LEAD LIMB LANDING MECHANICS BETWEEN VOLLEYBALL TASKS AND SHOE COLLAR HEIGHTS

MECÁNICA DE ATERRIZAJE DE LA PIERNA DOMINANTE ENTRE LAS TAREAS DE VOLEIBOL Y LAS ALTURAS DE LA CAÑA DEL CALZADO

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Abstract

Volleyball footwear may restrict ankle motion, altering knee mechanics during landing. Many players exhibit different landing strategies when performing offensive and defensive maneuvers. We sought to determine the effects of footwear and volleyball task on lower extremity landing mechanics. It was hypothesized that posterior and vertical ground reaction forces, and ankle and knee joint landing kinematics and kinetics would be different between shoes and tasks. Seventeen volleyball players landed from a spiking and blocking task in a mid-cut and a low-top volleyball shoe. The peak anterior ground reaction force was greater in the mid-cut shoe in the spiking task (p = .003) and the low-top shoe in the blocking task (p = .006) compared to the low-top shoe in the spiking task. The peak lateral (p = .002) and the peak posterior (p = .005) ground reaction forces were greater in the spiking task. Sagittal plane ankle initial contact angles (p = .018) and peak dorsiflexion angles (p = .026) were smaller in the mid-cut. Smaller sagittal plane ankle initial contact angles (p = .015) and peak eversion angles (p = .008), and greater peak dorsiflexion angles (p = .031) and peak inversion angles (p = .027) were observed in the blocking task. Peak internal plantarflexion moment was greater in the low-top. Changes in ground reaction forces and ankle mechanics did not translate proximally to impact knee landing mechanics.

Keywords: Footwear, landing, knee, volleyball, kinematics.

Resumen

El calzado de voleibol puede limitar el movimiento del tobillo, alterando la mecánica de la rodilla durante el aterrizaje. Muchos jugadores muestran diferentes estrategias de aterrizaje al realizar maniobras ofensivas y defensivas. Investigamos los efectos del calzado y la tarea de voleibol en la mecánica del aterrizaje de las extremidades inferiores. Se planteó la hipótesis de que las fuerzas de reacción del suelo posteriores y verticales, así como la cinemática y cinética del aterrizaje de las articulaciones del tobillo y la rodilla, serían diferentes entre los distintos tipos de calzado y tareas. Diecisiete jugadores de voleibol aterrizaron realizando una tarea de remate y bloqueo con un calzado de voleibol de caña alta y uno de caña baja. La fuerza máxima de reacción del suelo en dirección anterior fue mayor con el calzado de media caña durante la tarea de remate (p = .003) y con el calzado de caña baja durante la tarea de bloqueo (p = .006), en comparación con el calzado de caña baja en la tarea de remate. Las fuerzas máximas de reacción del suelo en direcciones lateral (p = .002) y posterior (p = .005) fueron mayores en la tarea de remate. Los ángulos iniciales de contacto del tobillo en el plano sagital (p = .018) y los ángulos máximos de dorsiflexión (p = .026) fueron menores con el calzado de media caña. En la tarea de bloqueo, se observaron menores ángulos iniciales de contacto del tobillo en el plano sagital (p = .015) y menores ángulos máximos de eversión (*p* = .008), así como mayores ángulos máximos de dorsiflexión (*p* = .031) e inversión (*p* = .027). El pico de momento de flexión plantar interna fue mayor en el calzado de caña baja. Los cambios en las fuerzas de reacción del suelo y la mecánica del tobillo no se tradujeron proximalmente en cambios en la mecánica del aterrizaje de la rodilla.

Palabras clave: Calzado, aterrizaje, rodilla, voleibol, cinemática.

Introduction

An effort has been made by the National Collegiate Athletic Association (NCAA) to monitor injuries in NCAA sports by implementing a sports injury surveillance system (ISP) (Kerr et al., 2014). Volleyball, one of the women's sports monitored by the NCAA's ISP, experiences an injury rate of 6.73 injuries per 1,000 athletic-exposures, with knee and ankle injuries accounting for the largest proportion of injuries (Chandran et al., 2021). By the nature of the sport, volleyball demands frequent jumping and landing when performing offensive and defensive tasks such as spiking and blocking. The majority of injuries in volleyball occur during these offensive and defense tasks with the lower extremities sustaining 58% of all reported injuries (Chandran et al., 2021; Tillman et al., 2004). Proper landing mechanics is pivotal to reduce injury risk in these athletes, as volleyball players can experience ground reaction forces (GRF) over four times their body weight (Zahradnik et al., 2015). Thus, it is essential that the ankle and the knee work in conjunction to dissipate these GRFs and absorb energy translating up the lower extremity. "Stiff" landings, characterized by greater vertical and posterior GRF, and smaller sagittal plane ankle and knee displacement, have been shown to increase the joint work of the ankle and knee joints to dissipate the body's kinetic energy while landing (Devita & Skelly, 1992). With the greater joint ankle and knee joint contribution, stiff landings have been associated to lower extremity injury risk, making smaller GRF and greater sagittal plane motion warranted while landing (Fong et al., 2011; Norcross et al., 2013a, 2013b).

