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Knee joint biomechanics under external focus instructions promoting a quiet, safe and soft landing

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ABSTRACT

Background: Anterior cruciate ligament injuries are common in young female athletes, often occurring during landing tasks. Attentional focus instructions may influence landing biomechanics and reduce injury risk, but comparative effects of different external focus (EF) cues remain unclear.

Methods: Twelve novice female volleyball players (age: 13.6 ± 0.6 years) performed double-leg drop landings from a height of 50 cm under four attentional focus conditions: (1) as quietly as possible, (2) as safely as possible, (3) as softly as possible, and (4) a no-focus control. A Qualisys 3D motion capture system and a Kistler force platform were used to analyze knee joint kinematics and kinetics during initial contact and the first two VGRF peaks, and time-series analysis was conducted to characterize the biomechanical landing pattern across conditions.

Results: All EF conditions significantly reduced biomechanical knee joint loading compared with the no-focus condition. Although no significant differences were found among the three EF instructions, the 'soft' landing instruction produced the most pronounced changes, showing the lowest maximal VGRF, increased knee flexion angles, and reduced internal rotation angles, relative to the no-focus condition.

Conclusion: EF instructions, particularly those emphasizing a soft landing, can effectively reduce knee joint loading and potentially lower anterior cruciate ligament injury risk in young female athletes. These findings highlight the value of incorporating specific attentional focus cues into injury prevention and training programs.

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1. Introduction

Biomechanical forces during landing are reduced when attention is directed towards the intended motor effects, which induce an external focus (EF), as opposed to specific body movements, which promote an internal focus (IF) [1–4]. In sports

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such as volleyball or basketball, EF instructions often include cues that emphasize the desired outcome, such as “land softly” [2,3,5] or “land quietly” [6], guiding athletes towards a specific landing goal or effect. While the aim of these cues is to promote biomechanically safe landings, no studies have directly examined the effects of a more explicit safety-oriented cue, such as “focus on landing as safely as possible.” Although these different attentional focus instructions appear highly relevant for reducing knee joint loading and injury risk, it remains unclear which focus cue is the most effective.

Landing is a task where the goal is to reduce the force applied to the ground while achieving optimal joint positioning of the lower limbs to minimize injury risk. Recent studies have identified specific biomechanical variables associated with increased ACL biomechanical loading and injury risk during landings [7–10]. For instance, high vertical ground reaction force (VGRF) [7], low knee flexion [7], increased internal knee rotation and moments [8,9], and large knee abduction angles and moments [7,10] have been shown to significantly increase the risk of non-contact ACL injuries. From the perspective of non-contact ACL injury mechanisms, video analyses suggest that ACL injuries often occur immediately after initial ground contact, during the first peak of VGRF (FP1), which typically happens within the first 17–60 ms [10,11]. FP1 occurs at the first toe touchdown (usually between 10 and 14 ms after initial contact), likely during the phase of passive loading and latent muscle activation [12,13]. However, some studies have indicated that the second peak of VGRF (maximum) is equally critical in assessing non-contact ACL injury risk, as maximum ACL strain has been observed during this phase [7,14]. However, rather than relying solely on discrete data analysis of the early stages of landing – critical for preventing ACL injuries – a comprehensive time-series analysis of the entire landing performance may provide deeper insights into the overall joint loading throughout the landing phase [2].

In this regard, recent studies utilizing time-series analysis have demonstrated the efficacy of EF compared with IF instructions in promoting a soft landing, as evidenced by the observed reduction in biomechanical forces and acute lateral femorotibial cartilage loading in experienced female volleyball players when compared with conditions involving knee bending (IF) or a no-focus condition [2,3]. However, the wording of EF instructions (e.g., promoting a quiet, soft, or safe landing) may differentially influence motor control and landing performance [15]. During a safe landing, individuals may direct their focus of attention towards proper posture, alignment, and balance to avoid injury. A soft landing primarily requires attention to achieving a smooth, cushioned landing, which may direct the athlete's focus towards the quality of the landing and gentle contact with the ground. Finally, when the goal is to achieve a quiet landing, the primary focus shifts to sound reduction upon landing, as the athlete seeks to minimize noise rather than directly modulate impact force. Therefore, to find the optimal attentional instructions for reducing knee joint loading during landing, it is crucial to examine the impact of various EF instructions on landing biomechanics.

Importantly, because non-contact ACL injuries typically occur in unpredictable, non-conscious, real-game scenarios, it is essential to investigate the preventive effects of EF landing instructions in a controlled training context. Previous research suggests that motor behavior shaped by attentional focus during practice can transfer to automatic performance in game-like situations, potentially reducing the likelihood of high-risk knee movements associated with ACL injuries [1,16]. Consequently, the aim of the present study was to investigate the effects of landing-specific EF instructions (i.e., quiet, safe, and soft) on drop-landing biomechanics. Based on previous literature highlighting reduced biomechanical loading under EF instructions compared with no-focus instructions, we hypothesized that all variations of attentional focus instructions would positively influence biomechanical variables associated with ACL strain, thereby reducing knee loading, compared with no-focus instructions [2,17]. While all forms of EF were expected to reduce biomechanical loading of the knee joint compared with the no-focus condition, we further explored whether differences existed between the various EF conditions.

