SELF-ASSESSMENT DURING JUMP SHOT DRILLS TRANSLATES TO DECREASED VERTICAL GROUND REACTION FORCES DURING SINGLE LIMB DROP JUMP LANDING

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ABSTRACT

Background: Prevention programs reduce hard and stiff landings associated with risk of anterior cruciate ligament (ACL) injury, yet cost and time are barriers to implementation. Providing feedback about landing mechanics during shooting drills at practices using minimal resources and time may improve adherence to educating athletes how to avoid risky mechanics associated with ACL injury when landing. Implementing video, auditory, written, and pictorial feedback into basketball practices to cue athletes on landing mechanics after taking a jump shot may soften the landing.

Purpose: The purpose of this study was to test whether implementing video, auditory, written, and pictorial feedback into a basketball practice jump shot drill (i.e., double limb drop jump landing task) will result in lesser vertical ground reaction force (vGRF) during a single limb drop jump landing without decreasing maximal jump height.

Study Design: Observational, Case-control Study

Methods: During a summer league, 16 female high school basketball players were assigned to an intervention (Int) or control (Con) group. The Int group (n=8) utilized delayed video feedback and task cards (written and pictorial cues) at six practices while the Con group (n=8) received typical coaching only. Cost and compliance with the intervention were measured. Pre- and post-season data collections included five single limb drop jumps from a 31 cm high box onto force plates. The vGRF impulses over the first 10% of landing were calculated for each limb. Data did not differ between limbs, thus data for both limbs were pooled. Two mixed model ANOVAs were used to compare groups over time ($p < 0.05$) for vGRF and maximum jump height, respectively.

Results: Compliance with the intervention was 100% and did not increase the time of drills. The implementation cost was less than \$10. A time*group interaction ($p = 0.04$; Int significantly decreased vGRF over time), main effect of time ($p = 0.004$), and no main effect of group ($p = 0.412$) were found for vGRF during single limb drop jump landings. A time*group interaction ($p = 0.03$; Int significantly decreased max jump height over time), no main effect of time ($p = 0.10$) and no main effect of group ($p = 0.32$) were found for max jump height.

Conclusion: Athletes landed more softly and jumped less high during a single limb drop jump landing task after receiving feedback during jump shot drills. High team compliance may occur since the intervention required minimal resources and addressed different learning styles.

Level of Evidence: Level 3b

Keywords: ACL, injury prevention, knee, movement system, soft landing, video feedback

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INTRODUCTION

An anterior cruciate ligament (ACL) injury is one of the most serious and costly lower extremity injuries an athlete can experience.¹ Young (15-25 year old) athletes account for more than half of the estimated annual 250,000 ACL injuries.² Young female athletes are twice as likely to suffer an ACL injury compared to their male counterparts.³ Neuromuscular training programs that include cues to land more softly have been proven to reduce ACL injury occurrence.^{4,5} However, barriers to implementing neuromuscular training programs include cost and lack of time.⁶ Compliance with neuromuscular training programs is low, and decreased compliance is associated with decreased effectiveness of the program.^{2,6} Utilizing a paradigm to educate athletes on proper landing techniques using minimal time and resources may increase compliance with the training program and in turn decrease risk of ACL injury.

Combining different types of feedback appears superior to use of a singular type of feedback for learning and retention of a new skill.⁷ Though multiple forms of feedback can alter biomechanics, enhance sports performance, and improve learning,⁸⁻¹⁰ how to best cue athletes during movement training is unclear. Concurrent feedback is effective at error correction and can improve performance, yet conflicting findings exist about the benefits of concurrent feedback on learning.^{11,12} Delayed feedback offers an athlete the opportunity to reflect on and incorporate the feedback, whereas concurrent feedback (i.e., sound heard when impacting the ground) does not. Thus, the learning and retention of a skill may be enhanced with delayed feedback.¹³ Viewing oneself has been found to be an effective tool for learning a skill as individuals try to imitate what they see on a screen or on a task card by the use of mirror neurons.¹⁴

Athletes may also resonate with cues that are corrective compared to avoidance or vice versa. Written cues on a task card can direct learners on how to properly perform a movement as well as what to avoid to inform different learning styles. For example, a “hard” landing may include unfavorable mechanics such as decreased hip and knee flexion.^{4,5} Thus, cues to avoid a “hard” landing and to land with increased hip and knee flexion would be a mix of avoidance and corrective cues. Another example could include cues to avoid inward knee collapse

