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Lowering minimum eye height to increase peak knee and hip flexion during landing

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Abstract

The purpose was to determine the effect of lowering minimum eye height through an externally focused object on knee and hip flexion and impact forces during jump-landing. Kinematics and ground reaction forces were collected when 20 male and 19 female participants performed jump-landing trials with their natural minimum eye height, and trials focusing on lowering their minimum eye height to an external object, which was set at 5% or 10% of standing height lower. Participants demonstrated decreased minimum eye height and increased peak knee and hip flexion during early-landing and stance phase when focusing on lowering eye height to the external object ($p < 0.01$). Peak vertical ground reaction forces during early-landing also decreased for the greater force group ($p < 0.001$). Jump-landing training through manipulating eye height provides a strategy that involves an external focus and intrinsic feedback, which may have advantages in promoting learning and practical application.

Keywords

ACL injury; motor control; landing; eye height; knee flexion; hip flexion

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Introduction

Anterior cruciate ligament (ACL) injuries commonly occur during jump-landing and cutting tasks (Dai, Mao, Garrett, & Yu, 2015; Koga et al., 2010; Krosshaug et al., 2007). Low knee and hip flexion angles, increased knee adduction/abduction angles, and greater impact ground reaction forces (GRF) are associated with increased ACL loading and greater risk of ACL injury (Bakker et al., 2016; Dai, Mao, Garrett, & Yu, 2014; Nordin & Dufek, 2017; Taylor et al., 2011; Yu, Lin, & Garrett, 2006). Aiming for lowering ACL injury risk, jump-landing training has been developed with a focus on increasing knee and hip flexion, minimizing non-sagittal plane knee motion, and decreasing impact GRF (Dai, Garrett, et al., 2015; Dai et al., 2016; DiStefano, Padua, DiStefano, & Marshall, 2009; Ericksen, Gribble, Pfile, & Pietrosimone, 2013; Munro & Herrington, 2014). Participants typically demonstrate improved jump-landing biomechanics immediately after training, although jump-landing performance as indicated by decreased jump height and increased stance time may be compromised (Dai, Garrett, et al., 2015; Dai et al., 2016; Munro & Herrington, 2014).

Instructions and feedback are commonly utilized to facilitate the modification of jump-landing techniques (Dai, Garrett, et al., 2015; Dai et al., 2016; Ericksen et al., 2013; Munro & Herrington, 2014). A recent review, however, has questioned the use of instructions and feedback with an internal focus during jump-landing training, which may inhibit the learning process compared with training with an external focus (Benjaminse et al., 2015).While internal focus refers to the focus on individuals' body movements, external focus is the focus of the effect of movements and their interactions with the environment (Wulf, McConnel, Gartner, & Schwarz, 2002). A study has found that a training duration as long as 9 months may be needed to retain the improvements in jump-landing techniques 3 months after ceasing the training, whereas a training duration of 3 months is not sufficient to result in long-term retention (Padua et al., 2012). As learning is defined as a relatively permanent change (Wulf et al., 2002), efforts are needed to improve the efficiency of jump-landing training and long-term retention.

Motor learning with an external focus may result in better skill acquisition in jump performance (Makaruk, Porter, Czaplicki, Sadowski, & Sacewicz, 2012; Wulf, Dufek, Lozano, & Pettigrew, 2010), balance performance (Chiviacowsky, Wulf, & Wally, 2010), and sports skills (Wulf et al., 2002; Zachry, Wulf, Mercer, & Bezodis, 2005) compared to learning with an internal focus. Recently, several training strategies that involve learning with an external focus have shown potential advantages in improving jump-landing and cutting techniques (Benjaminse et al., 2015; Celebrini et al., 2014; Gokeler et al., 2015; Welling, Benjaminse, Gokeler, & Otten, 2016), although there is a lack of training strategies that target sagittal plane motion during the landing phase, during which ACL injuries commonly occur (Dai, Mao, et al., 2015; Koga et al., 2010; Krosshaug et al., 2007). A previous study has shown that increased knee flexion is coupled with increased hip flexion during landing (Blackburn & Padua, 2008), resulting in lower vertical positions of the eyes. In addition, individuals are able to accurately perceive eye height relative to the environment, and the information of eye height has been used for perception of objects and execution of movements (Mark, 1987; Warren & Whang, 1987; Wraga, 1999).

