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EFFECT OF VARIOUS TYPES OF ATTENTIONAL FOCUS ON LOWER LIMB BIOMECHANICS DURING SINGLE-LEG DROP-LANDING

Diplomová práce

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Abstract:

The purpose of this study was to investigate the effect of various types of focus of attention on the knee and ankle kinematics and kinetics during a single-leg drop landing. A total of 21 healthy collegiate students completed 3 single-leg drop landing trails without any focus of attention instructions (control condition-CON), followed by 3 single-leg drop landings in each focus of attention condition (external focus-EF, internal focus-IF, and holistic focus-HF) which were presented in a counterbalanced order. The knee and ankle 3-D kinematics and kinetics were captured. The result showed that the peak vertical ground reaction force significantly decreased after adopting an HF compared to CON ($p=0.003$, $F=7.15$, $d>0.8$). No significant effect of the landing conditions was observed in the peak anteroposterior ground reaction force. Ankle adduction angle in the IF and ankle inversion angle in CON conditions were greater in the balance-maintenance phase after landing. The knee flexion angle was significantly greater in the IF condition compared to CON. The knee joint angular velocity in the sagittal and frontal planes was greater in the CON condition relative to other conditions with the focus of attention instructions. The findings of this study showed that an HF can be considered another beneficial type of focus of attention by decreasing peak vertical ground reaction force during single-leg drop landing. Future studies should concentrate on incorporating HF instruction into prevention programs and tracking injuries to see whether there is a reduction in lower limb injuries.

Keywords: Focus of attention, lower limb biomechanics, single-leg drop landing.

I declare that I have prepared this thesis independently under the supervision of Zdeněk Svoboda, Ph.D. I have listed all the literature and professional resources used, and I have adhered to the principles of scientific ethics.

Olomouc ……………2022

I would like to express my sincere recognition to my supervisor Zdeněk Svoboda, Ph.D. for his continuous support of my master thesis, his tremendous knowledge, wise advice during the thesis planning, and his positive energy. In addition, I would like to thank my husband Javad Sarvestan, Ph.D. for all of his inspiration and support and my family for their unconditional support and encouragement even with miles of distance. Last but not least, I would like to thank the tutors and the staff of the Faculty of Physical Culture at Palacký University Olomouc that helped and supported me a lot during my master's degree.

Table of Contents

Introduction

Non-contact Injuries During Landing

The occurrence of lower limb injuries during landing from a jump is common in team sports (Hootman, Dick, & Agel, 2007; Stuelcken, Mellifont, Gorman, & Sayers, 2016). Many of these injuries that are induced by the non-contact mechanisms (Gianotti, Marshall, Hume, & Bunt, 2009) are inflicted on the ligaments of the ankle or knee (Finch, Costa, Stevenson, Hamer, & Elliott, 2002). Acute non-contact lower limb injuries are induced by the interaction of external force and insufficient joint load attenuation (Shimokochi & Shultz, 2008) as a consequence of the player's own movements rather than contact with another player or objects (Marshall, Padua, & McGrath, 2007).

Anterior cruciate ligament injuries during landing

One of the injuries that often occur in non-contact situations is anterior cruciate ligament (ACL) injury (Dragoo, Braun, Durham, Chen, & Harris, 2012; Waldén, Hägglund, Magnusson, & Ekstrand, 2011). The ACL which has a critical function in ensuring knee stability, especially in the anterior-posterior direction (Hartigan, Lewek, & Snyder-Mackler, 2011), has been considered the most frequently injured ligament in the knee for the general population (Bollen, 2000). In general, the non-contact injury of the ACL occurs when the athlete exerts a great force or moment on the knee joint that causes the force induced to the ACL to go higher than the ultimate load capacity of the knee joint (Xu, Jiang, Cen, Baker, & Gu, 2020).

The highest number of ACL injuries that occurred among various non-contact movements are different between varied sports. According to the findings by Alentorn-Geli et al. (2009), the non-contact ACL injuries in soccer happen regularly during changing direction or cutting with deceleration, landing from a jump, or pivoting with small knee flexion angles, whiles Cochrane, Lloyd, Buttfield, Seward, and McGivern (2007) reported that the non-contact maneuvers during side-cutting and landing caused the majority of the ACL injuries in Australian football. In two sports badminton and basketball, most of the non-contact ACL injuries were observed during landing (Kimura et al., 2010; Krosshaug et al., 2007). In volleyball, following a spike, landing on one leg significantly increases the risk of non-contact ACL injuries (Xu et al., 2020).

The biomechanical risk factors associated with ACL injuries during landing have been extensively investigated. The proximal tibia anterior shear force is one of the joint forces that can increase ACL strain and cause ligament rupture (Markolf et al., 1995; Sell et al., 2007). Even though the loading pattern of the knee during non-contact ACL injuries occurs in multi-directional and multi-planar (Boden, Dean, Feagin, & Garrett, 2000; Olsen, Myklebust, Engebretsen, & Bahr, 2004), however, according to study findings proximal tibia anterior shear force plays a key role in the ACL's direct loading mechanism (Markolf et al., 1995). Yu, Lin, and Garrett (2006) reported that larger ground reaction forces (GRF) and knee extension moments are associated with increased proximal tibia anterior shear force.

Small hip and knee flexion angles could be considered one of the risk factors for non-contact ACL injury during landing (C.-F. Lin, Liu, Garrett, & Yu, 2008). The impact pressure on the knee (the anterior tibial shear force) increases as knee and hip flexion angles decrease (Yu et al., 2006; Zhang, Bates, & Dufek, 2000). The link between small hip and knee flexion angles and increased non-contact ACL injury risk has been strongly confirmed by research using several methodologies, including cadaver research (G. Li et al., 1999; Renström, Arms, Stanwyck, Johnson, & Pope, 1986), video analysis (Cochrane et al., 2007; Koga et al., 2010; Krosshaug et al., 2007), and biomechanical explanations (Yu & Garrett, 2007). The ACL strain force is greatly extended as the knee and hip flexion angles reduce and the knee and hip extension moment increase (Bakker et al., 2016; H. Zhou & Ugbolue, 2019). Due to the observation of the greatest ACL strain that occurs at initial contact during single-leg landing, knee flexion angles at initial contact are even more concerned than maximum vertical ground reaction force (VGRF) (Lamontagne, Benoit, Ramsey, Caraffa, & Cerulli, 2008).

Peak external knee valgus moment and greater knee abduction angle during landing are other biomechanical risk factor for ACL injury due to diminished neuromuscular control and enhance joint loads (Hewett et al., 2005). In the frontal plane, increased ACL strain was observed when the knee joint moment (valgus or varus) merged with a proximal anterior tibial force (Arms et al., 1984; Bendjaballah, Shirazi-Adl, & Zukor, 1997). Estimation of the valgus moment through inverse dynamic is considered one of the predictors of ACL injury in female athletes (Hewett et al., 2005). Hewett et al. (2005) reported that ACL-injured female athletes had larger knee abduction angles than non-injured players. There were also significant correlations between knee abduction angle and peak VGRF among ACL-injured individuals that were not observed in non-injured individuals.

Angular velocity, like joint moments, might be a key factor in interpreting neuromuscular control and the process of ACL injury. Yu et al. (2006) discovered a link between sagittal hip and knee angular velocity (flexion/extension angular velocity) and impact ground reaction forces on the knee joint's resultant when landing from a jump, indicating that angular velocity might be a key component of affecting ACL loading. They reported a relationship between knee angular velocity in the sagittal plane with peak VGRF and peak anteroposterior ground reaction force at initial foot contact with the ground during landing from a stop-jump task (Yu et al., 2006).

Other risk factors include a combination of internal tibial rotation and external knee valgus during single-leg landing, which resulted in higher ACL strain, and increased knee joint loading, which leads to ACL injuries (C. S. Shin, Chaudhari, & Andriacchi, 2011). In this line, Lee and Shin (2021) recently discovered a link between plantarflexion angle and several biomechanical ACL injury risk factors at initial contact during single-leg landing. The increased plantarflexion angle at initial contact resulted in a lower peak external knee valgus moment and combined peak external knee valgus plus tibial internal rotation moment, according to the findings. As a result, this study concluded that a larger plantarflexion ankle angle at landing would cause decreasing the risk of non-contact ACL injuries (Lee & Shin, 2021).

Ankle sprain during landing

The lateral ankle sprain (LAS) injuries have been identified as the most common type of injury among jump-landing-based sports including volleyball, basketball, and soccer, and a non-contact mechanism was reported responsible for nearly half of these injuries (Hootman et al., 2007; Roos et al., 2017). In addition, LAS has been generally known as an injury that frequently occurs in high school and college sports (Fernandez, Yard, & Comstock, 2007; Roos et al., 2017). LAS occurs as a result of sudden and extreme inversion, internal rotation, and plantar flexion of the ankle joint complex on an externally rotated distal tibia (Fong et al., 2009; Terada & Gribble, 2015). Whereas LAS injuries are often considered unimportant injuries and are not treated well, but, studies have recognized LAS as a recurring injury that keeps athletes to be away from participating in sports for remarkable time lost (Roos et al., 2017), and also causes an excess of deficiencies of sensorimotor and mechanical for a long time (Hertel, 2008). Furthermore, a relationship has been found between LAS during sports and a higher risk of ankle osteoarthritis incidence (Valderrabano, Hintermann, Horisberger, & Fung, 2006). Hence, researchers had needed to identify mechanical risk factors that related to an increased chance of LAS injuries during jump-landing.

During landing, foot position in the horizontal plane has been identified as a risk factor that may influence the occurrence of LAS when the foot lands in certain positions (Koshino et al., 2017). According to study results by Koshino et al. (2017), a single-leg landing with a larger toe-in position exposes the lateral ankle ligaments to injury risk. Ankle inversion angular velocity and inversion moment which are considered influential factors in the pathomechanics of LAS were been observed with larger peaks when the foot landed with toe-in compared with the natural or toe-out position (Koshino et al., 2017). Therefore, for avoiding LAS occurrence during single-leg landing, athletes might be instructed not to land with the toe-in position (Koshino et al., 2017).

Considering Single-leg Drop-landing as a High-risk Type of Landing

The pressure on the lower limb ligaments and joints is affected by different landing patterns. Single-leg landing after a spike in volleyball players results in a reduced knee and hip flexion angle and angular velocity of these two joints, as well as a larger joint moment, joint power, VGRF, and loading rate (Xu et al., 2020). As it was mentioned above the majority of these factors are linked to increasing ACL injury occurrence. Koshino et al. (2017) found that landing on one leg with considerable lower limb internal rotation can result in a great ankle inversion angle, angular velocity, and moment, so it's believed that a single-leg landing raises the risk of LAS. In the study by Nejishima, Urabe, and Yokoyama (2007) single-leg landing showed a greater knee valgus angle, and smaller knee flexion angle compared to double-leg, thus a single-leg landing is determined as a high-risk activity for the occurrence of ACL injuries. The activity of the lower-extremity muscles was increased during single-leg landing when compared to double-leg (Nejishima et al., 2007). In addition, Brown, McLean, and Palmieri-Smith (2014) reported that excessive quadriceps contraction especially greater rectus femoris pre-activity during a single-leg jump landing increased the peak externally applied anterior tibial shear force, and results in a higher risk of ACL injury. When the knee is fully extended (or near full extension) at landing on a single leg, extreme activation of quadriceps and/or inadequate hamstring activation, which cannot prevent dangerous knee abduction or anterior shear loading, increase the risk of ACL injury (Shimokochi & Shultz, 2008).