(dynamic limb valgus), as this may be a compensatory strategy used to land more softly. Avoiding dynamic limb valgus is important as this position is related to increased risk of ACL injury in young female athletes.⁵ Also, cues to promote limb symmetry may reduce asymmetrical ligament and soft tissue loading, and in turn reduce the risk of injury.¹⁵

Correlations between poor landing biomechanics, increased ACL injury rates, and recurrent injury rates imply that educating female athletes to land properly is necessary and bears good results; yet, barriers to implementation limit the educational exchange.^{2,16} When considering training tasks, it is suggested that female basketball athletes participate in landing tasks,¹⁷ with researchers proposing double as well as single limb jump training due to deficient landing mechanics during single limb landing tasks.³ Additionally, female basketball players land with riskier movement patterns during single leg landing compared to male players.¹⁸ However, it is uncertain if feedback provided during double limb landing transfers to single limb landing tasks.¹⁹ If an intervention includes only training a double limb jump landing task instead of double, right, and left jump landing tasks, then the training time is reduced by two-thirds. Additionally, incorporating training time into an already existing jump shot drill eliminates the need for added training time.

The purpose of this study was to test whether implementing video, auditory, written, and pictorial feedback into a basketball practice jump shot drill (i.e., double limb drop jump landing task) would result in lesser vertical ground reaction force (vGRF) during a single limb drop jump landing without decreasing maximal jump height. The hypotheses were that the intervention would: 1) be implemented into practice with use of minimal time and resources; 2) result in athletes landing more softly [i.e., decreased vertical ground reaction force (vGRF) over time] during a single limb drop jump landing task; and 3) not decrease maximal vertical jump height over time compared to the control group.

METHODS

Research Participants

Pilot data from collegiate female basketball players (unpublished data IRB#082416-011) was used to

power this study. DSS research online sample size calculator was used to perform an *a priori* calculation for the main variable of interest, vGRF impulse. Alpha error level was set at 5% and Beta Error level at 80%. Pre vGRF values (2.5 ± 0.49 N/kg) and post vGRF values (2.2 ± 0.82 N/kg) over the first 10% of stance during a drop jump landing resulted in a sample size estimate of seven. The feasibility of self-assessing landing was also tested with the collegiate athletes. A task card was created (Figure 1) to illustrate the essential aspects of proper landing and what to avoid based on biomechanical profiles expected to reduce risk of ACL injury.^{2,5,18,20,21} Pictures chosen from a Google image search were copied into PowerPoint 2016, cropped, and red lines were added to highlight wanted and unwanted positions. Eight

written cues were included to match these images to cue soft landings, symmetrical loading, and frontal plane trunk and lower limb control. Collegiate players reported that viewing the task from a frontal angle was preferred over a sagittal angle to self-assess the “Do’s and Don’ts” on the task card.

Sixteen female high school basketball players (Table 1) were recruited as a sample of convenience due to increased risk of ACL ruptures in young female basketball players.³ Inclusion criteria were high school-aged female athletes who participated in a summer basketball league for their respective high schools and available for pre and post data collections. Criteria for ineligibility included a current injury that would prohibit or cause pain when landing from a drop jump or prior drop jump training. The coach of the intervention team expressed interest in implementing this feedback paradigm. Thus a sample of convenience was used to recruit athletes from this team to comprise the intervention group. Of the 20 players on this team, eight met eligibility criteria, volunteered for the study, attended a data collection session before and after the summer league, and received the intervention. Control players were recruited from teams in the same league as the intervention group to match the high-school age and level of sport. Controls ($n=8$) consisted of four players from one team and four players from two other teams. This study was approved by the University of New England’s IRB (# 050117-001) and signed assent/consent forms were obtained from each research participant and her parent/guardian. Participants were then scheduled for the pre-intervention data collection session, which occurred at the university’s motion analysis lab.