Consequently, targeted eye height can be manipulated to modify landing techniques as landing to a lower eye height may result in increased knee and hip flexion angles.

Therefore, the purpose of the current study was to quantify the effect of lowering minimum eye height through an externally focused object on knee and hip flexion angles and impact GRF during a jump-landing task. It was hypothesized that lowering minimum eye height would result in increased knee and hip flexion angles and decreased impact GRF during landing. The findings may provide information for manipulating eye height as a potential strategy that involves an external focus and intrinsic feedback for jump-landing training.

Methods

Participants

Assuming an effect size of 0.5 for a paired comparison, a sample size of 34 is needed for a type I error no greater than 0.05 and a power no less than 0.8. Twenty male and 19 female participants of ages 18 or older (age: 21.7 ± 1.6 years; height: 1.74 ± 0.09 m; mass: 72.3 ± 12.9 kg) participated in the current study. At the time of testing, participants were playing sports that involved jump-landing tasks at least 1 time per week or had previously played at high school, college, or club levels. Participants were participating in sports/exercise at least two times per week for a total of 2–3 hours per week. Twenty-three participants were participating in jump-landing sports at the time of testing, while 16 participants had previous jump-landing sports experience. Exclusion criteria were consistent with a previous study (Dai et al., 2016). The current study was approved by the University of Wyoming Institutional Review Board. Participants signed consent forms prior to participation.

Procedures

Participants performed a warm-up protocol, consisting of 5-minute running and a set of each of walking toe touches, walking quadriceps pull, lunges, and two sets of lateral shuffles with each set performed for 27 meters. Reflective markers were placed on participants' root of nose between two eyes (mid-eye), trunk, pelvis, and jumping leg (Dai, Heinbaugh, Ning, & Zhu, 2014). Eight Vicon Bonita 10 cameras (Oxford Metrics Ltd, Oxford, UK) and one Bertec 4060–10 force plate (Bertec Corporation, Columbus, OH) were used to collect kinematic and GRF data at sampling frequencies of 160 Hz and 1600 Hz, respectively.

Participants performed a static trial in the anatomical position for calibration of relative positions among markers on the same segment. Participants then performed two to three practice trials and three official trials of the jump-landing task (Figure 1) without any instruction or feedback to establish baseline trials (DiStefano et al., 2009). The lowest vertical position of the mid-eye marker during landing was immediately identified as the minimum eye height using Vicon Nexus software, and the average of the three trials was calculated. Two lower minimum eye height levels were determined by subtracting 5 and 10% of participants' standing height from the minimum eye height in baseline trials. Next, at each lower eye height level, participants performed one practice and three official trials in each of three tasks: (1) perception of eye height, (2) jump-landing with feedback, and (3) jump-landing evaluation. The order of 5% lower eye height and 10% of lower eye height was counterbalanced among participants. Participants performed the perception of eye height first, jump-landing with feedback second, and jump-landing evaluation last for each lower eye height level.

A 0.024-m wide red tape was placed horizontally at one of the two targeted lower eye height levels on a rack one meter away from the force plate for the perception of eye height task (Figure 2). Participants squatted down to align their eye height to the middle of the horizontal tape and paused for approximately two seconds (Figure 2). Participants then performed the jump-landing task, and were instructed to lower their eye height to the height of the horizontal tape during landing before they jump vertically for a maximum height for the jump-landing with feedback task (Figure 1). The horizontal tape and rack were removed for the jump-landing evaluation task. Participants performed the jump-landing task, and were instructed to lower their eye height to the same height as in the jump-landing with feedback condition during landing before they jump vertically for a maximum height. No other instructions regarding joint movements or landing techniques were given. A trial was repeated if participants did not complete the jump-landing task in a fluid motion or reported that they did not feel they achieved the targeted eye height in the feedback or evaluation conditions. Participants rested for a minimum of 30 seconds between jump-landing trials.