Moreover, higher GRF values observed during single-leg landings compared to other types of landings are another reason to consider it as a high-risk type of landing (Heebner et al., 2017). Furthermore lower hip and knee mobility reduces force absorption during landing, resulting in greater ground reaction forces. Because of decreased motion at these joints during single-leg landing, the single-leg landing had shown higher vertical ground reaction force (VGRF) and posterior ground reaction force (PGRF) than the double-leg landing (Heebner et al., 2017).

Alongside the previous result, Heebner et al. (2017) also reported that drop landings showed higher VGRF and PGRF, as well as greater peak proximal anterior tibial shear force (PATSF) and peak valgus moment than stop-jump trials. The findings were identical to research by Sell, Akins, Opp, and Lephart (2014). When comparing the drop-landing to the stop-jump landing, knee loading increased due to lower peak knee and hip joint motion (Heebner et al., 2017), indicating a link between decreased knee flexion and greater VGRF during the drop-landing (Podraza & White, 2010). To conclude, single-leg drop-landing seems to be a high-risk movement that increases the occurrence of non-contact lower limb injuries.

Various Types of Focus of Attention

Improving motor skill learning is a common goal in many fields of study, including kinesiology, sports pedagogy, and physical therapy. One factor that can help enhance a learner's learning and performance of a motor skill is giving them the right instruction (G. Wulf, Hoss, & Prinz, 1998). One related aspect that has been studied over the past several years is the focus of attention of a learner induced by the instructor or trainer (Park, Yi, Shin, & Ryu, 2015; Wulf, 2013). Attentional focus is widely known as one of the paramount elements in motor performance and motor learning improvement (Calatayud et al., 2018). Since the early stages of studies on the focus of attention, the Internal focus of attention (IF) and External focus of attention (EF) have been investigated in the literature. IF refers to directing learners' attention to their body movement, whereas EF refers to directing learners' attention to the intended movement effect, such as implement, apparatus, and target (Gabriele Wulf, McNevin, & Shea, 2001). Only a few research have examined how the other types of focus of attention methods affect motor learning and performance when compared to an internal and external focus. A holistic focus of attention (HF), which is defined as a concentration on the general feeling or sensations connected with completing a movement, is one such example of another type of focus of attention (Becker, Georges, & Aiken, 2019).

It was presented that orienting the learners' attention focus to the external procedures or environment (EF – external focus) leads to learning benefits over the concentration on the body movements (IF – internal focus) (Shea & Wulf, 1999). According to the constrained action hypothesis (Gabriele Wulf et al., 2001), "an IF induces a conscious type of control, causing individuals to constrain their motor system by interfering with automatic control processes. In contrast, an EF promotes a more automatic mode of control by utilizing unconscious, fast, and reflexive control processes". The self-invoking trigger concept, which is compatible with the constrained action hypothesis posits that referring to one's bodily parts or movement results in self-evaluating and self-regulatory processing by enabling access to the brain representation of the self, resulting in conscious movement control (Gabriele Wulf, Dufek, Lozano, & Pettigrew, 2010). As a result, any cues that drive a person to focus on themselves have the potential to disrupt motor performance (McKay, Wulf, Lewthwaite, & Nordin, 2015). Misplacing attention under pressure conditions is one type of neuronal activation of the self, which impairs motor performance (Beilock & Carr, 2001). The OPTIMAL theory, which addresses the nature of cognitive-affective-motor, is another hypothesis for increasing motor performance. According to this idea, motivational and attentional factors (an EF) contribute to performance and learning by linking objectives to actions (Bruya, 2010). This theory expresses that an EF of attention by limiting a concentration on the self through leading focus towards the task objective causes promotes motor performance (Bruya, 2010).

Although research regularly shows that an EF benefits motor performance and learning when compared to an IF, identifying a relevant EF cue for some tasks can be challenging (Becker et al., 2019). Focus cues, which are brief sentences to lead the performer's attention into the appropriate attentional focus, can easily be designed by a coach or expert to direct attention to either the target or the implement (EF cues) within object projection tasks like golf or basketball. As an EF of attention has not been proven repeatedly to be beneficial in attentional focus studies that have involved tasks without a target or implement such as gymnastics or figure skating, it was said that might be difficult to provide appropriate EF cues for such tasks (Becker et al., 2019). The result of the study by Lawrence, Gottwald, Hardy, and Khan (2011) demonstrated a reduction in the performance of a novel gymnastics routine with an external focus, but Abdollahipour, Wulf, Psotta, and Palomo Nieto (2015) reported that using an external focus improved the performance of a gymnastics skill. In the study by Abdollahipour et al. (2015) the EF condition placed a tape marker on the participants' chests and instructed them to concentrate on the direction the tape marker was pointing after the half rotation while airborne. Although this experiment was successful and demonstrated the effectiveness of an EF, practitioners may find it challenging to apply this focus cue during training or competition since it seemed to be an unrealistic and impractical concentration (Becker et al., 2019). Another research in this line looked at how skilled dancers performed a pirouette (a pivot turn on one leg) under three different conditions: EF instruction, IF instruction, and no focus instruction (control condition). There was no significant difference in the quality of a pirouette across the three conditions (Chua, Sproule, & Timmons, 2018).

Some studies in the related line of research have suggested that focusing on the general feeling of a movement (HF) might be considered another attentional strategy to avoid conscious control of movement for tasks without clear EF cues (Becker et al., 2019). According to the constrained action hypothesis, Gabriele Wulf et al. (2001) in which stated "trying to consciously control one's movements constrains the motor system by interfering with automatic control processes that would 'normally' regulate the movement." an EF is presented as a way to prevent this procedure, however, finding by Becker et al. (2019) brought to mind that an HF might also attain this purpose. By concentrating on the general feeling produced by a movement rather than a particular movement, an HF may develop a higher level of automaticity than an IF. As a result, an HF looked to meet the purpose of minimizing conscious control (Becker et al., 2019). Although an HF does not concentrate on a movement's impact on the environment, it may have a comparable benefit to an EF since it seems that an HF concentrates on the effects of a movement that takes place within the body (Abedanzadeh, Becker, & Mousavi, 2022).

A brief review of the focus of attention experiments in varied contexts

Wulf et al. (1998) employed a ski simulator in the first experiment and directed participants' attention to either the pressure they applied on the wheels of the platform on which they were standing (EF) or to their feet that were applying the force (IF). On a retention test, in terms of learning the EF group outperformed better than both the IF and a control group that did not receive focus instructions (i.e., bigger movement amplitudes). In the second experiment, which involved balancing on a Stabilometer, G. Wulf et al. (1998) discovered that instructing to keep participants' attention on markers on the balance platform horizontal (EF), resulted in more effective balance learning than asking them to attempt focused to keep their feet horizontal (IF). The benefits of an EF in balance performance or learning have been investigated and repeated by standing still on various sorts of platforms, such as an inflated rubber disk (G Wulf, Lewthwaite, Landers, & Töllner, 2009) or a mobility platform (Laufer, Rotem-Lehrer, Ronen, Khayutin, & Rozenberg, 2007) that involved the Balancing Master and Biodex Stability systems, or standing still on a stable surface while executing a supra-postural task (McNevin & Wulf, 2002), or riding a Pedalo (Totsika & Wulf, 2003). The results have shown that Balance performance or learning has been improved when the performer's attention was directed to an EF (on a platform, markers attached to it, disk) as compared to an IF (on their feet). Recently, Becker and Hung (2020) investigated the effect of an IF, EF, and HF on sample entropy during a balance task on a stability platform. In the subject of postural control, entropy is a prevalent analysis method. The average uncertainty or regularity of a movement over time is represented by entropy. Smaller entropy levels suggest more regularity, whereas higher ones indicate less predictability (Becker & Hung, 2020). A quite high level of entropy (but not excessively) is characterized as a more adaptable posture which also implies more automatic movement during balance tasks (Isableu, Hlavackova, Diot, & Vuillerme, 2017; Roerdink, Hlavackova, & Vuillerme, 2011). In addition, decreases in postural control entropy are linked to an increased risk of falling (J. Zhou, Habtemariam, Iloputaife, Lipsitz, & Manor, 2017). According to the findings by Becker and Hung (2020), adopting an EF led to higher sample entropy values than using an IF or HF and showed the benefit of an EF in a balance task. In that balance task, an HF (focusing on feeling calm and stable) had no performance advantage over an IF (Becker & Hung, 2020).

In addition to improving balance performance and learning, various studies have demonstrated the benefits of an EF in motor skills that require accuracy (Gabriele Wulf, 2013).

An EF has been shown to enhance accuracy in hitting golf balls, kicking balls, throwing balls, darts, and Frisbees (Al-Abood, Bennett, Hernandez, Ashford, & Davids, 2002; Lohse, Sherwood, & Healy, 2010; D. C. Marchant, Clough, & Crawshaw, 2007; Gabriele Wulf, Lauterbach, & Toole, 1999; Gabriele Wulf & Su, 2007; T. L. Zachry, 2005). For example, accuracy in throwing a ball in a basketball free-throw has been proven to improve when participants were directed to focus on either the basket or ball trajectory rather than on wrist flexion or movement form (Al-Abood et al., 2002; T. Zachry, Wulf, Mercer, & Bezodis, 2005). Another example of the influence of EF in enhancing accuracy occurred in football kicking. It was demonstrated an enhanced accuracy in striking the target when participants' attention was focused on the area of the ball that they would strike (EF) compared to the part of the foot that would make contact with the ball (IF) (T. L. Zachry, 2005). After presenting HF of attention as an alternative to an EF (Becker et al., 2019), S. Shin and Kwon (2020) analyzed how an HF had impacted the performance accuracy of skilled golfers when compared to EF and no focus conditions (control group). Surprisingly, the control group yielded the most accurate results. Furthermore, the HF group showed close results to the control group (S. Shin & Kwon, 2020). They expressed that It was not possible to confirm the impact of EF and concluded the unnecessary of an EF for expert golfers (S. Shin & Kwon, 2020). In this line of study, Abedanzadeh et al. (2022) recently examined the effect of various types of attentional focus on badminton short-serve learning utilizing an accuracy-demand task among novice participants. The focus conditions included IF (Focus on the movement of the arm during the service), EF (Focus on the movement of the racquet during the service), HF (focus on feeling smooth and fluid when completing the serve), and control condition (no focus cue) (Abedanzadeh et al., 2022). An overall accuracy improvement was observed among the four groups. HF group served more accurately than IF and control groups through acquisition. Both HF and EF groups had more accurate serving than the control group in retention, while HF group served more accurately than IF and control groups in transfer. The outcomes of the study demonstrated that learning an accuracy-based task could benefit from both HF and EF (Abedanzadeh et al., 2022).