2. Materials & methods

2.1. Participants

Twelve adolescent female volleyball players from a single team (age: 13.6 ± 0.6 years, height: 170.1 ± 5.8 cm, body mass: 57.6 ± 6.1 kg, experience: 1.8 ± 0.8 years) were recruited for this study, similarly as in Slovák et al. [18]. An a priori power analysis with G*Power 3.1 indicated that 12 participants would be sufficient to identify significant differences between conditions in a within-participant design with a power ($1 - \beta$) of 0.85, a large effect size f of 0.4 ($\eta_p^2 = 0.14$) [2,19], the number of groups = 1, the number of measurements = 4, correlation among repeated measures = 0.5, nonsphericity correction $\epsilon = 1$, and an α level of 0.05 [20]. No history of musculoskeletal injuries (i.e., ligament, muscle, and tendon rupture, bone fracture, and joint dislocation) was reported by participants (legal guardian) within the last 12 months. Participants were unaware of the study's specific purpose, and their legal guardian signed the written informed consent before data collection. In addition, the verbal consent of participants was also obtained before the beginning of data collection. The ethical committee of the University of Ostrava approved this study (ethics code: 45/2021), which is in line with the 1964 Helsinki Declaration and its later amendments.

2.2. Experimental Set-Up

Landing kinematics were captured through a motion capture system with 10 cameras ($9 \times$ Oqus 700+ and $1 \times$ Oqus 510+, all from Qualisys, Inc., Gothenburg, Sweden). A force platform (Kistler 9286AA, Kistler Instruments AG, Winterthur, Switzerland)

land) was utilized to gather kinetic data [2,3]. Kinematic and kinetic data were recorded at sampling frequencies of 240 Hz and 2160 Hz, respectively. Reflective markers, 23 in total and each 12 mm in diameter (based on the Plug-In Gait Lower-Limb model), were attached to the pelvis and the landmarks of the right lower limb [2].

2.3. Study design and procedure

Each participant completed five trials of the drop landing task from a 50-cm height [2] under the four attentional focus conditions (QUIET – quiet, SAFE – safe, SOFT – soft, and CON – no focus condition). To prevent any potential order effects, the sequence of the conditions was counterbalanced at the condition level. To ensure a consistent drop height, participants were instructed to extend their dominant leg forward, maintain a straight position, and allow their body to descend freely. Throughout this movement, participants were required to keep their hands on their hips, ensuring a horizontal trajectory of the hip. To achieve symmetrical landings, participants were asked to land on both feet at the same time, with the dominant leg landing on the force plate [2]. Participants were given a 30-s break between trials and a 60-s rest between different conditions.

The descriptive instructions for all participants were as follows: “*The task is a drop landing. The goal is to drop off the box.*” Descriptive instructions were provided to all participants to maintain an identical task goal (i.e., drop landing) when performing across the different attentional focus conditions. Under the QUIET condition, participants were instructed: “*Focus on landing as quietly as possible.*” This cue aimed to minimize the sound of landing, encouraging controlled foot placement and reduced impact force at initial contact. During the SAFE condition, participants were instructed: “*Focus on landing as safely as possible,*” which was intended to promote body alignment, balance, and injury-preventive posture during landing. In the SOFT condition, the instruction was: “*Focus on landing as softly as possible,*” directing attention to cushioning the impact through increased joint flexion and smoother deceleration. Finally, under the CON (control) condition, no attentional focus instruction was provided, allowing participants to land naturally without specific focus. Attentional focus instructions were provided before each QUIET, SAFE, and SOFT landing trial. Participants were asked to focus solely on the assigned attentional instructions when performing landings. Participants performed the tests wearing their own shoes.

2.4. Data analysis and processing

Kinematics markers were detected and labeled using the Qualisys Track Manager (QTM Version 2021.1, Gothenburg, Sweden). Markers from the corresponding static trial were employed to identify joints and segments. A low-pass filter using a fourth-order Butterworth filter with 12-Hz and 50-Hz cut-off frequencies was applied to kinematics and kinetic data, respectively [2,21]. Knee angles were determined based on the relative alignment of two adjacent segments in three dimensions (flexion/extension, abduction/adduction, external/internal rotation) [22]. A Newton–Euler inverse dynamics technique with weight normalization was used to calculate knee moments [23]. Marker data were analyzed using Visual 3D software (C-motion, Rockville, MD, USA). The dependent variables analyzed for dominant lower limb were VGRF, knee angles (sagittal, frontal, and horizontal planes), and moments (frontal and horizontal planes). Data were statistically analyzed at three time points: (1) first contact with ground (FC), (2) first peak of VGRF (FP1), and second peak of VGRF (FP2) [21,24,25]. Because not all five trials met the required data quality standards, only four trials per condition were included in the statistical analysis.