Data reduction

Data were analyzed for the dominant leg. Marker coordinates and GRF data were filtered using a fourth-order Butterworth filter at a low-pass cut-off frequency of 15 Hz and 100 Hz, respectively. Joint centers, segment reference frames, and joint angles were defined and calculated as described in a previous study (Dai et al., 2016). Joint angles in the static trial were defined as a neutral alignment and subtracted from the angles in dynamic trials.

ACL injuries typically occur during the first 100 milliseconds after initial ground contact defined as early-landing (Dai, Mao, et al., 2015; Koga et al., 2010; Krosshaug et al., 2007). Stance phase was defined as between initial ground contact and toe-off. In addition to the minimum eye height and peak knee and hip flexion angles during stance phase, knee and hip flexion angles at initial contact and peak knee and hip flexion angle during early-landing were analyzed. Increased peak posterior and vertical GRF during early-landing have been shown to be associated with increased ACL loading (Bakker et al., 2016; Dai et al., 2014; Yu et al., 2006). Therefore, peak posterior and vertical GRF during early-landing were extracted for analysis. Jump height, stance time, and reactive strength index were extracted to assess overall jump performance (Stephenson et al., 2018). GRF were normalized to participants' body weight. Calculations were performed using subroutines developed in MATLAB 2013a (MathWorks Inc., Natick, MA).

Statistical analysis

The targeted eye height was subtracted from the actual eye height to quantify the accuracy of perception for the perception of eye height task. The differences between the actual eye height and target height were compared between the 5% Perception and 10% Perception conditions using a paired t-test. Dependent variables were compared using repeated-measures analyses of variance (ANOVA) with the testing condition (baseline, 5% feedback, 5% evaluation, 10% feedback, and 10% evaluation) as a within-participant factor for the jump-landing tasks. Paired t-tests were performed between each pair of two testing conditions if an ANOVA showed a significant main effect. The Benjamini-Hochberg procedure was applied to all paired t-tests to control the study-wide false discovery rate to be 0.05. Statistical analyses were performed using the SPSS Statistics 22 software (IBM Corporation, Armonk, NY, USA).

Results

The differences between the actual eye height and targeted eye height for the perception task were −0.002 ± 0.046 m and 0.009 ± 0.052 m during the 5% Perception and 10% Perception conditions, respectively, and significantly increased from the 5% Perception condition to the 10% Perception condition ($p = 0.025$). With regard to the jump-landing tasks, preliminary examination of data indicated that the changes in peak vertical GRF during early-landing may be different between individuals who demonstrated greater force and individuals who demonstrated less force. Therefore, participants were divided into a greater force group (11 males and 8 females) and a less force group (9 males and 11 females) based on the rank of their forces in baseline, and each group was analyzed separately for peak vertical GRF during early-landing. The peak vertical GRF during early-landing in baseline ranged between 2.65 and 4.20 body weight for the greater force group and 1.54 and 2.64 body weight for the less force group.