With a majority of volleyball injuries occurring in the lower extremity, the knee joint is particularly vulnerable. A high prevalence of anterior cruciate ligament (ACL) injuries occur in volleyball players (Ferretti et al., 1992; Kilic et al., 2017; Migliorini et al., 2019). In addition to characteristics of stiff landings, greater knee abduction angles and internal knee adduction moments have been associated to risk factors for ACL injuries (Boden et al., 2010; Leppänen et al., 2017). It has also been well established that foot placement and the motion at the ankle impacts the motion of the knee during landing (Fong et al., 2011; Kovács et al., 1999). An increase in energy absorption by the ankle and knee and decrease in vertical impact forces have been found when landing with a forefoot strategy, characterized by greater plantarflexion angles and landing on the ball of the feet, in contrast to a heel-toe strategy (Kovács et al., 1999), and a decrease in ankle dorsiflexion motion has been associated to changes in landing knee kinematics and kinetics (Fong et al., 2011; Hoch et al., 2015).

Different types of footwear have been show to influence lower extremity landing strategies as changes in dynamic stability, GRF, ankle kinematics, and muscular activity have been demonstrated across footwear conditions (Bowser et al., 2017; Braunstein et al., 2010; Harry et al., 2015). Recently, the footwear worn by volleyball players has evolved from a low-top volleyball shoe (LT) to a mid-cut volleyball shoe (MC). The MC is a type of high collar shoe that has a collar rising just superior to the talocrural joint and malleoli. The MC have been implemented into the sport to restrict frontal plane ankle motion (Kaminski et al., 2019) to prevent injuries such as lateral ankle sprains (Chandran et al., 2021; Ferretti et al., 1992). However, high collar shoes also limit sagittal plane ankle motion, as reductions in dorsiflexion range of motion have been reported in high-top football cleats and high-top basketball shoes (Daack & Senchina, 2014; Lam et al., 2015; Li et al., 2013; Tang et al., 2020). Similar restrictions have been observed in MC volleyball shoes (Cronin, 2001). Constraints in sagittal plane ankle motion have been associated with ACL injury mechanisms, namely increased vertical and posterior GRF, reduced knee flexion angle, greater frontal plane knee excursion, knee abduction angle, internal knee adduction moment, and knee anterior shear force (Fong et al., 2011; Hoch et al., 2015; Schroeder et al., 2021). It is possible the influence of MC limiting dorsiflexion motion may increase ACL injury risk in volleyball. However, very few studies have investigated the influence of footwear on ankle and knee joint mechanics. One study that investigated the impact of high collar footwear on the knee reported an increase in peak tibial internal rotation moment while wearing a high-top basketball shoe compared to a low-top netball shoe (Vanwanseele et al., 2014). This highlights the potential influence of MC on both ankle and ACL injury risk in volleyball players and warrants more research on lower extremity landing mechanics in these shoes.

In volleyball, there are unilateral movements that result in players taking-off and landing on one leg more than the other (Kalata et al., 2020). As a result, volleyball players have been shown to develop asymmetries in muscular strength and landing movement strategies (Markou & Vagenas, 2006; Sinsurin et al., 2017). These asymmetries between limbs typically result in leg dominance, characterized by one limb having greater dynamic control to more effectively absorb the high impact forces during landing (Edwards et al., 2012; Ford et al., 2003; Hewett et al., 2010). Leg dominance is a risk factor for ACL injuries as previous research has demonstrated that females exhibit asymmetries with internal knee adduction moments and with knee abduction angles between limbs (Ford et al., 2003; Hewett et al., 2005). Leg dominance has been identified in volleyball players but the limb at risk in these athletes remains unclear. In a unilateral landing task, Avedesian et al. (2019) observed that volleyball players landed on their non-dominant limb with greater internal knee adduction moments whereas Sinsurin et al. (2017) observed greater knee abduction angles and internal knee adduction moments when volleyball players landed on the dominant limb. The limb with increased knee abduction angles and internal knee adduction moments associated to ACL injury risk were contradictory throughout these studies, demonstrating that the incertitude in the current literature of identifying the limb exhibiting greater risk of injury when landing.

Adding ambiguity to the definition of the 'at-risk limb,' it has been suggested that the role of the limb during a volleyball task influences injury risk. During the spiking task, the direction of the three-step approach sequence is always in the forward direction with the same foot approach sequence. Right-handed players use a left-right-left footwork sequence and left-handed players use a right-left-right footwork sequence (Mercado-Palomino et al., 2021; Zahálka et al., 2017). Unlike the spiking task, players move in their dominant or non-dominant horizontal direction when performing a blocking task that alters the three-step approach sequence. The dominant direction of movement has previously been defined as the horizontal direction in which a volleyball player uses the same three-step approach sequence as their spiking sequence (Mercado-Palomino et al., 2021). A right-handed volleyball player, for example, moving in their dominant direction, utilizes the same left-right-left approach sequence as during the spiking task. However, in their non-dominant direction, a right-handed player may use a right-left-right approach sequence. Changing the direction of the approach sequence alters the roles of the limbs during the task. In the example of a right-handed player moving in their dominant direction, the left leg is the lead limb, and the right leg is the trail limb. In the non-dominant direction, the left leg is the trail limb while the right leg is the lead limb. Regardless of right or left leg, Mercado-Palomino et al. (2021) found the lead limb of the volleyball task exhibited greater ankle supination moment, internal knee adduction moments and knee internal rotation angles are observed, making the lead limb at greater risk of injury. In addition, volleyball players tend to land on the leg contralateral to their hitting arm when spiking a volleyball (Lobietti et al., 2010). A right-handed volleyball player, for example, lands more frequently on their left leg from a spike jump. Acknowledging that the contralateral leg of a volleyball player is both the lead limb and limb landed on more frequently, it is probable that the lead limb is at greater risk of injury (Avedesian et al., 2019; Mercado-Palomino et al., 2021). Instead of using a subjective or strength measure to identify a dominant or non-dominant limb, identifying the limb more frequently landed on in volleyball tasks may be better indicator of the at risk limb in volleyball players.