The pre-intervention data collection was performed during the first week of the summer basketball season (i.e., first week of July, 2017). Athletes in both groups were instructed to not alter training during the intervention phase (i.e., between pre and post data collections), so no new strength or fitness routine was started. The post-intervention data collection occurred within one week of completion of the summer season (i.e., last week of July 2017). During the summer league, practices occurred bi-weekly at the team’s high school gymnasium for three weeks.

Figure 1. This task card was designed to use written, pictorial, and auditory (i.e., don't land loud) cues of what to do to land properly and what not to do upon landing after taking a jump shot. Athletes were instructed to use this task card to systematically self-assess their landing performance when viewing the delayed video feedback of their jump shot.

Table 1. Descriptive / Demographic Data of Intervention and Control Group: means ($\pm$ SD).		
	Intervention (n=8)	Control (n=8)
Age (years)	15.4 ($\pm$ 0.7)	14.8 ($\pm$ 0.9)
BMI (kg/m ²)	21.6 ($\pm$ 2.5)	21.9 ($\pm$ 4.8)
History of injuries totals/ team	Concussion: 7 Back: 3 Hip: 0 Knee: 8 Ankle/foot : 22	Concussion: 7 Back: 2 Hip: 1 Knee: 5 Ankle/foot : 8
Years playing basketball	Basketball: 10 ($\pm$ 1.51) High School basketball: 2 ($\pm$.93) AAU basketball: 4.13 ($\pm$ 2.1)	Basketball: 7 ($\pm$ 3.12) High School basketball: 1 ($\pm$ 1.07) AAU basketball: 3.50 ($\pm$ 1.51)
kg= kilogram; m= meters; SD= standard deviation; AAU= Amateur Athletic Union.		

Data Collections

When the participants first arrived at the motion analysis lab, they were given a questionnaire to ascertain demographic information (Table 1). Participants were instructed to wear low ankle sneakers without braces or ankle tape during data collections. Participants were led through a short warm up: fast feet (15 seconds), double leg jumps (15 seconds), dominant and non-dominant single leg jumps (randomized, 15 seconds each limb), then five maximum height jumps from the floor.

After the warm-up, participants were told that they would be allowed drop jump practice landing on both legs and landing on one leg. The drop jump landing protocol was similar to Hewett and colleagues' protocol.⁹ Participants stepped onto a 31 cm box positioned 15.24 cm posterior to the force plate (BP600 1200, AMTI, USA) embedded in the ground. The bony prominence of the 5th metatarsal heads were palpated and a retro-reflective marker was placed on the participant's footwear to mark this location. Participants were positioned with their toes off the box so the marker over the 5th metatarsal head aligned with the front edge of the box. The drop jump instructions included: lean forward to drop off the box, do not jump off the box; once contact is made with the ground, then immediately jump as high as possible while attempting to rebound the basketball hanging from the ceiling. The basketball was attached to a pulley and a researcher raised or lowered the position of the ball's height to facilitate

best effort and promote maximal vertical jump height after landing.

Participants' drop jump landing mechanics were recorded using an eight camera three-dimensional (3D) motion capture system (Qualisys AB, Gothenburg, Sweden) set at 150Hz. Practice trials were given to instruct proper initiation of dropping off the box, landing cleanly on the force plate, and immediately jumping up once contracting the ground. Participants started with double limb drop jumps and completed two at 50% maximum effort and two at 100% maximum effort with rests as needed. Then the start leg was randomized for single drop jump landing trials. All participants reported that their right limb was their dominant limb defined as the leg they typically would use to kick a ball. Participants were then given two single limb practice drop jump landings at 50% maximum effort prior to collecting 100% maximum effort trials with rests as needed. A good trial was operationalized as properly dropping off the box, landing with clean foot contact on the force plate (AMTI, Watertown, MA, USA), and immediately jumping upon contacting the ground. Data were collected until eight good trials were completed during the single limb drop jump landing task. Lastly, participants repeated the single limb drop jump landing protocol on the contralateral limb until eight good trials were collected for this limb. Ground reaction forces and maximal jump height information collected during data collections were not shared with the participants until after the post-intervention data collection was completed.

Intervention Phase

After completion of the pre-intervention data collection, implementation of the intervention began at the next scheduled practice. The players in the intervention group received typical coaching and the feedback paradigm (i.e., viewed video of one's landing immediately after taking a jump shoot and used the task card to self-assess performance) during their high school summer league practices; whereas the players in the control group received typical coaching only. The orientation and intervention occurred during regularly held summer league basketball practices at the high school gymnasium twice weekly throughout the summer league.