Descriptive data and statistical significance were shown in Table 1. After the adjustment for the overall Type I error rate, the largest p value for a significant paired t-test was 0.022. Jump height decreased during the 5% evaluation, 10% feedback, and 10% evaluation conditions compared with the baseline condition. Stance time was the greatest during the 10% feedback and 10% evaluation conditions, the second greatest during the 5% feedback condition, the third greatest during the 5% evaluation condition, and the lowest during the baseline condition. Reactive strength index was the greatest during the baseline condition. Participants demonstrated the lowest minimum eye height and the greatest peak knee and hip flexion angles during stance phase during the 10% feedback and 10% evaluation conditions, the second lowest minimum eye height and the second greatest peak knee and hip flexion angles during stance phase during the 5% feedback and 5% evaluation conditions, and the highest minimum eye height and the least peak knee and hip flexion angles during stance phase during the baseline condition. Participants increased their peak knee flexion angle during early-landing during the other four conditions compared with the baseline condition, and these increases were greater for the 10% feedback and 10% evaluation conditions compared with the 5% feedback condition. Participants increased their peak hip flexion angles during early-landing during the 10% feedback and 10% evaluation conditions compared with the baseline and 5% feedback conditions. Compared with the baseline condition, participants decreased their knee flexion angles at initial contact during the 5% evaluation and 10% evaluation conditions and hip flexion angle at initial contact during the 5% feedback and 5% evaluation conditions. Participants in the greater force group demonstrated decreased peak vertical GRF during early-landing during the other four conditions compared with the baseline condition.

Discussion

The current work supports the finding that lowering minimum eye height would result in increased peak knee and hip flexion angles during stance phase. Increased knee and hip flexion angles during landing are associated with decreased ACL loading (Bakker et al., 2016; Dai et al., 2014; Taylor et al., 2011; Yu et al., 2006) and are commonly encouraged in jump-landing training that involves learning with an internal focus (Dai, Garrett, et al., 2015; Dai et al., 2016; DiStefano et al., 2009; Ericksen et al., 2013; Munro & Herrington, 2014). Participants focused on lowering their minimum eye height to an external object. Although no instructions related to joint angles were given, participants naturally increased their peak knee and hip flexion angles. In the meantime, significant increases in peak knee and hip flexion angles during stance phase were observed from the 5% feedback and evaluation conditions to the 10% feedback and evaluation conditions, suggesting a progressive change between the decrease in eye height and increase in peak knee and hip flexion angles.

Meanwhile, lowering minimum eye height resulted in increased knee flexion angles during early landing for most conditions. However, landing with lower minimum eye height decreased knee and hip flexion angles at initial contact during several conditions. These findings suggest that participants modified their movement patterns specific to the information they received, as the horizontal tape was provided at the lowest position of landing but not at initial contact. Previous studies have also shown that increases in peak knee flexion angles during stance phase did not necessarily increase knee flexion angles at initial contact (Dai, Garrett, et al., 2015; Dai et al., 2016). Since ACL injuries commonly occur during early-landing and peak ACL strain occurs when the knee flexion angle is the lowest (Taylor et al., 2011), increasing knee flexion angles at initial contact would be desirable and has been encouraged in previous studies (Dai, Garrett, et al., 2015; Lin, Liu, Garrett, & Yu, 2008). One strategy to overcome this negative impact could be placing another horizontal line for manipulating eye height at initial contact.

The current study supports that lowering minimum eye height would decrease impact vertical GRF for the greater force group, but not for the less force group. This result was consistent with previous studies, suggesting that individuals who demonstrate high-risk jump-landing patterns are more likely to improve after an intervention program (DiStefano et al., 2009; Myer, Ford, Brent, & Hewett, 2007). Impact vertical GRF could result in a tibia-femoral compressive force to load the ACL through a posterior tilted tibial plateau (Dai et al., 2014; Meyer & Haut, 2005). When the vector of vertical GRF does not pass through the knee joint center in the frontal plane, it could also cause an external valgus or varus moments to load the ACL (Markolf et al., 1995). Landing with increased knee flexion range of motion has been shown to decrease impact vertical GRF as it allows individuals dissipating the landing force over a longer period of time (Dai, Garrett, et al., 2015; Devita & Skelly, 1992). The current findings suggest that increased knee and hip flexion range of motion is effective in decreasing impact vertical GRF in individuals who demonstrate greater impact vertical GRF.