To display overall landing performance defined as the interval between the first occurrence of a VGRF > 20 N to maximal knee flexion [2], each landing trial was normalized to 101 data points and averages across participants/conditions were displayed using statistical parametric mapping (SPM) [2].

2.5. Statistical analysis

The Shapiro–Wilk normality test was used to check for normality of data distribution of the discrete and time-series data. For normally distributed discrete data, a one-way analysis of variance (ANOVA) with repeated measures was used to determine differences between the dependent variables under the EF conditions ($P < 0.05$). Here, Mauchly’s test was used to assess the assumption of sphericity. If the assumption was violated, the Greenhouse–Geisser and HuynhFeldt corrections were employed. A paired t -test with Bonferroni correction was used as a post-hoc test. For the ANOVA tests, the η_p^2 values of 0.01, 0.06, and 0.14 were considered small, moderate, and large effect sizes, respectively [26]. For pairwise comparisons, the repeated-measures version of Cohen’s d between group means that factor correlations between conditions were calculated and interpreted as trivial (<0.2), small (0.21–0.5), medium (0.51–0.8), or large (>0.8) [27,28].

For non-normally distributed discrete data, the Friedman test was used to evaluate the differences in mean ranks (M_{Rank}) among the conditions ($\alpha < 0.05$). The effect sizes for the non-parametric Friedman test were estimated using Kendall’s W (or Kendall’s coefficient of concordance), where values from 0 (indicating no relationship) to 1 (indicating a perfect relationship) [29]. In addition, a Wilcoxon signed-rank test with Bonferroni adjustment was used as the post-hoc test. To estimate the effect sizes between the conditions, the r effect size was calculated by dividing the z ’s score value by the square root of the number of pairs ($n = 12$) [30]. For consistency in reporting effect sizes, r -values were transformed to Cohen’s d -values using the formula $d = \frac{r}{\sqrt{1-r^2}}$ [31,32].

An SPM one-way repeated measures analysis of variance (ANOVA SPM1d-ANOVA1RM for time-series analysis – v0.4.3 – <https://www.spm1d.org>) was used to examine the differences in continuous data between the dependent variables and the attentional conditions ($\alpha < 0.05$). Where inter-condition differences were found, a paired-sample *t*-test (SPM1d paired *t*-test) with Bonferroni correction was used as a post-hoc test to compare differences between the conditions.

Adjustments were made for all multiple post-hoc comparisons by Bonferroni correction and set to 0.008 (0.05/6). The statistical analyses of discrete data were conducted using SPSS software (version 24; SPSS Inc, Chicago, IL, USA). The time-series data were processed and displayed using MATLAB (v. 2021b, MathWorks, Inc., Natick, MA, USA).

3. Results

3.1. Discrete time analyses

3.1.1. VGRF

There was a significant difference between attentional focus conditions for the FP2, $F(1.80,19.3) = 15.15$, $P > 0.001$, $\eta_p^2 = 0.58$ (Figure 1). A Bonferroni post-hoc test revealed significantly higher values of VGRF (in Newtons) in the CON ($M = 1918.6 \pm 436.9$) relative to QUIET ($M = 1330.5 \pm 329.2$, $P = 0.008$, $d = 1.13$), SAFE ($M = 1390.8 \pm 377.2$, $P = 0.016$, $d = 1.06$), and SOFT ($M = 1249.1 \pm 259.8$, $P = 0.003$, $d = 1.21$) conditions. No significant differences between attentional focus conditions were observed during the FC, $F(3,33) = 1.00$, $P = 0.404$, $\eta_p^2 = 0.08$, nor at the FP1, $X^2(3) = 5.22$, $P = 0.156$, $W = 0.15$.

3.1.2. Knee moments

No significant differences between the conditions were observed in frontal moments during the FC, $F(3,33) = 0.48$, $P = 0.699$, $\eta_p^2 = 0.04$, the FP1, $F(3,33) = 1.12$, $P = 0.356$, $\eta_p^2 = 0.09$; nor the FP2, $F(3,33) = 1.90$, $P = 0.148$, $\eta_p^2 = 0.15$. Similarly, no significant differences between the conditions were observed in horizontal moments during the FC, $F(3,33) = 0.72$, $P = 0.545$, $\eta_p^2 = 0.06$, the FP1, $F(3,33) = 0.31$, $P = 0.819$, $\eta_p^2 = 0.03$, nor the FP2, $F(3,33) = 1.95$, $P = 0.141$, $\eta_p^2 = 0.15$ (Figure 1).