The orientation to the intervention was provided by two individuals: a licensed physical therapist/ athletic trainer and an athletic training student who received a summer research stipend. The licensed physical therapist/ athletic trainer had 20-plus years of clinical experience and a PhD in Biomechanics and Movement Science. The athletic training student was in the 3rd year of her undergraduate education, had academic knowledge in kinesiology, knowledge of dysfunctional movement and how it related to injury, and practicum experience with noted skill in building rapport with high school athletes and educating them on self-assessing movements using knowledge of performance. The orientation consisted of familiarizing athletes to the task card (Figure 1), describing how to self-assess landing mechanics during a jump shot using the task card, and how to systematically assess performance while viewing their landing with the delayed video application. Players were instructed to listen to the sound upon landing and try to land soft and symmetrically without letting the knees fall inwards. Players were given strategies to self-assess such as when to listen to their landing, to view themselves from the ground up when watching the video feedback, and to use the task cards to prioritize one cue to implement at a time. Prior to starting the feedback paradigm, each athlete confirmed that she understood the information on the task card and how to use the different types of feedback to analyze her performance.

An Apple iPad® Mini 4 32GB (released in late 2015) was borrowed from the high school of the intervention team as it was not being used over the summer.

The iPad® Mini specifications included a 7.9" Retina Display, 2048 x 1536 Resolution, Dual-Core A8 Chip with Quad-Core Graphics, 8 MP iSight Camera, and 1080p HD Video (30 frames per second [fps]). The application, BaM Video Delay application (Orange Qube), was purchased for \$7.99 from the iTunes App store. This BaM Video Delay application was used to capture real time video simultaneously while replaying captured video after a set delay. For example, the athlete who just completed the jump shot could go to the iPad® Mini to view her performance while the app captured video of a second athlete currently taking the jump shot. The iPad® Mini was positioned to capture a frontal view of the participant completing a jump shot. The number of seconds of delay was set to approximately 10 seconds to ensure that the athlete had time to move to the iPad® Mini and be in position to view herself before the video replay started. The video replay speed was shown at the normal collection rate (30 fps) and the slow motion feature of the BaM Video Delay application was not used nor was the Slo-mo (120 fps) feature of the iPad mini® used.

The start of the drill was modified to have a teammate positioned under the basket to rebound the ball for the person starting the shooting drill. The shooter then proceeded directly to the iPad® to self-assess her landing while another player took a shot, and a third waited their turn in the shooting line. Sequentially, the athlete completed the shot, proceeded immediately to view the screen on the iPad®, and watched the video of herself to assess her landing mechanics during the jump shot. She compared her actual mechanics to the written and pictorial cues on the task card to determine whether she did or did not meet proper landing mechanics. After she finished viewing herself, she would go to the rebound line, then to the shooting line to take another jump shot. The athlete would reflect on her performance while in line. As the drill ended, the last player viewed the iPad® and took a moment to reflect on performance while another player retrieved her ball. Thus the inherent down time in line offset the time to reflect on the feedback gained during the self-assessment of the landing after the jump shot.

Each player continued this pattern three times (take a jump shot, go to the iPad®, self-assess performance,

retrieve a ball, and get back in line for the shooting drill). This feedback paradigm occurred during the jump shot drills at the beginning and end of every practice session (twice per week) over a three week period. Therefore, players viewed performance a maximum of 36 times: six practices with six views per practice. A member of the research team (i.e., licensed clinician or athletic trainer student) was present at each practice to document the number of times the intervention was completed throughout the season. The researcher oversaw each practice drill for the intervention group to verify that the feedback paradigm was implemented as designed, including ensuring that the athlete viewed the video of her landing and used the task card to self-assess her performance. The licensed clinician was present for the initial orientation, the first practice, and the last practice. The 3rd year athletic training student attended the initial orientation and all practices except the last practice. There was 100% compliance with the intervention completed as described for all practices.