Jumping-landing training through manipulating eye height may have advantages in promoting learning and practical application. Individuals focus on the outcome of their movements through self-perception of eye height and an external object. Based on the literature, training with an external focus may facilitate the learning process compared with learning with an internal focus (Wulf, 2013). In addition, training through manipulating eye height has a low cost and can be implemented by an individual independently. Participants receive intrinsic feedback of whether they have achieved the movement outcome through perception of eye height. This feedback occurs concurrently during training and does not require extra equipment or personnel. Furthermore, the information of eye height can also be utilized in sports environments. For example, a volleyball player may use the net as an external object for controlling eye height and movement patterns after landing from a block.

Several limitations existed in the current study. The immediate changes in biomechanical variables observed in the current study did not represent a permanent learning effect (Benjaminse et al., 2015). The decreased jump height and reactive strength index and increased stance time should be considered as decreased performance in sports competition (Dai, Garrett, et al., 2015). The long-term training effect on jump-landing biomechanics, performance, and movement variability (Nordin & Dufek, 2017) are unknown. In addition, only one horizontal line was placed to control eye height at the lowest position of landing. Including another horizontal line to constrain eye height at initial contact may achieve the goal of increasing knee and hip flexion angles at initial contact.

Conclusion

Lowering minimum eye height resulted in increased peak knee and hip flexion angles during stance phase during a jump-landing task. Lowering minimum eye height also decreased impact vertical GRF in participants who demonstrate greater impact vertical GRF. Jump-landing training through manipulating eye height provides a novel strategy that involves training with an external focus and intrinsic feedback. Additional control of eye height at initial contact may be needed to result in positive changes to landing kinematics at initial contact.

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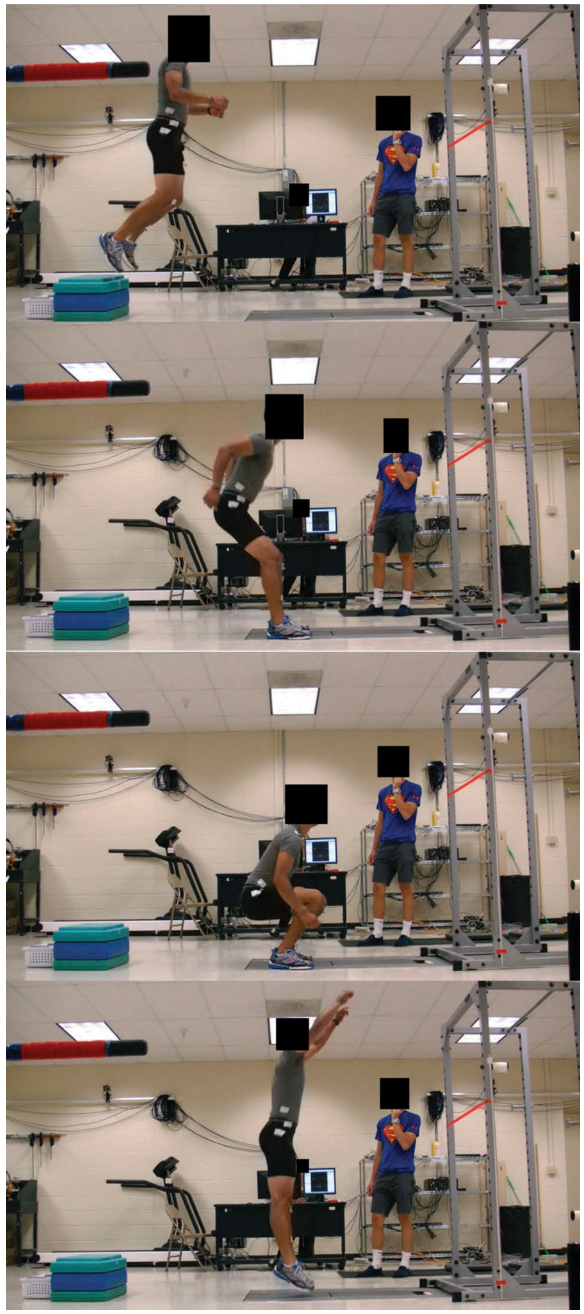

Figure 1.
The jump-landing with feedback.