3.1.3. Knee angles

There was a significant difference between attentional focus conditions in the sagittal angle during the FC, $F(3,33) = 6.58$, $P = 0.001$, $\eta_p^2 = 0.37$ (Figure 1). A Bonferroni post-hoc test revealed significantly lower flexion (in degrees) in the CON condition ($M = -17 \pm 5.4$) relative to QUIET ($M = -22.2 \pm 6.1$, $P < 0.001$, $d = 1.87$) and SOFT ($M = -21.4 \pm 5.5$, $P = 0.03$, $d = 1.02$) conditions. In addition, significant differences in sagittal angles were found between attentional focus conditions during the FP1, $X^2(3) = 15.91$, $P = 0.001$, $W = 0.44$. Specifically, lower flexion was observed significantly in the CON condition ($M = -22.3 \pm 5.4$) relative to QUIET ($M = -29.4 \pm 6.5$, $P = 0.013$, $d = 0.46$) and SOFT ($M = -28.4 \pm 5.3$, $P = 0.022$, $d = 0.43$) conditions. Additionally, there was a significant difference between the conditions in sagittal angles during the FP2, $X^2(3) = 17.12$,

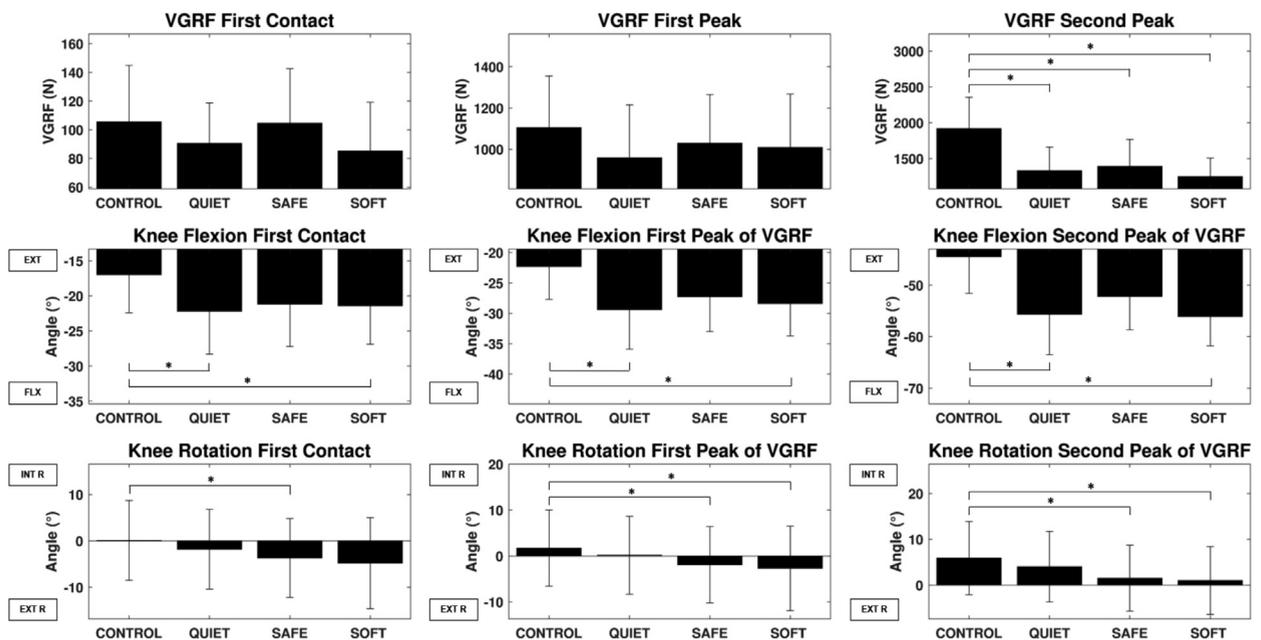


Figure 1. Significant differences among the biomechanical variables found during discrete data analysis. EXT, extension; EXT R, external rotation; FLX, flexion; INT R, internal rotation; VGRF, vertical ground reaction force. * Significantly different at adjusted alpha level 0.008.

$P = 0.001$, $W = 0.48$, where significantly lower flexion was found in the CON condition ($M = -44.5 \pm 7.1$) relative to QUIET ($M = -55.7 \pm 7.8$, $P = 0.018$, $d = 0.44$) and SOFT ($M = -56.1 \pm 5.7$, $P = 0.017$, $d = 0.46$) conditions.

A significant difference was found between attentional focus conditions in horizontal (transverse) angles during the FC, $F(1.65, 18.25) = 6.75$, $P = 0.009$, $\eta_p^2 = 0.38$ (Figure 1). A Bonferroni post-hoc test revealed significantly higher internal rotation (in degrees) in the CON condition ($M = 0.10 \pm 8.6$) relative to SAFE ($M = -3.7 \pm 8.5$, $P = 0.021$, $d = 1.08$) condition. In addition, a significant difference in horizontal angles was found between the conditions during the FP1, $F(1.65, 18.15) = 7.76$, $P = 0.005$, $\eta_p^2 = 0.41$, where significantly higher internal rotation was found in the CON condition ($M = 1.7 \pm 8.3$) relative to SAFE ($M = -1.9 \pm 8.3$, $P = 0.011$, $d = 1.20$) and SOFT ($M = -2.7 \pm 9.2$, $P = 0.033$, $d = 1.24$) conditions. Moreover, there was a significant difference in horizontal angles between the conditions during the FP2, $F(1.87, 20.62) = 10.06$, $P = 0.001$, $\eta_p^2 = 0.48$, where significantly higher internal rotation was found in the CON condition ($M = 5.9 \pm 8.0$) relative to SAFE ($M = 1.5 \pm 7.2$, $P < 0.001$, $d = 1.33$) and SOFT ($M = 1 \pm 7.4$, $P = 0.018$, $d = 1.06$) conditions.