In match play, Division I collegiate volleyball players land 44.5% of the time from a spiking maneuver and 55.5% from a blocking maneuver (Tillman et al., 2004). A spike is primarily a forward three step then jump-land movement pattern whereas a block is a lateral three step jump-land movement pattern (Lobietti et al., 2009). Landing mechanics may differ between landing from a spike or a block task, which may impact injury risk. Salci et al. (2004) noted a difference in knee flexion angles between a spike and blocking task after visual inspection, and Garcia et al. (2022) observed an ankle attenuation strategy during landing from a spiking task but a knee attenuation strategy when landing from the blocking task in experience volleyball players. Their results present potential differences in landing strategies volleyball players use between tasks that should be further explored further. The analysis of landing kinematics and kinetics from a spiking volleyball task has been conducted in volleyball-specific studies focused on identifying the biomechanical variables associated to injury risk (Bisseling et al., 2008; Oliveira et al., 2020; Sinsurin et al., 2013). However, less research has investigated the mechanics underlying the blocking task of volleyball or compared these skills between blocking and spiking. During the spiking task, volleyball players reach greater jump heights and as a result, may invoke greater vertical GRF (Lobietti et al., 2009). With greater vertical GRF being associated to ACL injuries, analyzing landing mechanics from a spike has often been utilized to assess sport-specific injury risk (Ueno et al., 2020). However, male volleyball players landing from diagonal and lateral directions compared to a forward landing exhibited greater knee abduction angles, which have been associated with ACL injuries (Sinsurin et al., 2013). Thus, the blocking volleyball task that incorporates lateral movement may increase the risk for injury in these athletes (Sinsurin et al., 2013).

The lead limb of a volleyball task is more susceptible to kinematics and kinetics associated to lower extremity injuries (Mercado-Palomino et al., 2021). As such, the purpose of this study was to compare the biomechanics of the lead limb when landing from an offensive and defensive volleyball task in two shoe conditions. This study aimed to determine which landing pattern and shoe may decrease sagittal plane motion and increase frontal plane motion which are common risk factors of lower extremity injuries (De Bleecker et al., 2020). It was hypothesized that an interaction would be present between shoe and task. It was hypothesized that participants would exhibit greater vertical and posterior directed GRF, smaller sagittal plane and frontal plane ankle joint angles and moments, smaller sagittal plane knee joint angles and moments, and greater frontal plane knee joint angles and moments, while wearing the MC compared to LT. Further, it was hypothesized that there would be greater vertical GRF, greater sagittal plane ankle and knee joint angles and moments, and during landing in the spiking task yet, greater frontal plane ankle and knee joint angles and moments in the blocking task.

Materials and Methods

Participants

Eighteen NCAA Division-1 college volleyball players were recruited to attend one laboratory session. An a priori power analysis for a two-way repeated measures analysis of variance (ANOVA) indicated a sample size of 17 to achieve an alpha of .05 and beta of .80 (Faul et al., 2007). Any participants that self-reported any current or past lower extremity musculoskeletal injury in the past six months, any cardiovascular, metabolic, or neurological disease, were pregnant, or had a history of ACL injury or chronic ankle injuries were excluded from the study. All participants provided informed consent approved by the University's Institutional Review Board prior to participating in the study.

Instruments

A six-camera motion capture system (Qualisys, Gotenburg Sweden) collected lower extremity three-dimensional (3D) marker coordinate data at 240 Hz. GRF data were synchronously recorded using two in-ground force plates (1200 Hz, AMTI Inc., Watertown, MA). Single anatomic reflective anatomic markers were placed bilaterally on the acromion process, iliac crest, greater trochanter, medial and lateral femoral epicondyles, medial and lateral malleoli, distal end of the second toe, and the first and fifth metatarsal heads and used to define segments. Rigid thermoplastic segmental tracking clusters were placed on the trunk and pelvis, and bilaterally on the thighs, shanks, and heel and used to track segmental motion. Once a static trial of three seconds was recorded, all anatomic markers were removed and only the tracking clusters remained for the landing trials. Participants completed testing in a tank-top, compression shorts, and with their hair in a ponytail to avoid covering any tracking markers.