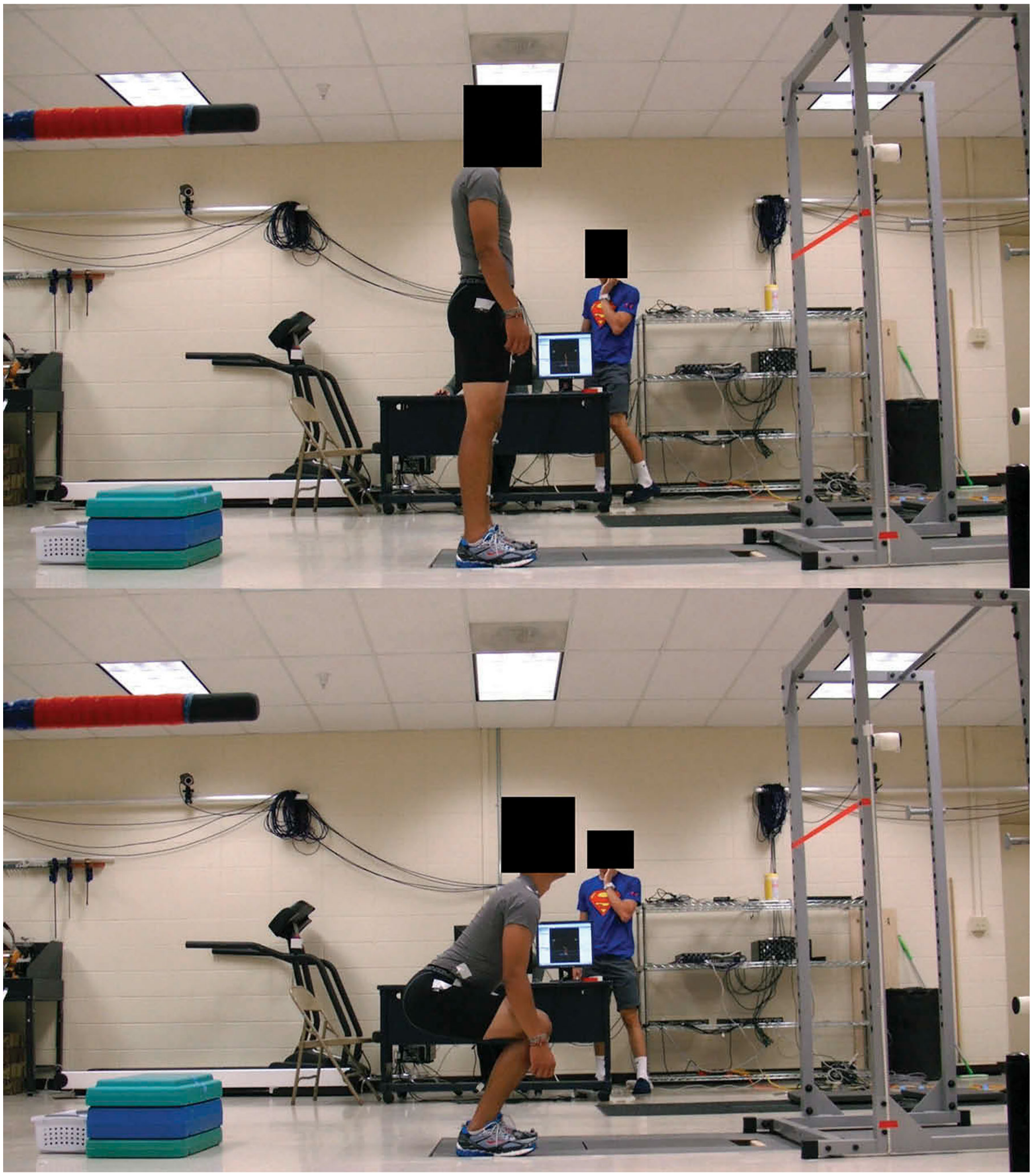

Figure 2.
The perception of eye height task.