No significant difference between the conditions were observed in frontal angles during the FC, $X^2(3) = 5.42$, $P = 0.143$, the FP1, $F(3, 33) = 0.26$, $P = 0.994$, $\eta_p^2 < 0.01$, nor the FP2, $F(1.53, 16.87) = 0.43$, $P = 0.605$, $\eta_p^2 = 0.04$.

3.2. Continuous time analyses

3.2.1. VGRF

There was a significant difference between attentional focus conditions for VGRF from 21 % to 29 % of movement time ($F^* = 5.898$, $P = 0.004$) (Figure 2). Bonferroni post-hoc comparison is presented in the Figure 2.

3.2.2. Knee angles

A significant difference between attentional focus conditions in sagittal angles was found from 5 % to 100 % of movement time ($F^* = 4.045$, $P = 0.001$) (Figure 2). Moreover, there was a significant difference in knee frontal angles between attentional focus conditions from 59 % to 94 % of movement time ($F^* = 4.143$, $P = 0.023$). Lastly, there was a significant difference between attentional focus conditions in the horizontal angles from 0 % to 18 % of movement time ($F^* = 4.171$, $P = 0.041$). Bonferroni post-hoc comparison is presented in the Figures 2 and 3.

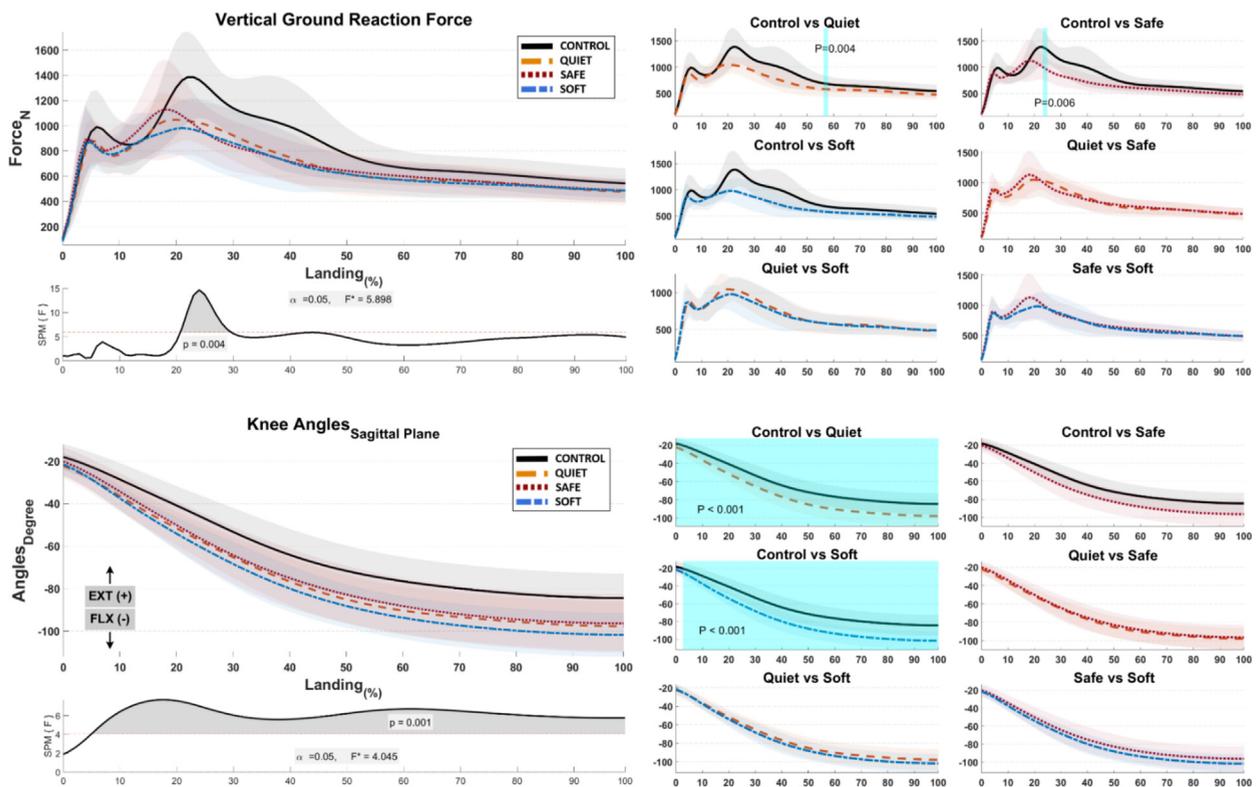


Figure 2. Time-series analyses of vertical ground reaction force and sagittal knee angles during overall landing performance. EXT, extension; FLX, flexion. Blue boxes indicate a significant difference between attentional focus condition at an alpha level of 0.008. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