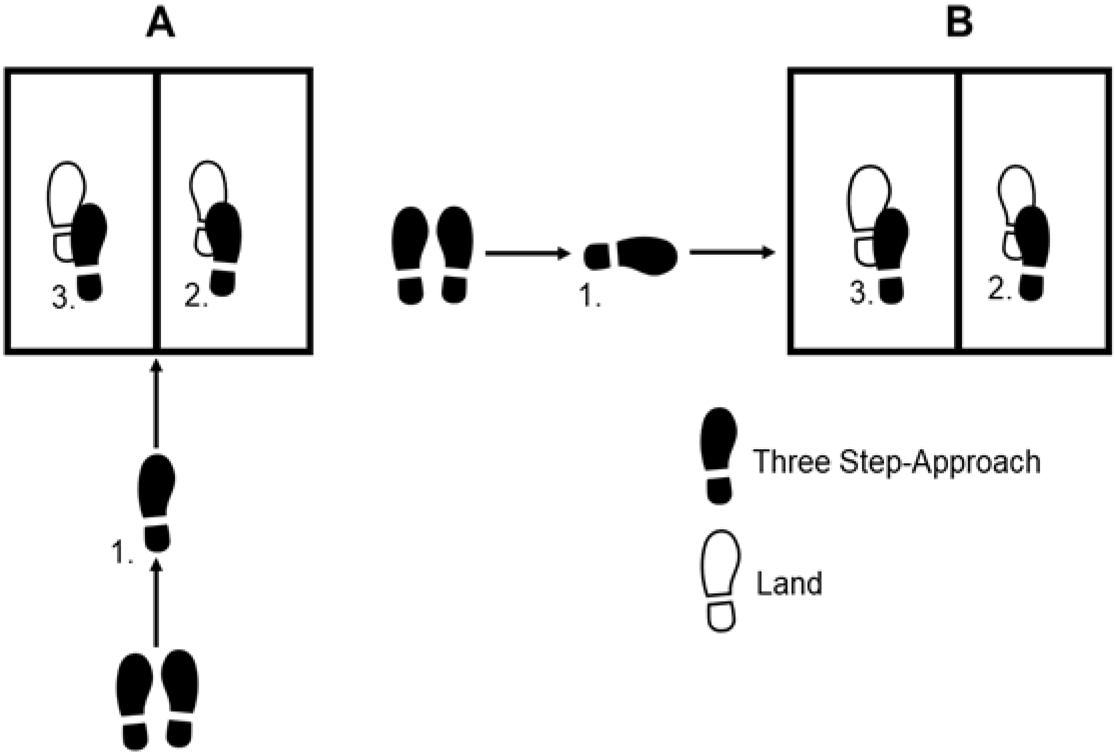
Procedure

Figure 1
The Adidas Crazyflight Volleyball Shoes Used in the Current Study

Note. Mid-Cut (left) and Low-Top (right) with the difference in collar height indicated by dashed lines.

First, participants completed a warm-up comprised of a 5-minute jog, stretching, and a familiarization period with the volleyball tasks. Participants then completed block jumps and spike jumps in both a MC and LT in a randomized order. In a standard US women's size 9 Adidas Crazyflight volleyball shoe, the MC collar height was 11 centimeters (cm), and the LT collar height was nine cm (figure 1). Three successful trials were completed with 30 seconds of rest given between trials and 3 minutes of rest given between shoe conditions. Each task utilized a three-step approach followed by a two-legged take-off in the participants' dominant direction. The dominant direction was identified as the direction in which the participants performed their normal three-step sequence while playing (Mercado-Palomino et al., 2021). To best reflect the spike approach observed while playing, participants started behind the force plates and moved horizontally into the plates (Garcia et al., 2022) (figure 2), while for the block approach, the participants started their approach on the right or left side of the force plates (dictated by the participant's dominant direction) and moved laterally into the plates (Lobietti, 2009; Sheppard et al., 2009). To simulate a game-like scenario, a target volleyball was suspended from the ceiling above the force plates. Participants were to use their arms as they normally would during the three-step approach and while in the air, reach for the ball as normally practiced in a game like environment (Garcia et al., 2022). Participants were instructed to take-off and land on both feet with one foot on each force plate. Additional trials were collected if participants did not take-off or land on different force plates and if the participant did not maintain balance for five seconds after landing (Garcia et al., 2022).

Figure 2
Example Footwork of the Spiking (A) and Blocking (B) Tasks Used in This Study



Note. The starting point of the spiking task was behind the force plates (A) while for the blocking task, participants started on either the right or left side of the force plate (B). Participants took a three-step approach, the first step being prior to contact with the force plate (1.), with the last two steps planting on each force plate (2. and 3.) to then maximally jump and land with each foot on one force plate. The participants during the spiking task moved horizontally while during the blocking task, participants moved laterally prior to maximally jumping.

All variables were identified during the landing phase of the task on the participant's lead limb. The lead limb was defined as the limb contralateral to the participants hitting arm. For instance, a right-handed volleyball player doing their volleyball movements in the dominant direction, the left-limb would correspond to the lead limb while the right-limb would correspond to the trail limb (Mercado-Palomino et al., 2020). The landing phase was defined as initial foot contact with the force platform to peak knee flexion (Garcia et al., 2022; Schroeder et al., 2021; Xu et al., 2020). Initial contact was defined as the first time point vertical GRF reached the threshold of 10 N. The variables of interest include initial contact knee and ankle joint angles, peak knee and ankle joint angles, internal peak knee and ankle joint moments, and peak ground reaction forces. Peak plantarflexion angles and peak knee extension angles were indicated by sagittal plane initial contact angles at the ankle and knee, respectively.

GRF data and three-dimensional marker coordinate data and were low-pass filtered using a fourth-order, zero lag, recursive Butterworth filter with a cutoff frequency of 10 Hz (Movahed et al., 2019; Xu et al., 2020). From the static trial, a musculoskeletal model was created. The hip joint center was placed 25% of the distance from the ipsilateral to contralateral greater trochanter markers (Weinhandl & O'Connor, 2010) and the knee joint centers were defined as the midpoint between the medial and lateral femoral epicondyle markers (Grood & Suntay, 1983). The ankle joint center was the midpoint between the medial and lateral malleoli markers (Wu et al., 2002). Lower extremity kinematics were computed in the joint coordinate system and internal joint moments were computed with a Newton-Euler inverse dynamics approach and resolved in the joint coordinate system (Grood & Suntay, 1983). Ankle dorsiflexion and inversion, and knee extension and adduction were defined as positive rotations.