Table 1

Means (standard deviations) of kinematic, kinetic, and performance variables and statistical significance.

		Baseline	5% Feedback	5% Evaluation	10% Feedback	10% Evaluation	*p* values of ANOVA
Jump Height (m)		0.45 (0.13)[c, d, e]	0.43 (0.13)	0.43 (0.13)[a]	0.43 (0.12)[a]	0.43 (0.14)[a]	**0.007**
Stance Time (ms)		517.0 (139.2)[b, c, d, e]	770.1 (155.8)[a, c, d, e]	740.0 (145.0)[a, b, d, e]	805.6 (156.4)[a, b, c]	794.6 (158.6)[a, b, c]	**<0.001**
Reactive Strength Index (m/s)		0.98 (0.50)[b, c, d, e]	0.61 (0.35)[a, d]	0.63 (0.34)[a, d, e]	0.57 (0.27)[a, b, c]	0.58 (0.30)[a, c]	**<0.001**
Minimum Eye Height (Body Height)		0.67 (0.07)[b, c, d, e]	0.57 (0.06)[a, d, e]	0.58 (0.06)[a, d, e]	0.53 (0.05)[a, b, c]	0.53 (0.05)[a, b, c]	**<0.001**
Knee Flexion Angle at Initial Contact (°)		24.7 (7.4)[c, e]	23.5 (7.5)	22.7 (6.9)[a]	23.8 (7.5)	23.3 (6.9)[a]	**0.016**
Peak Knee Flexion Angle during Early-Landing (°)		78.2 (8.9)[b, c, d, e]	82.0 (9.0)[a, d, e]	82.4 (8.8)[a]	83.4 (8.9)[a, b]	83.6 (9.2)[a, b]	**<0.001**
Peak Knee Flexion Angle during Stance Phase (°)		94.5 (16.8)[b, c, d, e]	120.1 (16.2)[a, d, e]	119.4 (16.7)[a, d, e]	126.7 (16.0)[a, b, c]	127.4 (16.0)[a, b, c]	**<0.001**
Hip Flexion Angle at Initial Contact (°)		44.5 (9.1)[b, c]	42.3 (9.6)[a]	42.1 (9.7)[a]	43.0 (9.7)	42.8 (9.4)	**0.014**
Peak Hip Flexion Angle during Early-Landing (°)		73.0 (12.1)[d, e]	74.5 (11.9)[d, e]	75.3 (11.7)	76.4 (11.7)[a, b]	76.5 (11.6)[a, b]	**0.009**
Peak Hip Flexion Angle during Stance Phase (°)		85.0 (15.7)[b, c, d, e]	105.4 (14.6)[a, d, e]	105.0 (14.5)[a, d, e]	111.3 (14.5)[a, b, c]	111.7 (14.4)[a, b, c]	**<0.001**
Peak Posterior Ground Reaction Force during Early-Landing (Body Weight)		−0.76 (0.20)	−0.77 (0.19)	−0.79 (0.21)	−0.74 (0.20)	−0.75 (0.22)	0.20
Peak Vertical Ground Reaction Force during Early-Landing (Body Weight)	Greater Force Group (n = 19)	3.14 (0.49)[b, c, d, e]	2.69 (0.53)[a]	2.71(0.57)[a]	2.77 (0.70)[a]	2.76 (0.71)[a]	**<0.001**
	Less Force Group (n = 20)	2.15 (0.36)	2.25 (0.55)	2.24 (0.62)	2.29 (0.55)	2.30 (0.58)	0.48

[a] significantly different from Baseline;

[b] significantly different from 5% Feedback;

[c] significantly different from 5% Evaluation;

[d] significantly different from 10% Feedback;

[e] significantly different from 10% Evaluation;