Direct measures such as muscular (electromyographic or EMG) activity, oxygen consumption, and heart rate, as well as indirect measures such as maximum force production, movement speed, or endurance, were used in a variety of studies to investigate the effect of attentional focus on movement efficiency. Movement efficiency is defined as a decrease in muscular activities while the same amount of work is done (Gurney, Mermier, Robergs, Gibson, & Rivero, 2001). To investigate this line of study, bicep curl exercises have been utilized in certain research to assess muscle activation under varied attention conditions. In a study, Vance, Wulf, Töllner, McNevin, and Mercer (2004) found that directing participants to focus on the weight bar (EF) rather than their arms (IF) resulted in lower integrated EMG activity in both agonist (biceps brachii) and antagonist (triceps brachii) muscles. Another research to support the previous study by adding a control condition expressed an equal level of EMG activity for IF and control conditions while muscle activity was lower in the EF condition (D. Marchant, Greig, & Scott, 2008).

In line with the previous study, Lohse et al. (2010) brought up that EF decreases EMG activities while increasing performance accuracy. According to the results of this study, an external focus on the flight of the dart enhanced throwing accuracy while simultaneously reducing EMG activity in the triceps muscle (Lohse et al., 2010). Another research that used a target-oriented task, free-throw shooting in basketball, yielded similar findings (T. Zachry et al., 2005). The results revealed that not only accuracy has increased but also EMG activity decreased in both the biceps and triceps brachii when participants were led to an EF (focus on the basketball hoop) rather than an IF (focus on the wrist flexion of their throwing arm)(T. Zachry et al., 2005).

Another research by Lohse, Sherwood, and Healy (2011) expressed that EF decreased co-contraction between agonist and antagonist muscle units in an isometric force production task. In comparison to the group with an EF instruction (focus on the force plate), the group with an IF instruction (focus on their calf muscles) produced less accurate force output and greater co-contraction across muscles, demonstrating less efficient muscle coordination. Marchant et al. (D. C. Marchant, Greig, & Scott, 2009) have found comparable findings using an isokinetic force production task. They also measured EMG activity in a control condition, which was shown to be at the same high level as the IF condition. With an EF of attention, decreasing co-contraction between muscle groups has been suggested as a rationale for higher jump height (Gabriele Wulf & Dufek, 2009), increased long jump lengths (Ong, Bowcock, & Hodges, 2010), and quicker running and swimming performances (Freudenheim, Wulf, Madureira, Pasetto, & Corrĕa, 2010; Ille, Selin, Do, & Thon, 2013).

The influence of various types of focus of attention on the performance of a standing long jump was examined from another perspective (Becker et al., 2019). Becker et al. (2019) compared standing long jump performance under four conditions: IF (focus to extend your knees as quickly as possible), EF (focus to jump as close as possible to the orange cone that was placed four meters far from the starting line), HF (focus on making your movement feel explosive), and baseline trials (no focus). According to the findings, the EF and HF groups both had better performance and performed a longer jump than an IF and the baseline condition, and there was no remarkable difference between EF and HF (Becker et al., 2019).

The focus of attention and injury prevention during landing

Besides improving performance, the attentional focus was investigated as a tool to prevent injuries. Recent research has shown that EF had a positive effect on landing biomechanics components which are known as ACL injury risk factors (Benjaminse, Welling, Otten, &

Gokeler, 2018; Gokeler et al., 2015; Welling, Benjaminse, Gokeler, & Otten, 2016, 2017). An ACL injury risk can be reduced by increasing knee flexion during landing (Hughes, 2014) and researchers have observed this increased knee flexion by utilizing an EF (Makaruk, Porter, Czaplicki, Sadowski, & Sacewicz, 2012; Welling et al., 2016). With a greater knee flexion range of motion (ROM) in the EF group, it was observed that participants had used more muscular activity to expand forces over multiple joints which causes a positive influence on the knee loading rate during landing (Benjaminse et al., 2018). Also, the IF group with less knee flexion ROM compared to the EF group had shown a stiffer landing performance which increases the risk of ACL injuries occurrence (Gokeler et al., 2015).

Welling et al. (2017) found that the EF group improved their landing technique during training sessions and some of those improvements were sustained after one week. These improvements in landing techniques can prevent ACL injuries (Welling et al., 2017). They reported that from the pretest to retention, the knee flexion angle increased, which indicated a softer landing movement. In addition, a strong positive correlation was discovered between knee valgus moment and VGRF, showing that using EF instructions resulted in a decreased knee valgus moment and a smaller VGRF in the training session (Welling et al., 2017). Furthermore, in both training sessions and post-test, there were strong negative correlations between knee flexion angle and VGRF, demonstrating that a larger flexion angle was associated with smaller VGRF, confirmed improving landing strategy following applying EF instructions (Welling et al., 2017). In this line, Widenhoefer, Miller, Weigand, Watkins, and Almonroeder (2019) investigated the effect of EF and IF instruction on impact forces during landing among rugby players. Surprisingly, rugby players in both groups with EF and IF instructions showed a significant reduction in peak VGRF in the retention condition compared to the baseline condition (Widenhoefer et al., 2019).

Harry, Lanier, Nunley, and Blinch (2019) examined whether EF can produce variations in time-dependent variables that are more closely linked to landing performance, like as energy absorption in the lower limb joints. They observed no difference in the peak VGRF along with loading rate and loading time between EF and IF conditions for males and females (Harry et al., 2019). The result of this study contradicted previous studies which showed a larger peak VGRF among males after adopting an IF and a smaller peak VGRF among females after adopting an EF (Welling et al., 2017) and lesser peak VGRF with an EF instruction against IF in total during landing (Widenhoefer et al., 2019). They also reported increased knee contributions to total angular work that occurred during EF compared to IF landings in both genders which demonstrated increased knee joint contributions to lower limb energy absorption for males and females with adopting an EF during landing (Harry et al., 2019). Furthermore, males showed smaller plantarflexion angles and larger knee flexion angles at initial contact when using an EF, whereas females had smaller knee flexion angles while using an EF compared to IF (Harry et al., 2019).

Advising athletes to land softly can be considered an instruction for a safe landing (Laughlin et al., 2011). The performance result of participants who were instructed to land softly had shown a lower peak ACL force and greater hip and knee flexion at initial contact, as well as a longer time to reach peak ACL force (Laughlin et al., 2011). Landing softly and smoothly can be considered an HF of attention which refers to concentrating on general feelings or sensations connected with completing a movement (Abedanzadeh et al., 2022; Becker et al., 2019). To the best of our knowledge, no study has applied an HF during a landing task and the effect of an HF on biomechanical factors related to injuries during landing was not being explored.

Aims

General aim:

The main purpose of this study was to determine how various types of focus of attention (IF, EF, HF) impact lower limb biomechanics during single-leg drop landing.

Specific aims:

I. To investigate the effects of various types of attentional focus on ankle angles in the sagittal plane during single-leg drop landing.

II. To investigate the effects of various types of attentional focus on ankle angles in the horizontal plane during single-leg drop landing.

III. To investigate the effects of various types of attentional focus on ankle angles in the frontal plane during single-leg drop landing.

IV. To investigate the effect of various types of attentional focus on the knee angles in the sagittal plane during single-leg drop landing.

V. To investigate the effect of various types of attentional focus on the knee angles in the frontal plane during single-leg drop landing.

VI. To investigate the effect of various types of attentional focus on the knee angles in the horizontal plane during single-leg drop landing.

VII. To investigate the effect of various types of attentional focus on the knee joint angular velocities in the sagittal plane during single-leg drop landing.

VIII. To investigate the effect of various types of attentional focus on the knee joint angular velocities in the frontal plane during single-leg drop landing.

IX. To investigate the effect of various types of attentional focus on the knee joint angular velocities in the horizontal plane during single-leg drop landing.

X. To investigate the effect of various types of attentional focus on the peak vertical ground reaction force during single-leg drop landing

XI. To investigate the effect of various types of attentional focus on the peak anteroposterior ground reaction force during single-leg drop landing.

Research Hypothesis

According to the background covered throughout the introduction, in sporting activities, non-contact injuries like ACL and LAS are common during landing (Dragoo et al., 2012; Gianotti et al., 2009). Identifying the biomechanical factors that contribute to these injuries can assist trainers and athletes in determining the appropriate instructions and techniques to reduce these risk factors and ensure a safe landing. One of the aspects that have been investigated over the past several years was the focus of attention of a performer induced by the instructor or trainer.

Previous studies have reported the advantages of utilizing an EF over an IF or an unbiased attentional focus (control condition) for reducing non-contact injuries during landing which can be suggested as a safe landing technique (Benjaminse et al., 2018; Gokeler et al., 2015; Makaruk et al., 2012). Since an HF was proposed as an alternative to EF to improve performance and its results revealed similar to that of EF (Becker et al., 2019) and on the other hand the benefits of an EF to reduce risk factors to prevent injuries are known, it's possible that using an HF during landing will provide benefits in terms of injury prevention. To our knowledge, no study has used an HF to look at biomechanical factors changes during landing. It's also unknown how an HF affects biomechanical factors linked to landing injuries. No study compared HF to EF and IF to determine the relevance of HF as a new approach for injury prevention. No study investigates the effect of IF, EF, HF, and no focus instructions on landing biomechanics.

We acknowledge that various landing tasks show variable biomechanical responses and no one task is ideal for analyzing a large range of biomechanical factors associated with lower limb injuries such as ACL and LAS. However, based on what was mentioned in the introduction and other research findings, a single-leg drop-landing task seems to be a high-risk task that could represent the risk factors of non-contact lower limb injuries in biomechanical investigations.

Hypotheses:

We hypothesize that:

I. Ankle dorsiflexion angle increases in the sagittal plane in the EF and HF conditions during single-leg drop landing.

II. Ankle adduction angle decreases in the horizontal plane in the EF and HF conditions during single-leg drop landing.

III. Ankle inversion angle decrease in the frontal plane in the EF and HF conditions during single-leg drop landing.

IV. The knee flexion angle increases in the sagittal plane in the EF and HF conditions during single-leg drop landing.

V. The knee abduction angle decrease in the frontal plane in the EF and HF conditions during single-leg drop landing.

VI. The knee internal rotation angle decrease in the horizontal plane in the EF and HF conditions during single-leg drop landing.

VII. In the EF and HF conditions the knee joint angular velocity in the sagittal plane increase during single-leg drop landing.

VIII. In the EF and HF conditions, the knee joint angular velocity in the frontal plane decreases during single-leg drop landing.

IX. In the EF and HF conditions, the knee joint angular velocity in the horizontal plane decreases during single-leg drop landing.

X. Peak vertical ground reaction force is smaller in EF and HF conditions compared to IF and CON.

XI. Peak Anteroposterior ground reaction force is smaller in EF and HF conditions compared to IF and CON.

Methods

Study Design

A cross-over study design was adopted. Dependent variables were 3-dimensional lower limb kinematics (knee and ankle angles and knee angular velocities), kinetics (Peak Vertical and Anteroposterior ground reaction forces), and independent variables were different types of focus of attention conditions.