Statistical Analysis

Descriptive statistics were calculated for all dependent variables. A two-way [Shoe (MC vs LT) × Task (Spike vs Block)] repeated-measures ANOVA was performed to evaluate the impact of the shoe conditions and task on the GRF, knee, and ankle biomechanical variables. Partial eta squared (ηp 2) was calculated as the effect size of the repeated measures ANOVA. Small, medium, and large effect sizes corresponded to the values of .0099, .0588, and .1379, respectively (Norouzian & Plonsky, 2018; Richardson, 2011). If a significant interaction was found, post-hoc paired sample t-tests with a Bonferroni correction were performed with Cohen's d calculated as the effect size. Cohen's d effect sizes between .00-.19 were classified as trivial, .20-.49 as small, .50-.79 as medium, and greater than .79 as large (Hopkins et al., 2009). Statistical significance was set at α = .05. All statistical analyses were performed using SPSS software (version 27, SPSS, Chicago, IL).

Results

Seventeen Division I female collegiate volleyball players were included in our analysis (age: 20.12 ± 1.32 years; mass: 72.29 ± 9.52 kg; height: 174.53 ± 6.37 cm; shoe size: 10.18 ± 1.26 US). One participant was excluded from the study due to a previous ACL rupture. Fourteen of the participants hit a volleyball with their right-hand with their left leg as the lead limb. Thirteen of the participants preferred to play in the MC compared to the LT.

A two-way repeated measures ANOVA revealed a significant interaction between shoe and task for peak anterior GRF (F(1, 17) = 6.338, p = .023) (table 1). Post-hoc analysis revealed a greater anterior directed GRF in the blocking task in the LT compared to the spiking task in the LT (p = .006, d = .68) and a greater anterior directed GRF in the spiking task wearing the MC compared to the spiking task in the LT (p = .003, d = .75). There was a significant main effect of task for peak lateral GRF (p = .002) and peak posterior GRF (p = .005).

Table 1
Ground Reaction Forces During Landing

	LT S	LT B	MC S	MC B	Shoe	Task	Interaction
			Mediolateral				
Peak Lateral	0.0039 ± 0.01	-0.0045 ± 0.01	0.0024 ± 0.01	-0.0042 ± 0.01	.708 (.009)	.002 (0.468)	.592 (.018)
Peak Medial	-0.2155 ± 0.044	-0.2375 ± 0.05	-0.2246 ± 0.05	-0.2389 ± 0.06	.447 (.037)	.096 (.163)	.530 (.025)
			Anteroposterior				
Peak Anterior	0.0781 ± 0.063	0.1059 ± 0.06^x	0.1147 ± 0.07^x	0.1011 ± 0.05	.052 (.217)	.441 (.038)	.023 (.284)
Peak Posterior	-0.1851 ± 0.04	-0.1581 ± 0.04	-0.1727 ± 0.05	-0.1489 ± 0.03	.051 (.217)	.005 (.394)	.798 (.004)
			Vertical				
Peak Vertical	1.8923 ± 0.28	1.7470 ± 0.27	1.7991 ± 0.35	1.7704 ± 0.30	.369 (.051)	.118 (.145)	.262 (.078)

Note. Ground reaction forces are presented as mean ± sd in % body weight (BW) for the low-top shoe spiking task (LT S), low-top shoe blocking task (LT B), mid-cut shoe spiking task (MC S), and mid-cut shoe blocking task (MC B). Interaction and main effect results are presented as p-value (η2). Bold represent statistical significance.

^{x} Statistically significant difference from the LT S.

A main effect of shoe was found for peak dorsiflexion angle (p = .026) (table 2) and initial contact plantarflexion angle (p = .018). A main effect of task was found for initial contact plantarflexion angle (p = .015), peak dorsiflexion angle (p = .031), peak eversion angle (p = .008), and peak inversion angle (p = .027). For ankle joint moments, a significant interaction between shoe and task for peak plantarflexion moment (F(1, 17) = 5.989, p = .026). A post-hoc analysis revealed a significantly larger peak plantarflexion moment in the spiking task wearing the LT compared to the spiking task wearing the MC (p = .008, d = .65). Additionally, a main effect of shoe was found for peak plantarflexion moment (p = .046).

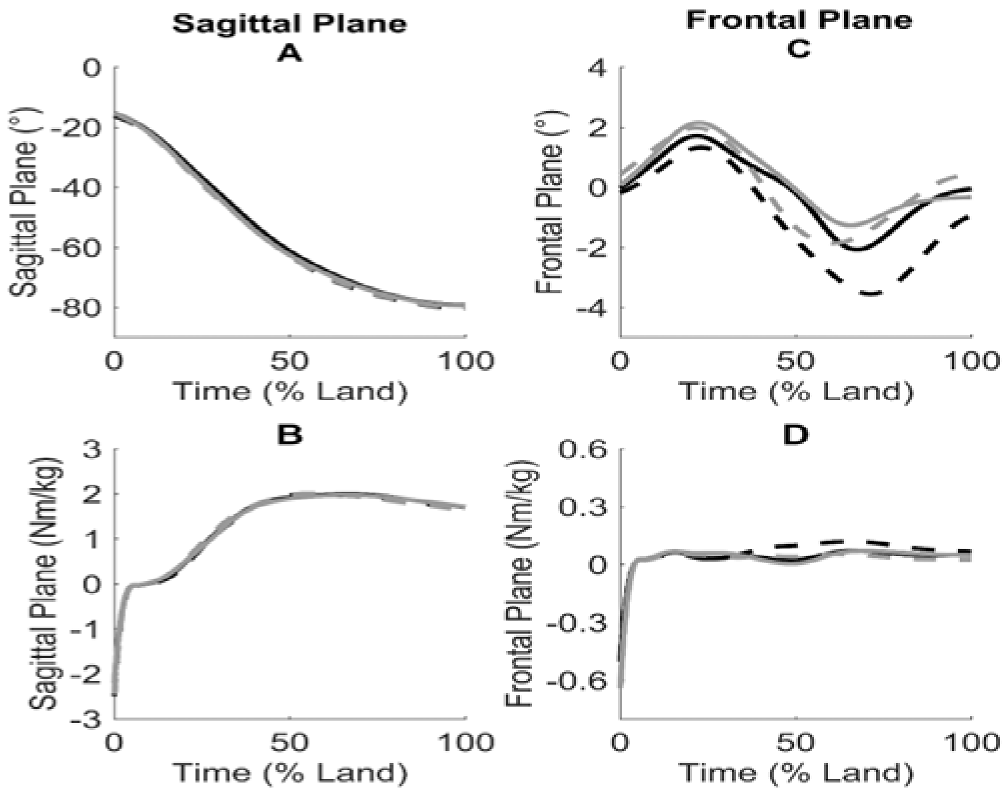
Table 2
Ankle Joint Kinematics and Kinetics