Data Analysis

The vGRF impulse, which is the vGRF over time, was calculated using Visual 3D software (C-Motion, Inc., Germantown, MD) during the first 10% of the

landing phase.¹⁶ Video analysis of ACL injuries sustained during basketball games indicates the time of injury can occur 50 milliseconds after initial contact, indicating that injury likely happens soon after landing.²² Additionally, the vGRF impulse provides greater detail than one instant in time (e.g., initial contact, peak vGRF). For example, the vGRF impulse captures data about the rate and attenuation of force soon after landing (Figure 2). Eight clean trials were collected during the single limb drop jump task for each limb and were viewed to assure the force plate data were usable. A 3D analysis of a standing / static trial was used to measure the distance from the floor to the pelvis via a marker cluster taped to the base of the sacrum and to measure participant's height by measuring the distance from the floor to a retro-reflective marker placed on the top of her head. This pelvis cluster was then used to track maximal vertical jump height. A custom written software program chose five random trials from the clean, usable options which were then used for data analysis. Average values for the vGRF impulse over first 10% of stance and maximum jump height data were calculated using five trials for the dominant and five trials for the non-dominant limbs during the single limb landing task.

Figure 2. Data in this graph illustrates the vertical ground reaction forces (Newtons normalized by kilogram) when dropping from a 31 cm box and landing on one limb. The entire landing phase is shown for each limb (dominant and non-dominant sides) for each group (control and intervention) for each data collection (before and after the intervention phase).

Statistical analyses were conducted using SPSS (IBM SPSS Statistics for Windows, Version 21.0. Armonk, NY: IBM Corp). This study was not powered to account for covariates; yet descriptive statistics were calculated for demographic and background variables for each group. (Table 1) Comparisons were performed to test whether dominant and non-dominant limb data could be combined. Two mixed model ANOVAs were used to compare differences between groups (intervention and control) and time (pre-intervention and post-intervention) for vGRF impulses and maximum jump height during the single limb drop jump landing tasks with limb data combined. Bonferroni confidence interval adjustments were used to further examine interaction effects. A p-value of $p < 0.05$ defined statistical significance.

RESULTS

Implementation of the feedback paradigm in the high school practice setting was feasible with minimal cost (i.e., less than \$1 to color print and laminate the task card, \$8 for BaM video delay application in the iTunes App store, iPad® was borrowed from the high school). If purchased, the iPad® mini would have cost \$329. Athletes who participated in the intervention did not take longer to complete the drill, nor did they have less attempts/ shots taken during the shooting drill. Since the feedback paradigm took less than 10 seconds, the intervention was efficiently incorporated into the “wait” time in line for the drill. Thus, the athletes obtained various types of feedback about their landing mechanics without adding time to complete the drill or disrupting the flow of practice. Additionally, the inherent

down time in the rebound and shooting lines was utilized to efficiently reflect on their landing performance during the jump shot.

There were no statistically significant differences between limbs for the single limb drop jump landing task (i.e., vGRF impulse over 10% of stance: $p = 0.097$; max jump height: $p = 0.201$), thus data for the dominant and non-dominant limbs were combined. (Table 2) Findings for vGRF impulse during the first 10% of the landing phase included a group by time interaction ($p = 0.04$), main effect of time ($p = 0.004$), and no main effect of group ($p = 0.412$). Post hoc analysis revealed a decrease of 0.32 Ns/kg (a decrease of 32% bodyweight) over time for the intervention group and no change in the control group. (Table 3)

Findings for maximal vertical jump height included a group by time interaction ($p = 0.03$) and no main effect of time ($p = 0.100$) or group ($p = 0.320$). Post hoc analysis revealed a decrease of 0.023 m (2.3 cm; 0.91 inches) over time for the intervention group and no significant change in the control group. (Table 4)

DISCUSSION

The main purpose of this study was to test the feasibility of providing varied types of feedback on landing mechanics to female high school basketball players using minimal time and resources. Findings indicate that delayed video feedback and task cards can be implemented within scheduled practice times without financial burden. The immediate effects of the intervention on the movement system were juxtaposed as vertical ground reaction forces (vGRF) during the early phase of landing from a

Table 2. Vertical ground reaction forces (Ns/kg) for biomechanics for single limb landings for group and limb over time; means (SD).				
	Dominant		Non Dominant	
	Pre-intervention	Post-intervention	Pre-intervention	Post-intervention
Intervention Group	2.33 (0.64)	2.20 (0.63)	2.57 (0.45)	2.06 (0.37)
Control Group	2.61 (0.69)	2.63 (0.74)	2.53 (0.82)	2.38 (0.76)
N= Newton; s= seconds; kg= kilogram; SD= standard deviation.				

