, combination of low knee flexion with frontal plane loading could increase risk of ACL injury at the instant of FP1 during landing after block in the (T) condition.

Movements of the trunk in the frontal plane could influence the frontal plane moment of force at the knee (Powers, 2010). Our results showed large differences (ES 0.9–1.1) in the trunk tilt at FC, FP1 and FP2. Trunk movement in the frontal plane showed almost zero tilt (range 0.1–0.4 deg.) above the left lower limb in the (S) condition. On the contrary, the trunk movement in the frontal plane showed lateral tilt (2.3–2.7 deg) above the right lower limb in the (T) condition. The position of the arms in combination with trunk tilt in the (T) condition possibly shifted the centre of mass towards the right lower limb as suggested by Powers (2010). Movement of the centre of mass over the stance limb during cutting or landing manoeuvres on one foot could create a valgus moment at the knee due to a shift in the resultant ground reaction force lateral to the knee joint centre (Powers, 2010). Trunk tilt may result in the ground reaction force vector shift lateral to the knee joint centre creating a valgus moment at the knee joint (Hewett et al., 2009). This would suggest that position of the arms during the (T) condition accompanied by trunk tilt towards the right lover limb would have an increased risk of an ACL injury in the right knee.

Studies which compared differences between participants which suffered an ACL injury and healthy participants suggest that ACL deficient participants showed greater total frontal plane trunk excursion (Fryer et al., 2018) and lower maximum of the knee flexion (Hewett et al., 2005) during landing. Active trunk flexion in sagittal plane during landing increased knee and hip flexion angles (Blackburn & Padua, 2008). Volleyball players are not able to use significant trunk flexion to increase knee flexion due to the position of the hands above the head during the block landing and the close presence to the net. Favre et al. (2016) showed that increasing knee flexion during a block landing only affected the valgus angle and valgus moment for the group of participants who landed in an adducted position at initial contact and had no significant effect on the group that landed in an abducted position. The delays in the peak of valgus moment resulted in an increased range of the knee flexion angle at the occurrence of this peak value after the modification of landing technique. Therefore, the risk of an ACL injury could potentially be decreased, even for the same amplitude of the peak of the valgus moment, because the knee joint was more flexed and therefore the ACL load was reduced (Favre et al., 2016). Therefore, players should be taught to land with greater knee flexion and adjust conditions of the exercises during training sessions to prefer proper technique of the blocking from point of view position of the hand above the net.

This study has several limitations. First, while the protocol in this study was ecological, participants may actually jump higher in a real match situation thereby landing from much greater heights. Therefore, the effects of the conditions (T, S) in this study may be a lower estimate of the actual forces placed on the body during such landings. Second, participants may combine the position of the arms with other unanticipated movements in a real match situation. These other movements may exacerbate the landing loads on the knee. These additional loads were not determined in this study. Third, players could achieve landing after a block as a single-leg or a double-leg landing; this fact is not considered in this study.

Conclusions

The results of the present study suggest that position of the arms accompanied by trunk tilt towards right lower landing limb during landing after block could increase the risk of ACL injury in the knee. The values of the associated risk factors of non-contact ACL injury appear to be related to the tilt of the arms and the accompanying trunk tilt during the blocking manoeuvre. The tilt of the arms above the net significantly decreases knee flexion, increases first and second peak of vertical ground reaction force, increases valgus moment at the instant of the first peak of vertical ground reaction force and lean the trunk towards the right lower limb. The confluence of these factors places the player in a "risky" position to incur an ACL injury. Unfortunately, players are not able to eliminate lateral tilt of arms during blocking movement in competitive matches. If the players use lateral tilt of the arms in training or competition match, then they should be taught to land with greater knee flexion and use a double-leg landing. These actions may avoid placing the player in an untenable position and repeatedly overloading the knee.

Suggestion for coaching

- Coaches\trainers should be aware that the tilted arms during the blocking movements are potentially a greater risk for ACL injury than the blocking movements without tilt of the arms.
- During a practice session, coaches\trainers should monitor the number of the blocking movements with titled arms for all players and particularly for those with a previous knee injury.
- Coaches\trainers should decrease the number of the blocking movements with titled arms in training.
- Coaches\trainers should be taught to land with greater knee flexion and, if possible, a double-leg landing.
- Coaches\trainers should include balance and stabilization exercises in training to support frontal knee stabilization.

Disclosure statement

The authors report no conflict of interest.

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