	LT S	LT B	MC S	MC B	Shoe	Task	Interaction
Ankle Angle							
Peak Dorsiflexion Angle	25.1 ± 5.85	26.2 ± 5.00	23.9 ± 5.10	24.6 ± 4.90	.026 (.273)	.031 (.260)	.560 (.022)
Peak Eversion Angle	-4.2 ± 3.18	-2.6 ± 3.22	-3.5 ± 3.21	-2.5 ± 3.00	.332 (.059)	.008 (.366)	.264 (.077)
Peak Inversion Angle	3.3 ± 4.64	4.9 ± 3.59	4.2 ± 4.07	5.1 ± 3.71	.231 (.088)	.027 (.270)	.377 (.049)
Initial Contact Plantarflexion Angle	-30.9 ± 6.61	-29.0 ± 6.81	-29.1 ± 6.61	-27.7 ± 6.34	.018 (.305)	.015 (.315)	.661 (.012)
Initial Contact Inversion Angle	0.8 ± 5.87	1.6 ± 4.70	1.3 ± 5.62	2.0 ± 4.79	.537 (.024)	.226 (.090)	.985 (.000)
Ankle Moment							
Peak Plantarflexion Moment	-1.6 ± 0.32	-1.47 ± 0.33	-1.4 ± 0.28[x]	-1.4 ± 0.31	.046 (.225)	.818 (.003)	.026 (.272)
Peak Dorsiflexion Moment	-0.0 ± 0.01	-0.0 ± 0.02	-0.0 ± 0.02	-0.0 ± 0.02	.772 (.005)	.298 (.067)	.142 (.130)
Peak Eversion Moment	-0.1 ± 0.06	-0.1 ± 0.05	-0.1 ± 0.05	-0.1 ± 0.05	.766 (.006)	.261 (.078)	.264 (.077)
Peak Inversion Moment	0.1 ± 0.04	0.1 ± 0.05	0.2 ± 0.05	0.1 ± 0.05	.374 (.050)	.074 (.186)	.257 (.080)

Note. Initial contact and peak joint angles are presented as mean ± sd (°) and internal peak joint moments are presented as mean ± sd in % body mass (BM) for the low-top shoe spiking task (LT S), low-top shoe blocking task (LT B), mid-cut shoe spiking task (MC S), and mid-cut shoe blocking task (MC B). Interaction and main effect results are presented as p-value (η2). Bold represent statistical significance.

[x] Statistically significant difference from the LT S.

Figure 3
Knee Joint Kinematics and Kinetics During Landing Between Shoe and Task



Note. Sagittal plane knee joint angles (A) and internal knee joint moments (B). Frontal plane knee joint angles (C) and internal knee joint moments (D). The low-top shoe spiking task is indicated by the solid black line. The low-top shoe blocking task is indicated by the solid grey line. The mid-cut shoe spiking task is indicated by the dashed back line. The mid-cut shoe blocking task is indicated by the dashed grey line.

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A significant interaction between shoe and task was observed for peak knee abduction angles ($F(1, 17) = 6.092$, $p = .025$) (figure 3). The peak knee abduction angle was -4.6 ± 3.77° for the LT in the spiking task, -4.5 ± 3.55° for the LT in the blocking task, -5.7 ± 2.89° for the MC in the spiking task, and -4.3 ± 2.75° for the MC in the blocking task. However, post-hoc analysis did not reveal any statistically significant pairwise comparisons (figure 3). The variability between shoe and task conditions was not large enough to remain significant with an adjusted alpha level. No other interactions or main effects were found between shoe and task conditions at the knee.

Discussion

With differing types of footwear worn and different offensive and defensive tasks inherent in volleyball, the purpose of this study was to determine the effects of both footwear and task on the lead limb landing mechanics in female collegiate volleyball players. We hypothesized that in the MC, participants would land with greater vertical and posterior GRF, smaller sagittal and frontal plane ankle joint mechanics, smaller sagittal plane knee joint mechanics, and greater frontal plane knee joint mechanics. We also hypothesized that in the spiking task, participants would exhibit greater vertical GRF and greater sagittal plane ankle and knee joint angles and moments but in the blocking task, greater frontal plane ankle and knee joint angles and moments.