Participants

Our sample consisted of 21 (13 female, 8 male) healthy active collegiate students of the faculty of physical culture at the Palacky university between the age of 20 and 27 years old who voluntarily participated in this study (Table 1). The inclusion criteria included: a) no history of severe ankle sprain, and b) no history of muscle or ligament rupture or surgery, joint laxation, and bone fracture within the previous 12 months of the measurement (Gribble et al., 2016; Gribble et al., 2013). Participants reported no current lower-limbs pain at the time of measurements. The entire measurement protocol aims and measurement-related risks of injury were comprehensively explained to individuals. The procedures followed were in accordance with ethical standards for human experimentation in compliance with the 1964 Helsinki Declaration. The thesis was part of the project "Assessment of dynamic balance in various conditions", which was approved by the Ethical Committee of the Faculty of Physical Culture Palacky University Olomouc with the ethic code of 78/2018 (Appendix 1). All participants signed a written informed consent form.

Table 1. Characteristics of participants (n=21).

Age	24.44±2.37
Weight	67.70±14.11
Height	170.35±10.51
BMI	23.16±3.06

Task and Setting

The task adopted for this research was a single-leg drop landing executed at the faculty of physical culture's biomechanics laboratory. This task entails landing participants by their dominant leg on a force plate positioned on the ground from a 30-cm high box that was 5 cm behind the force platform. The Kistler force platform (1000Hz, Kistler, 9290AD, Winterthur, Switzerland) was used for this measurement, and six Vicon® VCAM motion capture cameras (Oxford Metrics, Oxford, UK) synchronously recorded the marker trajectory of lower extremities markers with the sampling rate of 200fps (figure 1). All of the settings were calibrated before testing.

Instrument and Procedure

After a 10-minute dynamic warm-up, and before starting the test, All of the participants were asked to kick a ball to identify which leg was their dominant leg (Fu et al., 2017). The dominant leg was the one they chose to kick with (Pappas & Carpes, 2012). Right after, anthropometric measures of all subjects were taken and followed by the attaching of sixteen 14mm-diameter passive reflective markers to the anatomical landmarks by an expert researcher based on Plug-In-Gait lower body marker placement settings (placed on bony landmarks of anterior superior iliac, posterior superior iliac, thighs, knees, tibias, ankles, toes and heels of both legs) (Sarvestan, Ataabadi, Svoboda, Kovačikova, & Needle, 2020; Sarvestan & Svoboda, 2019). Prior to the landing test subjects were needed to undertake a static standing trial in order to identify the segment coordinate system of the lower limb in a global coordinate system (Nigg, 2007).

Thereafter, Participants were told that they would complete a total of twelve single-leg drop-landing tasks and received general instructions about the drop-landing task and practiced the task to get familiar with it and noticed that is different than jump-landing. For performing the single-legged drop-landing test, participants stood on top of the 30cm box, bent their elbows on their chests, and hanged the landing leg in a non-weight bearing position for 3 seconds (figure 1). The examiner then cued participants to step off and land on the test leg, and keep the body balanced for 20 seconds. All participants first completed three baseline trials with no attentional focus instructions (control condition). Following baseline trials, the three experimental conditions (i.e., external, internal, holistic) were presented in a counterbalanced order. Each experimental condition consisted of three trials during which the participant was asked to focus all of their attention on a prescribed focus cue while landing. The external focus cue was “focus on the area that you land on (the force plate)”, the internal focus cue was “focus on bending your knee when you land”, and the holistic cue was to “focus on making your movement feel soft and smooth”. Each time the participant prepared to land the primary investigator repeated the focus cue to be used. In order to prevent fatigue caused by testing, intervals of 1-minute rest were placed between each trial. The tests were repeated in case the participants were not able to maintain the stance position for 20 seconds during the test.

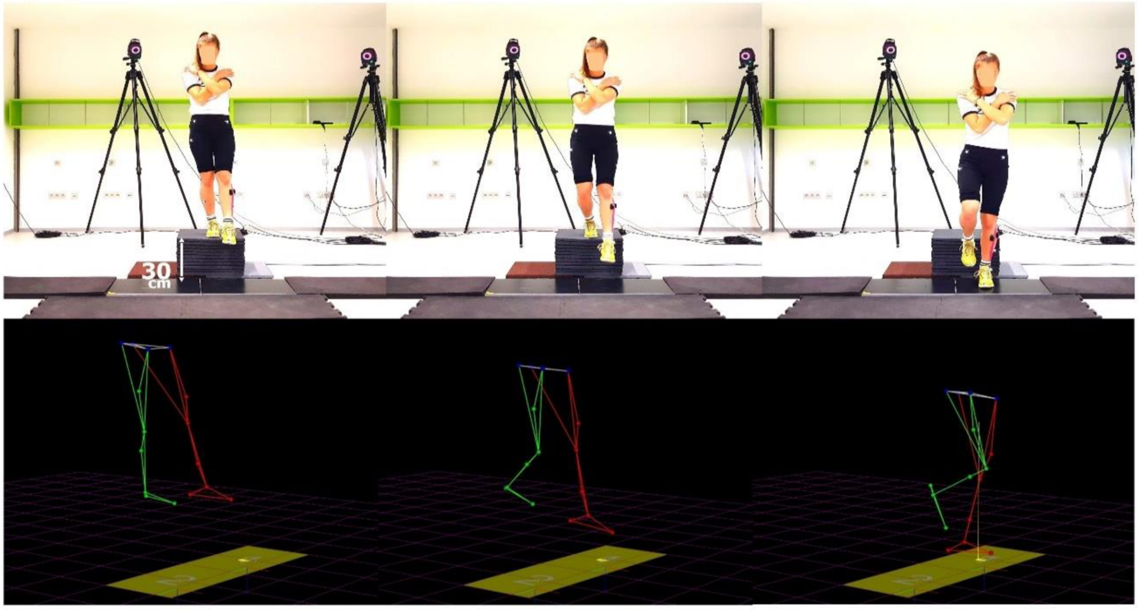


Figure 1. The manner of performing single-legged drop-landing, and schematic view of markers trajectory of lower limbs (Sarvestan, Needle, et al., 2020).

Data Analysis

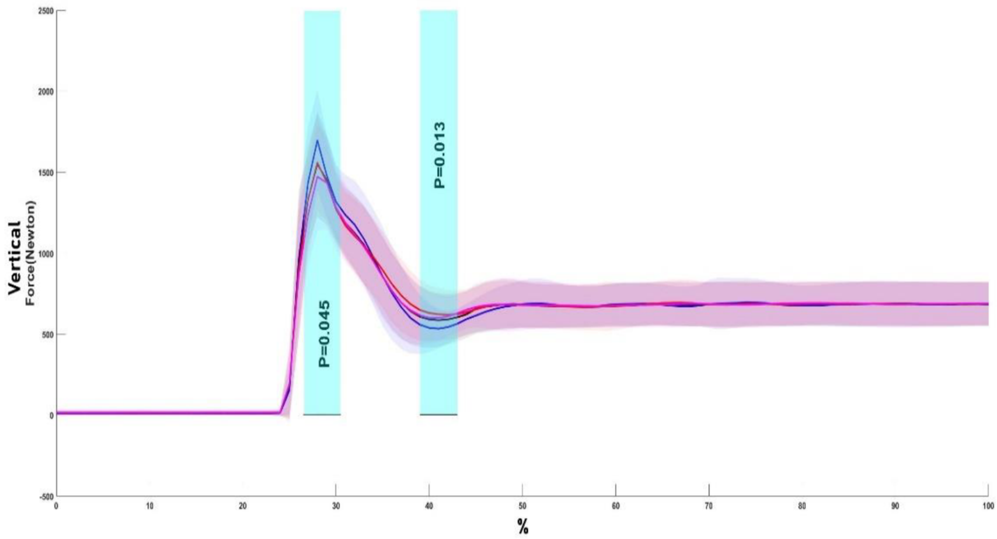
In this study, we defined the landing phase as the time between 0.5 second before the initial contact to 1.5 seconds after it. The maximum resultant GRF measures in vertical and anteroposterior directions were exported for further statistical analysis. Employing 3-dimension kinematic data of a static trial (the reference frame), the spatiotemporal position of pelvis, thigh, shank, and foot segments were identified, reconstructed, labeled, and gap-filled using the Vicon® Nexus software (Version 1.8.6, Oxford Metrics, Oxford, UK). Nevertheless, we only focused on the foot-shank-thigh coordinate to export the ankle and knee angles. A 4^{th} order Butterworth filter (zero-lag) with a cut-off frequency of 10 Hz was applied to smooth the data for the output model. The global reference frame was defined as: the positive Z-axis as vertical upward direction, the positive Y-axis as mediolateral direction, and the positive X-axis as anteroposterior direction (Sarvestan, Svoboda, & Linduška, 2020). The Cardan methods were also used to calculate the joints angles, in the following order: positive angle direction for the ankle dorsiflexion/inversion, and knee flexion order between foot-shank and shank-thigh segments (Kainz et al., 2017; Sarvestan, Svoboda, Baeyens, & Serrien, 2020; Wu et al., 2005). The angular velocity values for the knee joint were calculated as the first derivative of the joint angle-time series (Fuchs et al., 2019; Sarvestan, Svoboda, & Linduška, 2020). The entire data processing was conducted in a blinded manner by investigators.

Statistical Analysis

Prior to data analysis, the Shapiro-Wilk normality test was employed to check the data distribution normality of the kinematic data ($p>0.05$). One-Way repeated measure ANOVA (SPM1d-ANOVA1RM) statistical test was used to compare the vertical and anteroposterior ground reaction forces, ankle and knee angles, and knee angular velocities during single-leg landing performance under 4 different conditions: EF – external focus, IF – internal focus, HF – holistic focus, and CON – control conditions ($\alpha<0.05$). Where the inter-condition differences were highlighted, we used a paired-sample t-test (in time-series analysis) with the Bonferroni post-hoc correction to compare the condition-by-condition differences ($p=0.05/4=0.0125$). For the entire analysis, we used the spm1d package (v0.4.3) (www.spm1d.org). The Partial Eta Square (η_p^2) values were calculated to interpret the effect sizes. The $.01 \leq \eta_p^2 < .06$ was considered as a small effect size, while the $\eta_p^2 \geq .06$ and $\geq .14$ were considered as moderate and large effect sizes, respectively (Sink & Mvududu, 2010). The entire data and statistical analyses were conducted using MATLAB (v. 2021b, MathWorks, Inc., Natick, MA, USA).

Results

The Shapiro-Wilk test confirmed the normality of data distribution ($p>0.05$). Figure 2 portrays the vertical and anteroposterior forces in different landing conditions. As the SPM1d-ANOVA1RM depicts, there was a significant effect of the landing conditions at peak applied vertical forces ($p=0.045$, $F=5.39$, $\eta_p^2 \geq 0.14$), where the participants produced considerably greater vertical force in the CON condition. The post-hoc test revealed a significant difference between the CON and HF conditions ($p=0.003$, $F=7.15$, $d>0.8$). No significant difference was observed between the CON condition and IF and EF. The second significant difference was observed from the 38% to the 43% of the performance ($p=0.013$, $F=6.46$, $d>0.8$), where the participants started to maintain balance. Nevertheless, the post-hoc test portrayed no significant difference between every 2 conditions. As for the anteroposterior force, the SPM1d-ANOVA1RM was failed to detect a significant effect of the landing conditions.