Table 3. Vertical ground reaction forces (Ns/kg) for single limb landings for groups and times with data for dominant and non-dominant limbs collapsed
Means (standard error) and lower – upper bound of the 95% confidence interval.

	Pre-intervention	Post-intervention
Intervention Group	2.45 (0.21) 2.00-2.91	2.13 (0.20) 1.70-2.57
Control Group	2.57 (0.21) 2.12-3.02	2.51 (0.20) 2.07-2.94
N= Newton; s= seconds; kg= kilogram.		

Table 4. Maximal vertical jump height (m) for single limb landings for groups and times with data for dominant and non-dominant limbs collapsed
Means (standard error) and lower – upper bound of the 95% confidence interval.

	Pre-intervention	Post-intervention
Intervention Group	0.271 (0.014) 0.241-0.302	0.248 (0.013) 0.220-0.276
Control Group	0.277 (0.014) 0.247-0.307	0.281 (0.013) 0.252-0.309
m= meters.		

single limb drop jump decreased, yet the maximal vertical jump height decreased. Although the reduction in vGRF are promising, altered cueing appears warranted to have athletes land softer without compromising jump height performance immediately after landing.

The novelty of this study is that it provides a platform for coaches and sports specialists to use combined cues to educate female athletes about proper landing mechanics. Feedback was chosen purposefully to accommodate different learning styles (i.e., visual/spatial, auditory, verbal). Feedback included task cards (i.e., corrective and avoidance cues using pictures and written instruction, and an auditory cue to focus attention to sound on impact) as well as use of a delayed video application (i.e., video of oneself landing after a jump shot was immediately viewed and athletes self-assessed landing mechanics). Integrating a feedback paradigm into the flow of the scheduled practice setting that required minimal financial resources was also purposeful. Since this intervention

was implemented without increasing practice time and with minimal cost, this intervention shows promise for high compliance rates with coaches and athletes.^{2,6,23} Evidence already supports that coach-led prevention programs can be effective at reducing the risk of ACL injuries in athletes.^{24,25} Also, a recent meta-analysis reported that in-season training alone is not as effective at lowering risk of knee injury when compared to pre-season training.²⁶ Though this intervention was implemented during the summer league and not pre-season, training athletes to land more softly during a low-stakes league may allow prioritization of learning to improve a skill compared to prioritization of other goals when in-season.

The implications that cueing athletes how to land properly during a common shooting drill may translate to a provocative single limb drop jump task improves the likelihood for coaches to utilize this educational paradigm. The transference of altered performance during a single limb drop jump landing task after training using a feedback paradigm

during a double limb landing task (i.e., jump shot) is a desired effect for two reasons. First, the significant decrease in vGRF during single limb landings suggests that training athletes to land softly during a single limb task is not required in addition to task training when landing on both limbs. Others²⁷ have found that movement training during jump landing tasks transferred to cutting tasks. Second, the statistically significant decrease in vGRF impulse over time for the single limb drop jump (i.e., decrease of 0.32 Ns/kg) is likely clinically meaningful as it equates to a 15% difference from pre- to post-intervention (i.e., $[(\text{Post vGRF} - \text{Pre vGRF}) / \text{Pre vGRF}] * 100$). Though there is greater vGRF during a single compared to double limb landing,²⁸ more is known about risk of injury and magnitude of vGRF during double limb landings. For example, Hewett and colleagues reported that those who went on to rupture their ACL exhibited 20% larger peak vGRF (i.e., 208 N) than those who did not get injured (1266 N vs 1058 N, respectively).⁵ The cumulative effects of softer landings are also noteworthy as game analysis of professional basketball players indicate players average 70 jumps per game, though this is position dependent.²⁹

The benefits of reduced vGRF immediately upon landing are clear, yet the reduction in maximal jump height over time in the intervention group was unwanted. The primary goal is to keep athletes healthy; however, vertical jump height performance is desirable regardless of playing position.³⁰ Comparisons between vertical jump height in female junior elite athletes (e.g., mean 15.2 years old) based on rank and position (i.e., point guard, shooting guard, forward, and center) indicated that only the best ranked point guards jumped significantly higher (i.e., 7.8 cm) than point guards with lower ranking.³¹ It is unclear whether this study's finding of a 2.3 cm (i.e., 0.91 inches) decrease in maximal jump height influences performance.