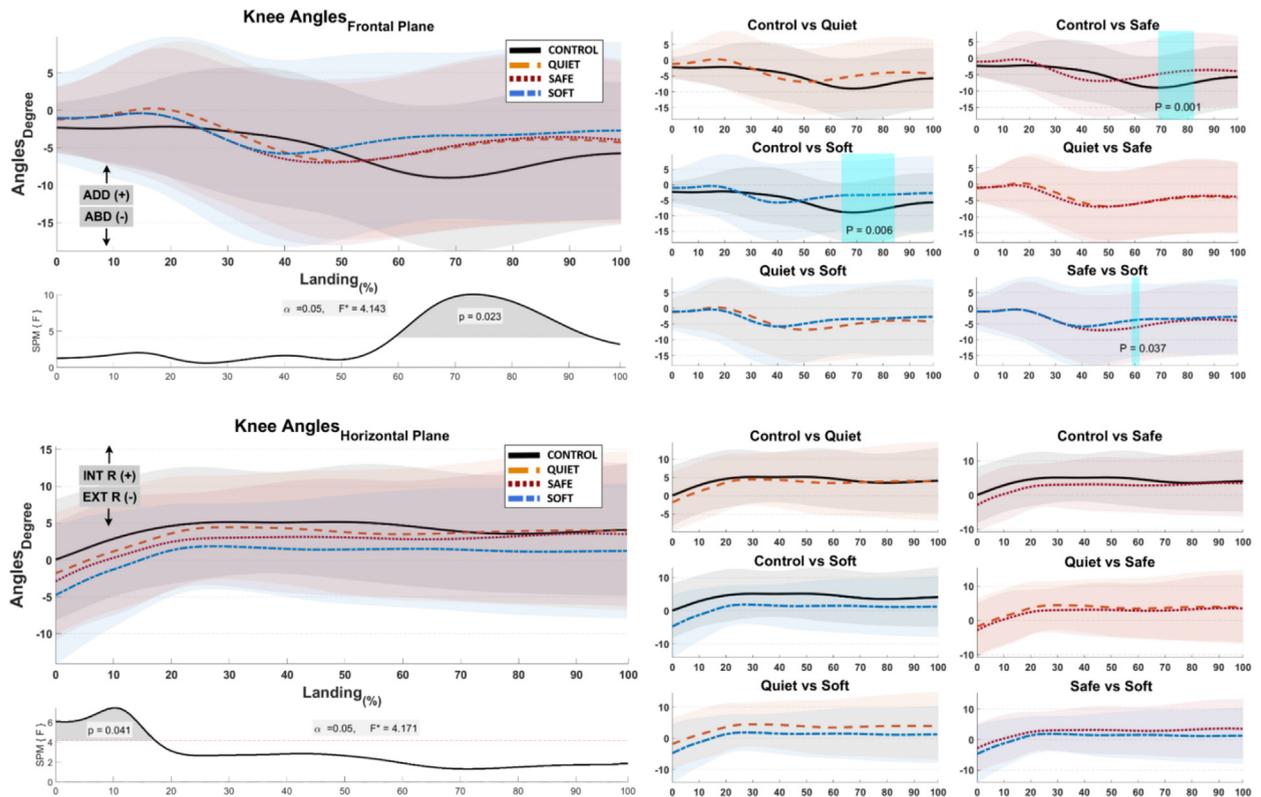


Figure 3. Time-series analyses of frontal and horizontal knee angles during overall landing performance. ABD, abduction; ADD, adduction; EXT R, external rotation; INT R, internal rotation. Blue boxes indicate a significant difference between attentional focus condition at an alpha level of 0.008. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

3.2.3. Knee moments

No significant differences were found in the frontal moments during the course of landing between the attentional focus conditions ($F^* = 4.599$, $P \geq 0.198$). However, there was a significant difference in horizontal moments from 41 % to 57 % of movement time ($F^* = 4.709$, $P = 0.028$) (Figure 4). Bonferroni post-hoc comparison is presented in the Figure 4.

4. Discussion

This study builds on recent research on landing biomechanics under attentional focus instructions in experienced female volleyball players [2,3]. Our previous findings demonstrated that EF instructions directing athletes to perform soft landings improved knee biomechanics and potentially reduced lateral femorotibial cartilage loading during landing [2,3]. The purpose of the present study was to investigate the effects of landing-specific EF instructions (i.e., quiet, safe, and soft) on drop-landing biomechanics. Consistent with our hypothesis, all types of EF instructions, compared with the CON condition, reduced biomechanical forces during landing, which decreased knee joint loading and lowered the likelihood of ACL injuries. Specifically, all EF instructions optimized VGRF and sagittal/horizontal angles. This was achieved without significant differences in knee moments across attentional focus conditions compared with the CON condition. These findings suggest that: (a) the attentional focus instructions investigated can effectively reduce risk-related biomechanical variables (e.g., VGRF, flexion, and horizontal angles), while (b) they do not significantly influence potentially risky knee moments during double-leg landings.