Shoe Collar Height

As anticipated, changes occurred in GRF, lower extremity kinematics, and kinetics during landing between the MC and LT. However, kinematic, and kinetic changes attributable to footwear were only observed at the ankle. Contrary to our hypotheses, when performing the spiking task, participants in the MC landed with greater peak anteriorly directed GRF compared to both the LT in the spiking task, and during the blocking task. Participants also landed with reduced plantarflexion angles at initial contact and exhibited smaller peak dorsiflexion angles in the MC compared to landing in the LT, partially supporting our hypotheses, yet with no changes between shoes were observed in the frontal plane. Common mechanisms of lateral ankle sprains, to be further discussed later, occur in the frontal plane (Morrison et al., 2010). In the present study, the MC did not restrict greater frontal plane motion or alter mediolateral GRF compared to the LT. This suggests that different volleyball shoes with greater collar heights than the MC are warranted if players are attempting to reduce frontal plane ankle motion and their risk of lateral ankle sprains while playing. When landing in the LT, a greater peak internal plantarflexion moment was observed. The greater peak dorsiflexion angles while wearing the LT may have contributed to this increased plantarflexion moment. Previous research has associated smaller peak dorsiflexion angles to increased vertical and posterior GRF (Fong et al., 2011; Hoch et al., 2015). In the MC, there was a reduction in peak dorsiflexion angle however, contrary to our hypotheses, there were not any changes in peak vertical and posterior GRF. The lack of changes in the vertical and posterior GRF may have been contributed by the hip and knee playing a larger role than the ankle in dissipating energy during a double-leg landing (Steeves, 2008), or volleyball players adaptation to exhibit better force attenuation strategies when landing as a result of frequently wearing shoes that limit their sagittal plane ankle motion. However, more research is warranted to corroborate these posed theories. Instead, a greater peak anterior GRF was observed in the MC during the spiking task but the same change in peak anterior GRF was not observed during the blocking task. The unseen change in frontal plane ankle kinematics and kinetics, peak posterior GRF, and unsystematic changes in peak anterior GRF resulting from wearing the MC suggests that the shoe collar height was not large enough from the LT to invoke any changes in landing mechanics associated to lateral ankle sprains or ACL injuries.

With the changes in GRF, and ankle kinematics and kinetics, it was anticipated that these would translate up the kinematic chain and impact the knee landing kinematics and kinetics. However, the knee landing mechanics in the sagittal and frontal planes between the MC and LT were not significantly different. The changes in GRF and ankle mechanics may not have been large enough to induce alteration in knee landing kinematics and kinetics. Another potential reason for similarities in knee kinematics and kinetics during landing may be contributed to the ankle's role to dissipate GRF and promote better landing strategies. For static dorsiflexion range of motion, Hoch et al. (2015) found moderate correlations to maximum ankle dorsiflexion during landing ($r = .49$), to maximum knee flexion ($r = .69$) and vertical GRF ($r = -.47$). The participants assessed by Hoch et al. (2015) landed with a sagittal plane initial contact ankle angle of -26.24 ± 7.70° and exhibited total ankle sagittal plane range of motion of 44.73 ± 8.77°. Malloy et al. (2015) demonstrated a significant negative correlation between a mean 15.0 ± 3.9° static ankle dorsiflexion flexibility and peak internal knee adduction moment ($r = .442$) and a significant positive correlation to peak knee flexion angle ($r = .385$) and peak knee abduction angle ($r = .355$). Hoch et al. (2015) and Malloy et al. (2015) demonstrated that decreasing sagittal plane motion at the ankle altered sagittal plane and frontal plane kinematics and kinetics at the knee associated to ACL injury risk, yet in the present study, the smaller sagittal plane motion in the MC did not yield these same results. Overall, the MC in this study had larger initial contact angles at the ankle and knee, and larger peak dorsiflexion and peak knee flexion angles than Hoch et al. (2015). This suggests that even in the MC, the volleyball players still landed in the MC with large enough plantarflexion angles for a forefoot landing strategy that aided in using the ankle more effectively to attenuate GRF and reduce risk of ACL injury (Boden et al., 2009).

Volleyball Task

Significant differences in GRF and ankle kinematics occurred between the spiking task and the blocking tasks. No changes occurred in ankle kinetics or knee kinematics and kinetics between tasks. In the spiking task, participants exhibited greater peak posterior GRF, peak medial GRF, and greater peak eversion angles during landing. Contrarily, participants landed with greater peak anterior GRF, smaller initial contact angles, greater peak dorsiflexion angles, and greater inversion angles during the blocking task.

Our hypothesis that there would be an increase in vertical GRF landing from the spiking task was not supported, as the vertical GRF between tasks were not significantly different. In the blocking task, the ankle initial contact angles were smaller but with greater peak dorsiflexion angles than in the spiking task. Greater sagittal plane ankle range of motion allows for the ability to attenuate GRF (Fong et al., 2011; Hoch et al., 2015). The compensation of greater peak dorsiflexion angles during the blocking task may have been great enough to attenuate the GRF and been a potential reason the vertical GRF remained similar between the two volleyball tasks.

Participants in the spiking task exhibited greater posterior and lateral GRF during landing compared to the blocking task. The nature of the spiking task has participants move with forward momentum towards the force plate and then with this momentum translated into vertical momentum as best as possible as the participant jumps and lands (Wagner et al., 2009). Ali et al. (2014) demonstrated that increasing horizontal landing distance led to larger peak posterior GRF. Although the horizontal distance was not accounted for in the present study, it is plausible the horizontal momentum generated from the spiking task itself may have accounted for the greater magnitude of posterior GRF.