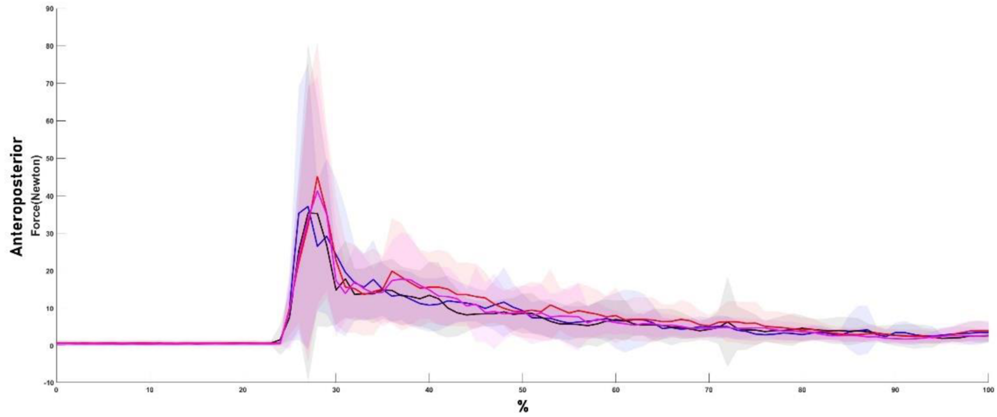


Figure 2. Vertical and anteroposterior ground reaction forces and their differences in different landing conditions. Blue, black, red, and magenta lines represent the CON condition, EF condition, IF condition, and HF condition, respectively. The cyan boxes highlight the significant effects of the landing conditions.

The ankle movements in the sagittal, horizontal, and frontal planes are presented in figure 3. No significant effect was observed in the ankle dorsiflexion angles in the sagittal plane between all conditions. In the horizontal plane, significant effects were observed after the start of the balance-maintenance phase, approximately from the 42% to 47% ($p=0.047$, $F=4.11$, $\eta_p^2>0.06$), and from the 72% to 87% ($p=0.034$, $F=4.85$, $\eta_p^2>0.14$) of the performance, where the ankle joint faced more adduction in IF condition. Nevertheless, the post-hoc test portrayed no significant difference between every 2 conditions. Similarly in the frontal plane, participants exhibited greater ankle inversion angles during the CON condition, compared to the rest of the conditions, from the 42% to 51% ($p=0.043$, $F=4.54$, $d>0.8$) and 63% to 98% ($p=0.011$, $F=7.28$, $d>0.8$) of the performance. The post-hoc test was failed to show a significant difference between every 2 conditions.

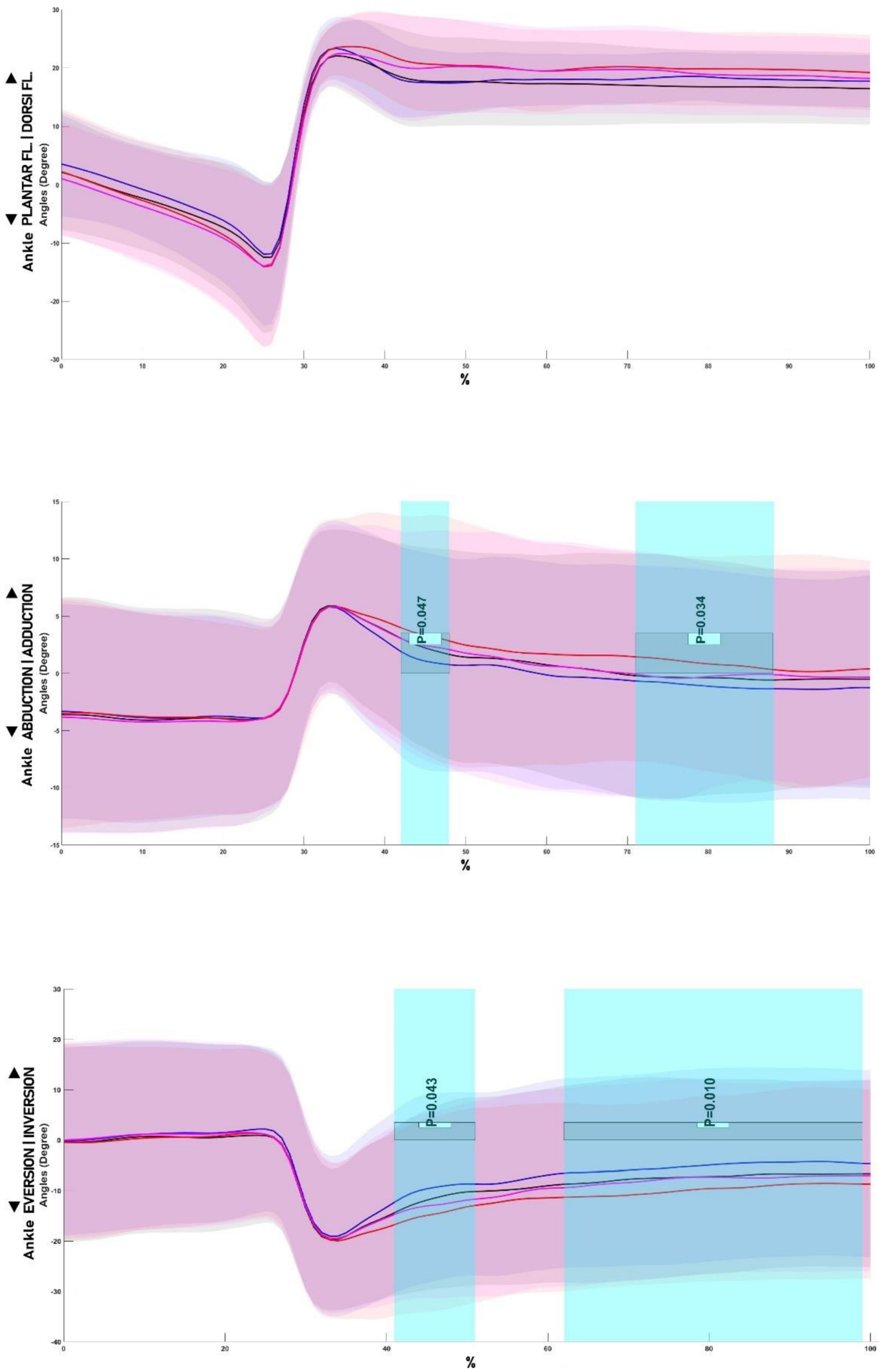
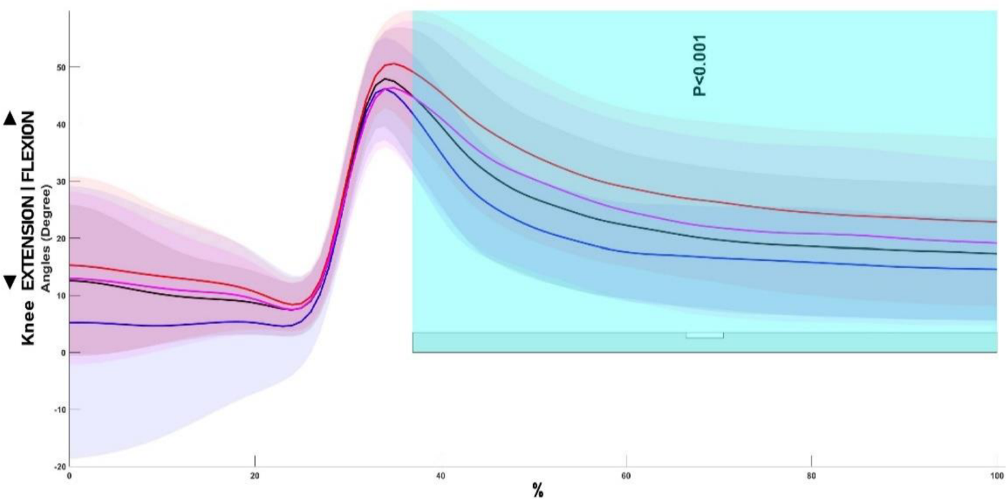
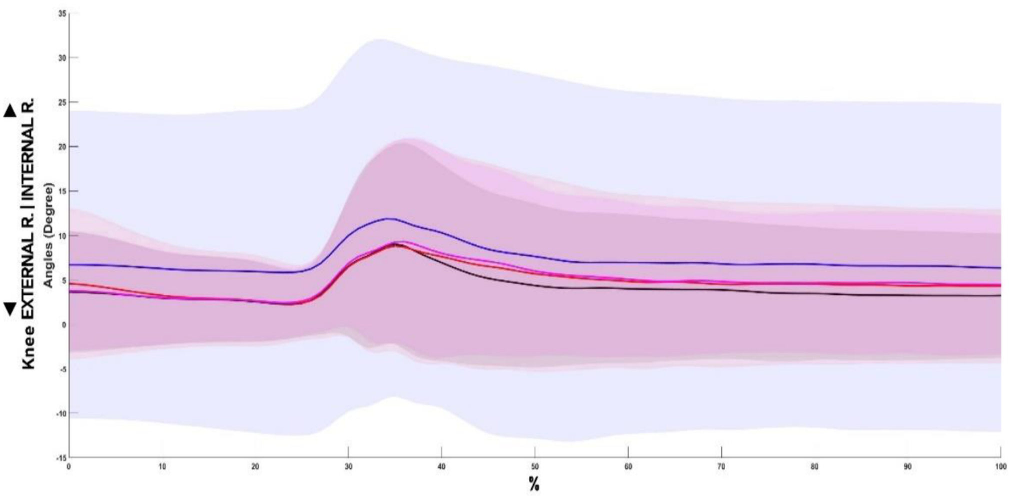


Figure 3. 3D ankle movement and their differences in different landing conditions. Blue, black, red, and magenta lines represent the CON condition, EF condition, IF condition, and HF condition, respectively. The cyan boxes highlight the significant effects of the landing conditions.

In the knee joint movements, participants produced significantly greater knee flexion angles in the IF condition ($p<0.001$, $F=8.72$, $\eta_p^2>0.14$) almost from the start of the balance-maintenance phase to the end of the performance (figure 4). The post-hoc test revealed a significant difference between the IF and CON condition ($p<0.001$, $F=8.72$, $d>0.8$), where the participants exhibited greater knee flexion angles in the IF condition. No significant effect of the landing conditions was observed in the knee angles in the horizontal and frontal planes.