Even though no significant differences were observed between EF conditions, instructions directing participants to perform a soft landing revealed the greatest biomechanical improvements compared with the CON condition. Specifically, landings executed under the SOFT condition demonstrated the lowest average internal rotation angles throughout the entire landing phase compared with CON. This finding suggests improved horizontal stabilization of the knee, potentially contributing to the prevention of ACL injuries [33,34]. Moreover, the SOFT condition showed the lowest average maximum VGRF and increased flexion angles, which may indicate that this attentional focus strategy is particularly effective in minimizing sagittal plane loading compared with the other attentional focus cues investigated. This suggests that EF instructions emphasizing a “soft” landing may facilitate more efficient motor control and reduce the likelihood of erroneous motor patterns during dynamic landing transitions.

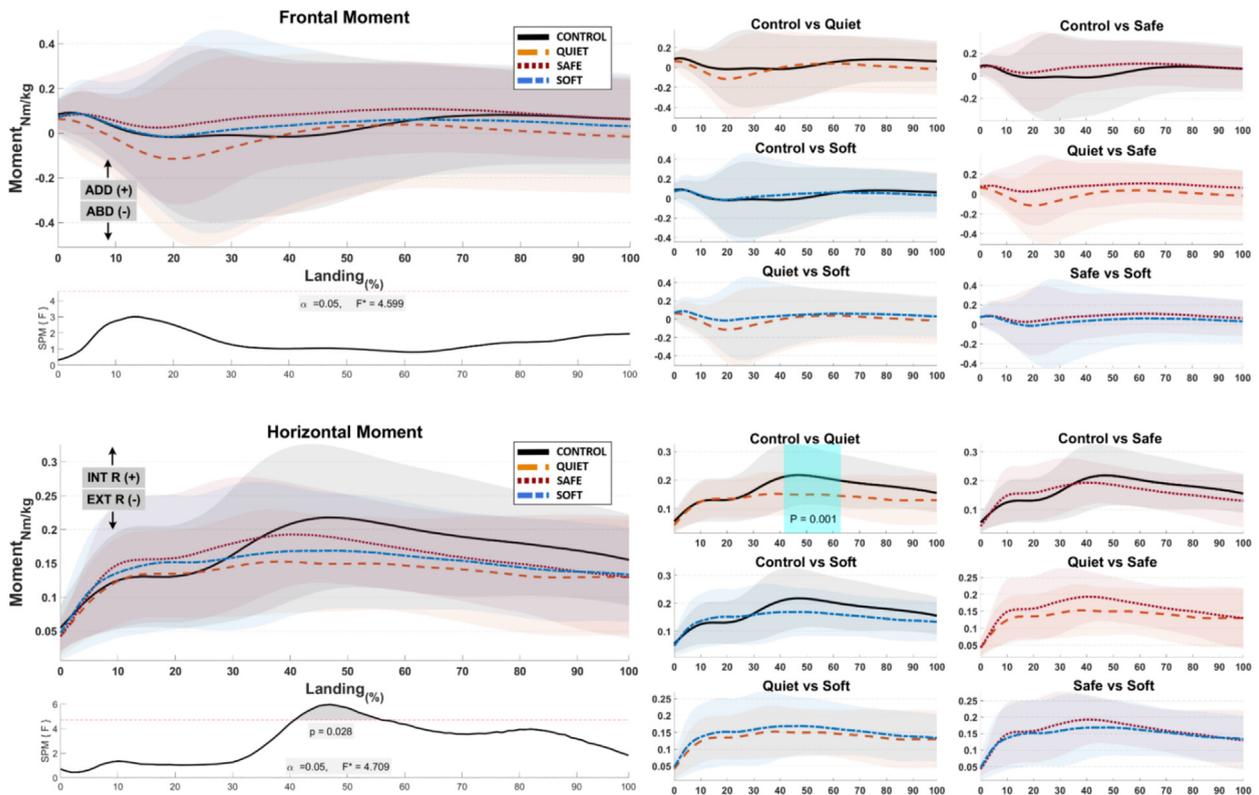


Figure 4. Time-series analyses of frontal and horizontal knee moments during overall landing performance. ABD, abduction; ADD, adduction; EXT R, external rotation; INT R, internal rotation. Blue box indicates a significant difference between attentional focus condition at an alpha level of 0.008. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Optimized sagittal plane landing biomechanics (i.e., VGRF, loading rates, and flexion angles) under attentional cues promoting soft landings have been demonstrated in previous studies, while their effect on knee moments appears negligible [2,17]. For example, Milner et al. reported that directing the attention of recreational athletes (age: 25 ± 2 years) towards soft landings resulted in reduced peak VGRF and increased peak knee flexion compared with a no-focus condition, with no significant differences in peak abduction moments [17]. Similarly, a study by Slovák et al. on drop landings in competitive female volleyball players (age: 20.4 ± 0.8 years, competitive experience: 6.3 ± 0.8 years) revealed reduced VGRF and loading rates, along with a significant increase in flexion angles compared with the no-focus condition [2]. These effects were similarly achieved without significant differences in frontal and horizontal knee moments [2]. The absence of significant differences in frontal and horizontal moments during drop landings under attentional focus instructions may be attributable to landings being performed from safe heights and on to both lower limbs, potentially reducing the occurrence of excessive rotational forces creating knee frontal and horizontal moments [35].