Additionally, in the spiking task, participants landed with greater lateral GRF while in the blocking task, the mediolateral GRF was directed medial the entirety of the landing phase. Accompanied with the greater magnitude of lateral GRF, the participants exhibited greater initial contact and peak plantarflexion angles and greater peak eversion angles during landing from the spiking task. In the blocking task, participants exhibited greater peak dorsiflexion angles and greater peak inversion angles. Another prevalent injury in volleyball, lateral ankle sprains, are caused by mechanisms of excessive ankle inversion angles and medial GRF (Morrison et al., 2010). Greater peak inversion angles and medial GRF were exhibited during landing from the blocking task, potentially making landing from a block more susceptible to lateral ankle sprains than landing from a spike. With these aforementioned changes in both mediolateral GRF and ankle kinematics between the two volleyball tasks, changes in ankle kinetics were anticipated, yet there were no changes in ankle kinetics between tasks. The changes in GRF and ankle kinematics may not have been large enough to impact ankle kinetics or the proximal joint at the knee.

Contrary to our hypotheses, there were no significant differences in knee landing kinematics and kinetics between volleyball tasks. This is a novel finding, as minimal research has directly compared the spiking and blocking tasks in female volleyball players and their risk of injury when landing. Salci et al. (2004) noted anecdotally that between spike and block landings, the knee flexion angles across landing visually differed, thus, leading them to believe there may be different landing strategies across tasks. In support of different landing strategies between volleyball tasks, Garcia et al. (2022) found that experienced male volleyball players landed with different strategies between the spike and block. In the spiking task, Garcia et al. (2022) found participants landed with an ankle attenuation landing strategy of larger initial contact plantarflexion angles and larger dorsiflexion range of motion. In the blocking task, Garcia et al. (2022) noted participants landed with a knee attenuation strategy of larger knee flexion range of motion. Comparing the initial contact angles at both joints to Garcia et al. (2022), the participants in the current study participants landed with greater initial contact plantarflexion angles and greater initial contact knee flexion angles. The lack of statistically significant changes in the knee frontal plane angles and moments in the current study is in support of knee frontal plane mechanics reported by Garcia et al. (2022) between tasks. The blocking task utilized by Garcia et al. (2022) was only vertical in nature whereas in the current study, the blocking task may have incorporated mediolateral displacement in the air from the participants momentum moving into the force plates from the right or left sides. With volleyball players previously demonstrating greater knee abduction angles as a result from landing from lateral directions (Sinsurin et al., 2013), we anticipated greater frontal plane knee kinematics and kinetics. The participants in the current study seemed to have adapted better landing strategies with greater sagittal plane initial contact angles at the ankle and knee without changes in the frontal plane knee joint angles and moments that would be associated to lower extremity injuries.

Limitations

The results of this study should be considered within the context of several limitations. First, the jump height prior to landing was not standardized. A volleyball was suspended from the ceiling above the height of the net to provide the players with a realistic visual and the players were instructed to maximally jump as they would in a game. However, the maximal effort and jump height was subjective to the players themselves. Another limitation of this study was the type of shoes worn. The shoes worn were the athlete's own personal shoes given to them by the university's athletic department to compete in. The shoes were the same age, make, and model, but the wear and degradation of the shoes were not quantified which may have altered the results. Additionally, a limitation of this study was that the participants only represent a small portion of experienced Division I NCAA volleyball players, and the participants were not classified by their position. Comparing novice to experienced volleyball players during landing from volleyball movements, Garcia et al. (2022) suggested that experienced volleyball players landed with better strategies in lower extremity kinematics and kinetics compared to novices. This suggests that further research comparing landing GRF, kinematics, and kinetics between a spike and blocking task in a novice population is warranted.

Conclusions

The type of shoe and type of volleyball task influenced GRF and ankle mechanics during landing. The changes in GRF and ankle mechanics were not of great enough magnitude to impact knee landing mechanics between shoe conditions and between volleyball tasks. The MC and LT could be worn interchangeably without increasing knee kinematics and kinetics (i.e. greater GRF, reduced knee flexion angle, knee abduction angle, internal knee adduction moment) associated to ACL injuries. The greater peak medial GRF and greater peak inversion angles observed while landing from the blocking task suggests that volleyball players may be more susceptible to mechanisms of lateral ankle sprains during the blocking task. Training to improve ankle mechanics during landing may likely be effective in reducing ankle injury risk while playing.

Novice volleyball players may have different landing strategies than experienced players condoning the expansion of the scope of this study into novice populations to potentially identify injury risk between tasks in volleyball players with less experience. Additionally, as the collar height of the MC rose just superior to the talocrural joint and malleoli, assessing the impact of footwear transversing further up the tibia on the ankle and knee biomechanics and potential injury risk is warranted.

Ethics Committee Statement

This study was performed in accordance with the Declaration of Helsinki and was approved by the local Institutional Review Board - approval: 22-923. All adult participants provided written informed consent to participate in this study.

Conflict of Interest Statement

The authors declare no conflicts of interest.

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Authors' Contribution

Conceptualization LL, TT &; Methodology LL,TT; Software LL; Formal Analysis LL; Investigation LL; Writing – Original Draft LL, TT; Writing – Review & Editing LL, SP, PD, SP, TT. All authors have read and agreed to the published version of the manuscript.

Data Availability Statement

Dataset available on request from the authors.

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