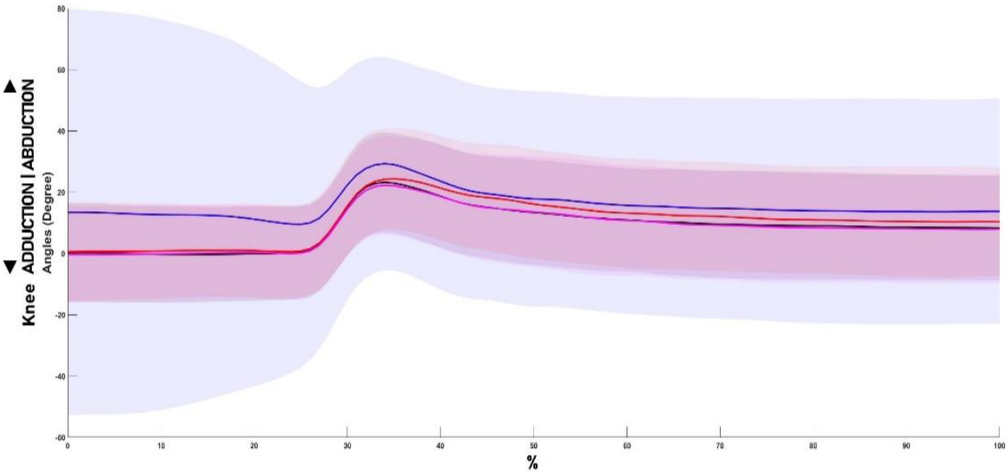
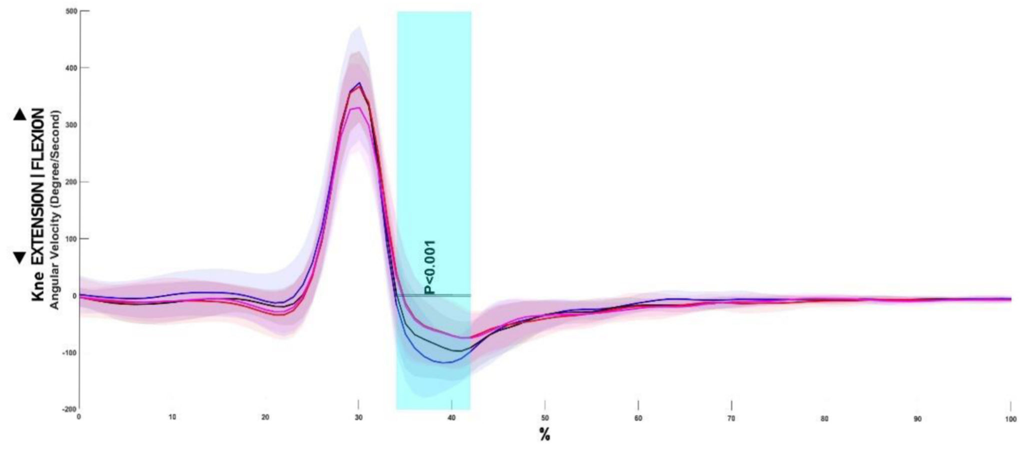
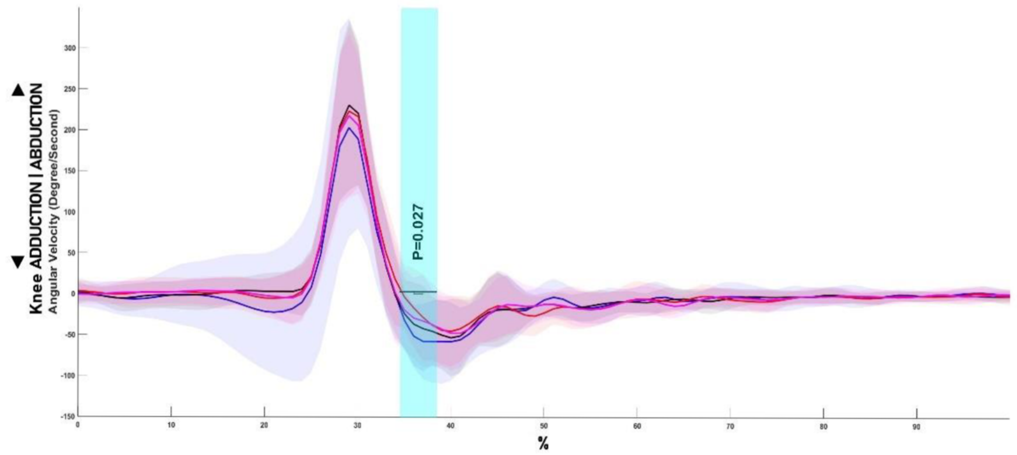


Figure 4. 3D knee movement and their differences in different landing conditions. Blue, black, red, and magenta lines represent the CON condition, EF condition, IF condition, and HF condition, respectively. The cyan boxes highlight the significant effects of the landing conditions.

From the angular velocity point of view, Figure 5 shows the knee joint angular velocities in the sagittal, frontal and horizontal planes. In the CON condition, the participants extended their knees with greater velocities after they reached the peak knee flexions ($p<0.001$, $F=9.18$, $\eta_p^2>0.14$). A similar situation happened in the knee frontal plane, where the participants produced greater knee adduction angular velocities ($p=0.027$, $F=6.64$, $\eta_p^2>0.14$) in the CON condition. However, the post-hoc test highlighted no significant difference between every 2 conditions. In the knee horizontal plane movements, no significant effect of the landing conditions was observed.





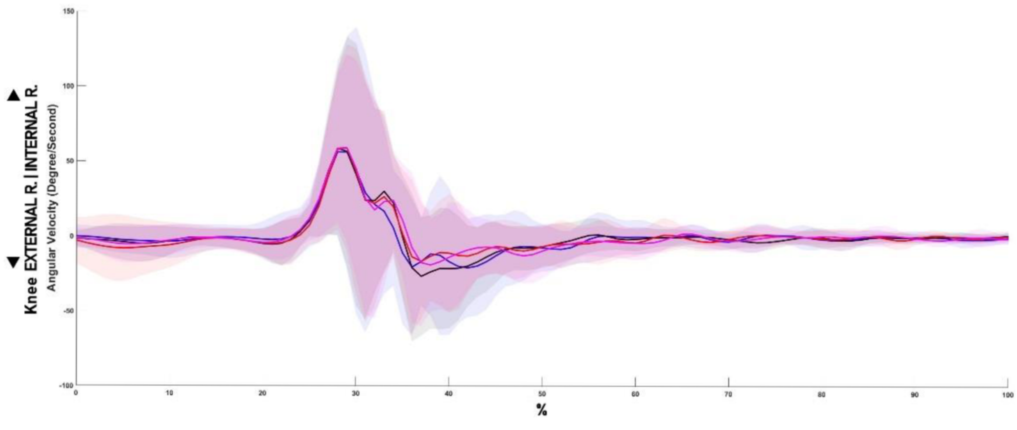


Figure 5. 3D knee joint angular velocities and their differences in different landing conditions. Blue, black, red, and magenta lines represent the CON condition, EF condition, IF condition, and HF condition, respectively. The cyan boxes highlight the significant effects of the landing conditions.

Discussion

The effects of focus of attention have been frequently investigated in a variety of motor skills, such as balance skills (Rhea, Diekfuss, Fairbrother, & Raisbeck, 2019), and accuracy skills (Yamada, Kuznetsov, Diekfuss, & Raisbeck, 2021), as well as movements kinematics (Gokeler et al., 2015). The advantages of an EF over IF in both beginners and experienced individuals have been established (Gabriele Wulf & Su, 2007), although not always. According to some research, no difference was observed between EF, IF and CON conditions, for example when expert acrobats did a simple balance task (Gabriele Wulf, 2008) or trained athletes completed a 10-meter sprint (Winkelman, Clark, & Ryan, 2017). In some other instances, EF and IF led to weaker performance in a sprint task than in the CON condition (Porter & Sims, 2013). Moreover, based on the constrained action hypothesis, EF avoids conscious control of movement and led to an automatic mode of control by utilizing the unconscious (Gabriele Wulf et al., 2001). According to related studies, an HF might be another effective method for avoiding conscious control of movement (Becker et al., 2019). In addition, some research pointed out the benefits of using an EF over an IF in landing techniques that can prevent the incidence of injuries (Welling et al., 2017). Therefore, this present research aimed to investigate how three types of focus of attention (EF, IF, and HF) affect landing biomechanics of the lower limb during a single-leg drop landing task.

First of all, regarding our first, second, and third hypothesis our result didn’t demonstrate any significant effect of the landing conditions in ankle angles at the initial contact phase of landing in the three planes, and based on our result, it seems that using the focus of attention instructions doesn't affect ankle movements at the initial contact of a single-leg drop landing. This result is in line with Haines, Murray, Glaviano, Gokeler, and Norte (2020) that reported no difference in ankle ROMs in the sagittal and frontal planes after utilizing an EF and IF during jump-landing tasks.

Our first hypothesis was rejected. We hypothesized that ankle dorsiflexion angle increases in the sagittal plane during single-leg drop landing after adopting an EF and HF. Our outcomes didn't show any difference for the ankle dorsiflexion angle in the initial contact as well as the balance maintenance phase after landing which means the ankle dorsiflexion angle didn't differ between the four conditions which are in line with Harry et al. (2019) study that reported no difference in ankle angles in the sagittal plane between EF and IF condition regardless of sex. To our knowledge, no study investigated the effect of three types of focus of attention on ankle angles in the sagittal plane, as well as frontal and horizontal planes, and the majority of the related study only investigated the effect of EF and IF on the knee and hip movements. In addition, the number of studies that investigate the impact of EF and IF on ankle movements is a few and most of them only focus on the sagittal plane and reported plantar and dorsiflexion of the ankle (e.g., Harry et al. (2019)). Therefore, it is quite challenging to compare our outcomes with other studies. In the first hypothesis of the present study, we expected to find an increase in ankle dorsiflexion angle in the EF and HF compared to the IF and CON condition. Therefore, our hypothesis was rejected since we didn't find any significant difference in the ankle dorsiflexion angle between different conditions.

Our second hypothesis was partially confirmed. We hypothesize that ankle adduction angle decreases in the horizontal plane in the EF and HF conditions during single-leg drop landing which means we also expected to see the opposite result in the IF and CON conditions. In the horizontal plane, at the start of the balance maintenance phase, we found a significant difference between IF and other conditions. This result shows that participants had greater ankle adduction with utilizing IF instruction to keep their balance after single-leg drop landing. In the horizontal plane during single-leg landing, after initial contact, rapid ankle adduction occurs in the foot, and the ankle joint exhibit ankle abduction to return the foot to its natural position to keep the body balance. In the IF condition, ankle adduction returned to its natural position slower than in other conditions which can result in greater foot adduction. Foot adduction (calcaneal supination) can result in ankle sprain injuries (J.-Z. Lin, Lin, Tai, & Chen, 2022) which means utilizing an IF instruction with greater ankle adduction might increase the risk of ankle sprains after a single-leg drop landing during the balance phase. Although, our findings didn't show any significant difference between every two conditions, based on our findings it seems that IF resulted in decreased participants' balance performance with a greater ankle adduction angle in the balance phase after single-leg drop landing which is consistent with other studies' outcomes expressed that using an IF had disadvantage in balance tasks over EF (Park, Yi, Shin, & Ryu, 2015). Moreover, in the balance maintenance phase, our findings showed close results for EF and HF conditions in horizontal plans (figure 3) which shows the advantage of using an EF and HF relative to an IF in the balance maintenance phase after a single-leg drop landing with a smaller ankle adduction angle. To our knowledge, no study compared these three types of focus of attention instruction during the balance phase after a single-leg drop landing phase. However, Becker and Hung (2020) reported the benefit of using an EF on sample entropy during a balance task on a stability platform over HF and IF, and they found no performance advantage of using an HF over an IF. We give the possibility of the difference in the tasks can make difference in results and suggest future research to investigate the effects of various types of focus of attention (EF, HF, and IF) during either balance tasks or keeping balance after a single-leg landing.