The biomechanical enhancements observed during the landing process when utilizing EF instructions may suggest that these instructions exert a similar influence on the motor control system, aiming to minimize injury risk during landing. In other words, all EF instructions likely support the redirection of attentional focus towards the desired movement outcome (e.g., quietness, safety, or softness), leading to comparable biomechanical adaptations aimed at reducing knee joint loading. These biomechanical adaptations – evidenced by smooth, dynamic transitions and reduced knee joint loading during landing – may reflect participants' focus on the task's goal or goal-action coupling [16,36]. In this regard, EF has been identified as a significant contributor to goal-action coupling, serving to consolidate the connection between an individual's intended movement and the subsequent activation of their neuromuscular system [16].

The findings from the time-series analysis showed that the SOFT and QUIET conditions resulted in significantly greater knee flexion throughout almost the entire landing phase compared with the CON condition ($P < 0.001$) (Figure 2), which is particularly relevant when assessing ACL injury risk based on sagittal knee joint angles. This is crucial because movement in the sagittal plane – primarily governed by the knee extensors and flexors (i.e., mainly the quadriceps and hamstrings) – significantly contributes to joint load absorption during landing [37]. Although several other statistically significant differences were identified in this study, their impact on ACL injury risk assessment appears minimal, as these differences occurred later in the landing phase. Conversely, a comprehensive view of the entire time course of landing showed that, under the SOFT condition, the lowest values of VGRF and internal knee rotation were observed, while knee flexion angles

were the highest among all evaluated conditions. These findings support the hypothesis that a “softer” landing strategy – with increased knee flexion – reduces knee loading and may therefore lower the risk of injury [2,37].

A few limitations of the present study should be noted. This investigation solely examined knee biomechanics. Consequently, analyzing all lower limb joints could provide a more comprehensive understanding of potential contributing factors to ACL injury, such as hip adduction, as suggested by Hewett et al. [7]. Additionally, the absence of significant differences between attentional focus conditions may be attributed to limited statistical power to detect small effects (i.e., subtle differences among EF instructions) and the use of adjusted familywise error rates. Future studies are therefore advised to employ larger sample sizes for a more effective investigation of the benefits of different EF instructions. Moreover, subsequent research could incorporate more realistic landing scenarios, such as single-leg landings or dual-task conditions (e.g., using attentional focus cues during landing after a volleyball block, as in Zahradník et al.) [25], to extend these findings across a broader range of landing tasks. In addition, this study did not include a manipulation check to assess adherence to the assigned attentional focus instructions. This may be an important consideration, as post-experiment feedback regarding participants’ focus could clarify attentional adherence, particularly in the CON condition. Lastly, while ACL injuries occur under unpredictable conditions without conscious control, our study investigated biomechanical changes under specific EF instructions in a controlled environment. These findings may inform how safer landing mechanics can be instructed, trained, and integrated into practice sessions.

5. Conclusion

Overall, the present study revealed that EF instructions directing athletes to perform quiet, safe, and soft landings can be beneficial for reducing the biomechanical forces acting on the knee joint during drop landings in novice, young female volleyball players. While no significant differences were observed between the different types of EF conditions investigated, instructions promoting a soft landing appeared to be more effective in facilitating biomechanical changes associated with smoother and less injury-prone landing performance in the sagittal and transverse planes compared with the no-focus condition.

There were minimal changes in knee moments, suggesting that the EF cues investigated do not significantly alter the rotational forces acting on the knee joint. Our findings have practical implications for athletes, coaches, physical education teachers, and physical therapists. Our results highlight the potential of using various EF instructions with young female volleyball players to reduce landing forces on the knee joint and, consequently, decrease the likelihood of ACL injuries.

Ethics statement

The ethics committee of the University of Ostrava approved this study (45/2021), which is in line with the 1964 Helsinki Declaration and its subsequent amendments.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used ChatGPT (OpenAI) to check for grammatical errors. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

CRediT authorship contribution statement

Lukáš Slovák: Writing – review & editing, Writing – original draft, Resources, Project administration, Methodology, Investigation, Conceptualization. **David Zahradník:** Writing – review & editing, Methodology. **William M. Land:** Writing – review & editing, Conceptualization. **Javad Sarvestan:** Writing – review & editing, Methodology. **Takehiro Iwatsuki:** Writing – review & editing, Methodology. **Kevin A. Becker:** Writing – review & editing. **Reza Abdollahipour:** Writing – review & editing, Supervision, Methodology, Conceptualization.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this study.

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