Our third hypothesis was partially confirmed. We hypothesize that ankle inversion angle decreases in the frontal plane in the EF and HF conditions during single-leg drop landing. In the frontal plane, participants in the CON condition performed the balance maintenance phase with a rapid transfer from peak ankle eversion to inversion compare to other conditions with the focus of attention instructions. However, the ankle didn't meet inversion which is known as a risk factor for LAS occurrence during neither the CON condition nor the other three conditions with the focus of attention instruction. Moreover, we didn't find a significant difference in ankle inversion angle between every two conditions. Hence, it seems that the focus of attention doesn't affect ankle movement angle during single-leg drop landing in the frontal plane. Haines et al. (2020) also reported no difference in ankle ROMs in the frontal plane after adopting an EF and IF during the jump-landing task. We are unaware of any studies which examine the effect of three types of focus of attention on ankle movement angle in the frontal plane during landing and are not able to compare our outcomes.

In general, the number of the study that investigates the effect of focus of attention on ankle angle kinematics during landing is a little and among them examining ankle kinematics in the sagittal plane was common relative to the other planes such as frontal and horizontal planes. The ankles exert inversion and plantar flexion, internal rotation, and foot adduction while doing dynamic tasks such as cutting, jumping, and landing movements, which can result in ankle sprains, ACL injuries, and other lower extremity-related injuries (Kim, Palmieri-Smith, & Kipp, 2021; Y. Li, Wang, & Simpson, 2020; Olsen et al., 2004; Stotz et al., 2021). Investigating ankle ROM and ankle movement in all planes makes a comprehensive understanding of ankle kinematics which won't happen by examining ankle angles only in the sagittal plane by observing ankle plantar/dorsiflexion. Therefore, exploring ankle angle kinematics in all of the three planes under the various focus of attention instructions is an important concern that can reveal whether that instruction prevents ankle injuries such as chronic ankle instability and LAS or can result in increasing the risk of these injuries. Based on a substantial correlation between ankle sprains history and knee injury history, some research suggested that ankle sprains may be linked to knee injuries (Kramer, Denegar, Buckley, & Hertel, 2007; Y. Li et al., 2020). Hence, understanding the role of focus of attention instruction in ankle kinematics seems to be important to prevent lower limb injuries.

Our fourth hypothesis was rejected. We hypothesized that the knee flexion angle increases in the sagittal plane in the EF and HF conditions during single-leg drop landing. In the sagittal plane, however, we observed a significant difference in the knee flexion angle in the IF condition almost from the start of the balance maintenance phase to the end of the performance. We observed that participants had a greater knee flexion angle after adopting an IF during single-leg drop landing. Increased knee flexion angles during landing potentially reduce forces on the ACL, and as result minimize the risk of ACL injury (Devita & Skelly, 1992; Hughes, 2014). A stiff landing with a more extended knee potentially produces greater VGRF compared to a soft landing with a more flexed knee (Devita & Skelly, 1992). Therefore, a soft landing is more beneficial than a stiff landing in terms of preventing injury (Devita & Skelly, 1992; McNitt-Gray, Hester, Mathiyakom, & Munkasy, 2001).

Our result is inconsistent with previous research. Previous studies reported the advantages of using an EF over IF during landing by observing greater knee flexion angle by adopting an EF instruction. For example, Benjaminse et al. (2018) observed an increase in the knee flexion angle during a simple jump-landing task by utilizing EF compare to IF and some other related studies reported the same findings (Gokeler et al., 2015; Welling et al., 2016). While a few studies didn't find any difference in the knee flexion angle during landing between EF and IF. For example, Haines et al. (2020) didn't observe any difference in the knee flexion angle between an EF and IF during a jump-landing task. The type of landing tasks and specific instructions provided may have impacted our findings. In the present study, participants performed a single-leg drop landing task and keep their balance after that while in the previous studies participants completed a different task (e.g., a jump-landing task (Benjaminse et al., 2018)). Difference tasks demand difference and specific focus of attention instructions. For example in the study by Welling et al. (2016), they asked participants to perform a drop vertical jump task and the main purpose of the performance was to jump as high as they can. Therefore, the specific focus of attention instructions they used was different than what we used in the present study as our task was a simple single-leg drop landing. Some studies' emphasis took place on a higher and longer jump after the landing performance and because of that their focus of attention instructions was aligned with this aim. For example, for the IF condition, Welling et al. (2016) instructed participants to focus on "extending their knees as rapidly as possible after the landing on the force plate" to perform a vertical jump, and in the present study, we instructed participants to focus on bending their knee while their land on the force plate and keep their balance after that. As we mentioned several times, knee flexion during landing is known as a biomechanical factor which can reduce the risk of non-contact ACL injury by reducing the proximal tibia anterior shear force (Hughes, 2014; Yu et al., 2006). Hence, based on our result, it seems that the instruction we used as an IF which was instructing participants to focus on bending their knee during their landing can increase the knee flexion angle during a single-leg drop landing task and can decrease the risk of ACL injury.

Furthermore, most ACL injury prevention programs instructed athletes with an IF and ask them to focus on conscious movement execution (Hewett, Ford, & Myer, 2006). Natural movement coordination is disrupted by conscious control of movements (IF) (Gabriele Wulf & Lewthwaite, 2016). In such tasks as landing, jumping, and cutting, instructing athletes to focus internally to improve their awareness and knee control necessitates attentional capacity (Holm et al., 2004). As a result, the athlete's potential to foresee, identify, adapt and respond to situations that arise on the field is reduced. Hereupon, some studies suggested utilizing an EF instead of an IF in the ACL injury prevention programs because a person's own movements are performed more automatically when utilizing an EF which necessitates less attentional demands (Benjaminse, Welling, Otten, & Gokeler, 2015; Gabriele Wulf, 2013). As a result, with a more attentional capacity, the athlete has a greater ability for anticipating and responding to the actions of opponents in a timely and effective manner (Gokeler, Benjaminse, Seil, Kerkhoffs, & Verhagen, 2018). Therefore, although our result demonstrated the advantage of using an IF in terms of increasing knee flexion angle and potentially reducing the risk of ACL injury during single-leg drop landing, we should notice that in our task, participants weren't asked to perform the landing in the sports field or a competition condition and they didn't need to divide their attentional capacity and focus on other situation which needs more focus capacity and usually occurs in the field and during the games. Hence, future studies need to consider that effect of focus of attention on landing biomechanics and preventing lower limb injuries might be different in the controlled laboratory environment and sports fields (Yamada, Higgins, & Raisbeck, 2022).

Our fifth and sixth hypotheses were rejected. No significant difference was found in the knee angles in the frontal and horizontal planes which means knee abduction angles and knee internal rotation angles didn't differ between the four conditions. These outcomes are inconsistent with some related research. For example, Haines et al. (2020) found that lesser knee valgus angles (knee abduction) at initial contact and peak knee valgus with adopting an EF compared to IF during a jump-landing task. Differences in the tasks, experimental design, and verbal focus of attention instructions might be the reason for different outcomes. Our result is in line with the previous research (Welling et al., 2016) which reported no difference in the knee valgus angle between IF and EF conditions during landing from a drop vertical jump task.

Our seventh hypothesis was rejected. We hypothesized that in the EF and HF conditions, the knee joint angular velocity in the sagittal plane increase during single-leg drop landing. We didn't find any significant difference in the knee joint angular velocities in the sagittal plane at the initial foot contact with the ground during landing under various conditions. The knee joint angular velocity in the sagittal plane at the initial contact is known as a biomechanical factor that influences the magnitude of peak ground reaction forces and ACL loading (Wang, Gu, Chen, & Chang, 2010; Yu et al., 2006). Based on the present study findings, it seems that focus of attention instruction doesn't affect the knee joint angular velocity in the sagittal plane at the initial contact during a single-leg drop landing.

Our eighth hypothesis was partially confirmed. We hypothesized that in the EF and HF conditions the knee joint angular velocity in the frontal plane decreases during single-leg drop landing. The results demonstrated that in the frontal plane, the knee angular velocity in the CON condition was greater than in other conditions with the focus of attention instructions. A greater knee angular velocity in the frontal plane which indicates the higher knee valgus and varus velocity was suggested as a reason for loss of control in the frontal plane and causes potential contributors to injuries (Jenkins, Williams III, Williams, Hefner, & Welch, 2017). It means participants without any focus of attention instruction (CON condition) are more exposed to loss of their balance and shows the benefit of using various types of focus of attention instructions compared to the CON condition.

Our ninth hypothesis was rejected since our outcomes didn't show any difference in the knee joint angular velocity in the horizontal plane between the four conditions during single-leg drop landing. We are unaware of any previous study that has investigated the effect of various types of focus of attention (EF, IF, HF) on the knee joint angular velocity in the sagittal, frontal and horizontal planes. Therefore, comparing our results is challenging. Hence, further research is essential to explore the effect of focus of attention instructions on the knee joint angular velocity during landing in all anatomy planes.

Our tenth hypothesis was partially confirmed. We hypothesized smaller peak VGRF in the EF and HF conditions compared to IF and CON. The result showed a remarkably greater VGRF in the CON condition compared to the three conditions with the focus of attention instructions. A greater VGRF might lead to greater forces in the knee and, as a result, a higher risk of ACL injury (Benjaminse et al., 2015). In addition, a significant difference was found between the CON and HF conditions that show when participants were instructed to focus on feelings of a smooth and soft landing, a smaller peak VGRF was produced. Therefore, we can express that adopting an HF instruction during single-leg drop landing might decrease peak VGRF and as result reduce the risk of ACL injury. To the best of our knowledge, no study investigated how an HF affects VGRF during landing and we cannot compare our outcomes with other studies. Hence, more research is required to examine the effect of HF on VGRF to confirm our findings.

Moreover, our result didn't show any significant difference between EF and CON which is not in line with some literature findings. For example, Welling et al. (2017) reported using EF instructions resulted in a smaller VGRF during landing in the training sessions compared to CON and IF. One of the reasons for the difference in our findings from the previous study could be the differences between our task, which was single-leg drop-landing, with their task, which was a jump-landing task. However, the difference in peak VGRF between EF condition and CON is observable in figure 2 which shows smaller VGRF with adopting an EF compared to CON, but it wasn't significant. In the present study, no significant difference in peak VGRF was found between EF and IF conditions during single-leg drop landing which is in line with study findings by Harry et al. (2019) that reported no significant difference in peak VGRF between EF and IF during countermovement vertical jump landings. They also mentioned that utilizing different landing tasks might be the cause for different study outcomes (Harry et al., 2019).

The results of the present study didn't reveal significant effects of the landing conditions in the peak anteroposterior ground reaction force during single-leg drop landing which rejects our eleventh hypothesis. The magnitude of anterior tibial shear force, which is a predictor of ACL injury, is influenced by ground reaction forces (e.g., vertical and anteroposterior ground reaction forces) (Sell et al., 2007; Yu et al., 2006). Based on our outcomes, the focus of attention instructions seems to not make a significant effect on the magnitude of peak anteroposterior ground reaction force during the single-leg drop landing task. This finding is not consistent with finding study by Dalvandpour, Zarei, Abdoli, Abbasi, and Mohamadian (2021) that point out posterior ground reaction force reduction by utilizing EF instructions in the Preventing injuries Enhance Performance (PEP) program. They observed that peak posterior ground reaction force decreased after 8 weeks of training sessions among the group which received EF instructions during the PEP injury prevention program (Dalvandpour et al., 2021). We investigated the immediate effects of various focus of attention instructions on peak anteroposterior ground reaction force during single-leg drop landing tasks whereas they explored the impacts of EF and IF instructions after 8 weeks (Dalvandpour et al., 2021). Therefore, we cannot compare our outcomes and we suggest that further research is essential to explore the immediate and long-term effect of focus of attention instruction on anteroposterior ground reaction force during landing. Moreover, most of the related research explored the effect of focus of attention instructions on only VGRF and not on anteroposterior ground reaction force (for example, Harry et al. (2019); (Welling et al., 2017)). Future research requires investigating the effects of focus of attention instruction on both of the ground reaction forces which are known as influencers in ACL injury occurrence.

Generally speaking, most related studies which investigated the effect of focus of attention on landing kinematics and lower limb injuries, focused on the knee ROMs and knee movement, some of them mentioned hip ROMs and only a few of them reported ankle joint ROMs and ankle movement. For example, Benjaminse et al. (2018) expressed that an EF not only can improve landing technique but also transfer those improved movement techniques. They examine the knee ROMs in the sagittal and frontal planes and hip ROMs in the sagittal plane to report technique improvement of a landing during a double-leg jump-landing task under various conditions. Although the knee flexion angle, knee valgus angle, and hip flexion angle are proper indicators of movement technique during landing, we suggest examining all of the lower limb joint ROMs and joints movements (hip, knee, ankle) in the three-dimension to obtain a comprehensive understanding of lower limb kinematics under the different focus of attention instruction condition.

Moreover, most of the studies didn't investigate the effect of focus of attention on landing biomechanics and techniques in the 3-dimension and only examine lower limb kinematics in the 2-dimension or used the Landing Error Scoring System (LESS) (for example, Welling et al. (2016); (Yamada & Raisbeck, 2020)). Using the LESS is a valid clinical method to assess movement quality (Padua et al., 2009), however, we suggest using direct measurement of lower extremity biomechanics in the 3-dimension besides using LESS to have comprehensive values of movement quality and examination of lower limb injury risk factors.

In the present study, we investigated the 3-dimensional assessment of the effect of three types of focus of attention (EF, IF, and HF) on the knee and ankle joint kinematics during a single-leg drop-landing and reported an extensive result regarding the knee and ankle kinematics. However, due to a lack of evidence in related research, we were not able to compare some of our results mostly in the findings related to the HF condition.

The present research was unique in terms of investigating the effect of an HF on landing biomechanics. To the best of our knowledge, no study explored the effect of an HF on landing kinematics and kinetics. The result of the present study demonstrated a significant difference in the peak VGRF after adopting an HF during a single-leg drop landing compare to the CON condition. Athletes are usually advised to land soft and smooth to prevent lower limb injuries such as ACL. Our result showed that when participants were instructed to focus on feelings of a smooth and soft landing, they produced smaller peak VGRF during a single-leg drop landing. Greater peak VGRF is associated with greater proximal tibia anterior shear force and an increased risk of non-contact ACL injury (Yu et al., 2006). Therefore, instructing athletes with an HF which is to focus on feelings of a smooth and soft landing can result in smaller VGRF and smaller proximal tibia anterior shear force and as a result, prevent non-contact ACL injury.

Limitations

The present study is not without limitations. Firstly, we didn't examine the effect of various types of focus of attention on hip kinematics which is considered an important component of lower limb biomechanics during landing. Small hip flexion angle is considered one of the risk factors for non-contact ACL injury during landing (C.-F. Lin et al., 2008). In addition, there is some study that reported the effect of EF on the increasing hip flexion angle during landing (Haines et al., 2020). Future studies need to add hip joint kinematics to explore the effect of various focus of attention on lower limb biomechanics during landing. The second limitation of the present study was including both female and male participants without making a comparison between the gender-specific responses. Some of the previous research showed that females and males made different responses to the focus of attention instructions and their results differed from each other (Benjaminse et al., 2015; Harry et al., 2019; Welling et al., 2016). Future studies need to consider this concern. The third limitation can be the duration of our examination in which we only examine the immediate effect of different focus of attention instructions on single-leg drop landing biomechanics. Future studies should explore the focus of attention instruction impacts for a longer period of time because the focus of attention usually affects both motor performance and motor learning (Gabriele Wulf, 2013).

Conclusion

The present study provided initial evidence of the effect of various types of focus of attention on the lower limb biomechanics during a single-leg drop landing. Generally speaking, most of the significant differences we observed in the knee and ankle angles under various condition was related to the balance-maintenance phase after a single-leg drop landing. It means that focus of attention instruction seems to influence the knee and ankle angles in the balance-maintenance phase rather than the initial foot contact with the ground during a single-leg drop landing. In addition, we found a significant difference between the knee flexion angle in the IF and CON condition which shows participants exhibited a greater knee flexion angle during a single-leg drop landing after adopting an IF.

Moreover, we found that instructing participants to focus on feelings of a smooth and soft landing (HF) decreased the peak VGRF and as result can reduce the risk of ACL injury. According to the previous research that suggested an HF might be another effective method for avoiding conscious control of movement like an EF, and with regard to our result which shows decreasing the peak VGRF during a single-leg drop landing after adopting an HF, we strongly suggest to future studies to investigate the effect of using an HF beside EF and IF instruction on the lower limb biomechanics during landing tasks as well as ACL injury prevention programs.

The concept of considering an HF as an alternative for EF is quite new and the number of studies that examined an HF in the different motor performance, movement techniques, and injury prevention is a few. Therefore, we cannot generalize the result of the current study. However, the present study provided initial evidence of how EF, IF, and HF influence lower limb kinematics and kinetics during a single-leg drop landing. Future research should investigate the effect of these various types of focus of attention on the hip, knee, and ankle biomechanics to determine the important role of these focus of attention in preventing lower limb injury occurrence. Moreover, Future studies should concentrate on incorporating HF instruction into prevention programs and tracking injuries to see whether there is a reduction in ACL injuries.

Summary

Lower limb injuries during landing from a jump are prevalent in team sports, and many of these injuries are caused by non-contact mechanisms that injure the ankle or knee ligaments, such as lateral ankle sprains (LAS) and anterior cruciate ligament (ACL) injuries. Instructing athletes by various types of focus of attention influence their motor performance and motor learning. The external focus of attention (EF- focus on the intended movement effect) has the most advantages over the internal focus of attention (IF-focus on the body movement) in terms of motor performance and learning, but not always. In addition, some studies suggested using the EF in the ACL prevention injuries programs because they found that adopting EF can minimize the biomechanical risk factors during a high-risk motion such as landing from a jump compared to IF. Moreover, due to the difficulty of focusing on the EF cues in some movements like dance and gymnastics performance, some research suggested utilizing another type of focus of attention called holistic focus (HF) that emphasizes the general feeling or sensations connected with completing a movement. The benefits of using an HF in motor performance and learning has confirmed by some studies while some research didn't find any advantages after adopting an HF. We were unaware of any previous study that has investigated the effect of using an HF in lower limb prevention injuries. Identifying the effect of various types of focus of attention on the lower limb biomechanics during landing clarifies whether the focus of attention instruction can help to minimize biomechanical risk factors during landing and as a result prevent injuries or not. Hence, the main aim of this study was to investigate the effect of various types of focus of attention (EF, IF, HF) on the knee and ankle kinematics and kinetics during a single-leg drop landing.

This study adopted a cross-over design. A total of 21 healthy active collegiate students of the faculty of physical culture completed three single-leg drop landing trails without any focus of attention instructions (control condition-CON), followed by three single-leg drop

landings in each focus of attention condition (EF, IF, HF) which were presented in a counterbalanced order. The knee and ankle three-dimensional Kinematics were captured using a 6-camera motion analysis system and a force platform was used for capturing kinetics in this measurement. In this study, the landing phase was defined as the time between 0.5 second before the initial contact to 1.5 seconds after it. One-Way repeated measure ANOVA statistical test was used to compare the vertical and anteroposterior ground reaction forces, ankle and knee angles, and knee angular velocities during single-leg landing performance under 4 different conditions: EF, IF, HF, and CON ($\alpha<0.05$). After highlighting the inter-condition differences, a paired-sample t-test (in time-series analysis) with the Bonferroni post-hoc correction was used to compare the condition-by-condition differences ($p=0.05/4=0.0125$).

The result of this study showed that the peak vertical ground reaction force significantly decreased after adopting an HF compared to CON ($p=0.003$, $F=7.15$, $d>0.8$). No significant effect of the landing conditions was observed in the peak anteroposterior ground reaction force. Ankle adduction angle was greater in the IF (from the 42% to 47%, $p=0.047$, $F=4.11$, $\eta_p^2>0.06$, and from the 72% to 87%, $p=0.034$, $F=4.85$, $\eta_p^2>0.14$) and ankle inversion angle was greater in the CON conditions (from the 42% to 51%, $p=0.043$, $F=4.54$, $d>0.8$, and from 63% to 98%, $p=0.011$, $F=7.28$, $d>0.8$) in the balance-maintenance phase after landing. The knee flexion angle was significantly greater in the IF condition compared to CON ($p<0.001$, $F=8.72$, $\eta_p^2>0.14$). The knee joint angular velocity in the sagittal and frontal planes was greater in the CON condition relative to other conditions with the focus of attention instructions ($p<0.001$, $F=9.18$, $\eta_p^2>0.14$, and $p=0.027$, $F=6.64$, $\eta_p^2>0.14$).

We suggested that an HF can be considered another beneficial type of focus of attention by decreasing peak vertical ground reaction force during single-leg drop landing and can result in lower limb injury prevention. However, this present study was the first study that investigated the influence of an HF on landing biomechanics and further studies are needed to explore it. Future studies should concentrate on incorporating HF instruction into prevention programs and tracking injuries to see whether there is a reduction in ACL injuries.

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Appendix 1

Fakulta
tělesné kultury

Vyjádření Etické komise FTK UP

Složení komise: doc. PhDr. Dana Štěrbová, Ph.D. – předsedkyně
Mgr. Ondřej Ješina, Ph.D.
doc. MUDr. Pavel Maňák, CSc.
Mgr. Filip Neuls, Ph.D.
Mgr. Michal Kudláček, Ph.D.
prof. Mgr. Erik Sigmund, Ph.D.
Mgr. Zdeněk Svoboda, Ph.D.

Na základě žádosti ze dne 14. 12. 2018 byl projekt výzkumné práce (základního výzkumu)

Autor /hlavní řešitel/: Mgr. Denisa Nohelová
Spoluřešitelé: Mgr. Zdeněk Svoboda, Ph.D., Mgr. Lucia Bizovská; Mgr. Lukáš Ondra

s názvem
Hodnocení dynamické rovnováhy v různých podmínkách

schválen Etickou komisí FTK UP pod jednacím číslem: **78/ 2018**
dne: **31. 12. 2018.**

Etická komise FTK UP zhodnotila předložený projekt a **neshledala žádné rozpory** s platnými zásadami, předpisy a mezinárodními směrnicemi pro výzkum zahrnující lidské účastníky.

Řešitelka projektu splnila podmínky nutné k získání souhlasu etické komise.

za EK FTK UP
doc. PhDr. Dana Štěrbová, Ph.D.
předsedkyně

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