The decline in maximal jump height may be due to several reasons. First, athletes in the intervention group spent three weeks learning how to land from a jump and may have switched their focus during the post-intervention data collection. Perhaps the pre-intervention data collection drop jumps were automatic, then switched to controlled processing at the post-intervention data collection to jump correctly

which requires attention.¹³ The two-task focus (e.g., attention to a movement pattern and maximum jump height) may interfere as attention is a limited resource. Second, attention to maximal jump height performance was never cued during the intervention. During the intervention, cues were given to land correctly and likely contributed to decreased vGRF; whereas cues to maximize jump height were only given during the pre- and post-intervention data collections. Third, the task card included primarily internally focused cues that directed attention to body position with only one externally focused cue (i.e., don't land loud). Evidence suggests that feedback directed at one's movements (i.e., explicit cues with internal focus) may worsen performance.¹⁰

Since performance declined (i.e., reduced maximum jump height) in the intervention group, recommendations to change cues to counteract this unwanted effect are provided. A staggered intervention approach may be beneficial: first cues to land properly, then switch attention to land properly while maximizing jump height. Borrowing from existing evidence, including externally focused cues, to improve jump height performance also appears warranted.³²⁻³⁴ Motivational and attentional cues have also been shown to improve jump height performance,³² thus follow-up studies should use cues to increase jump height. Since internal cues may worsen performance¹⁰ and external cues have been shown to improve kinematics during jump training, perhaps the cues on the task card should focus the athlete's attention externally and not internally.^{27,32} For example, keeping the externally focused cues (i.e., land quietly) and changing internally focused to externally focused cues may augment learning to land softly without decreasing jump height performance.³⁵ Evidence also suggests that two-dimensional external cues (i.e., keep markers on knees apart) may help avoid a dynamic limb valgus position.³⁶ Others propose cueing hip muscles to decrease dynamic limb valgus to make the athlete more aware of muscle activation during landing.³⁷ Further research is needed to ensure that young female athletes are cued to learn how to land safely while also optimizing performance.

Though modification of the cues have been proposed, the recommendation to use varied sources

of feedback to cater to different styles of learning among athletes on one team remain.²³ Concurrent auditory cues (i.e., sound at the impact of the landing) and delayed feedback (e.g., written, pictorial, visual, video of oneself doing the task) allow for different mechanisms to process the information. Of all types of feedback, delayed feedback may be preferable to instantaneous feedback because of the opportunity for the athlete to learn and self-correct.³⁸ The feedback paradigm used simple observation, self-assessment, and reflection to mitigate high impact forces. This paradigm supports the notion that including more technical components (e.g., observing one's force vectors, joint angles, and moments in real time) in to a training paradigm was not associated with better outcomes.²⁶ Additionally, providing enhanced expectations for performance (e.g., comparative feedback such as your performance was better than average or better than others), autonomy support (e.g., have the athlete decide on the type of feedback or how the feedback is delivered), and an external focus of attention (e.g., exert less force on the ground) in combination may lead to superior motor learning.³⁹ Therefore, since female basketball players are at high risk for ACL injuries,⁴⁰ coaches should consider a multi-modal approach to train athletes to avoid risky landing mechanics associated with ACL injury.⁴¹

When considering these findings, it is important to consider the limitations. This study was not a prevention study and effects on limb position cannot be inferred as the sample size was small and not powered to investigate measures of dynamic limb valgus. Additionally, it is unknown which forms of feedback each participant primarily used. Though the written and pictorial cues were provided to self-assess frontal plane motion, the effects of these specific cues on limb kinematics are unknown. Although statistically significant and large magnitude of change was found in vGRF for the intervention group which may reduce risk of ACL injury, not all risky biomechanics were tested (e.g., knee and trunk mechanics and limb asymmetries during landing).⁴¹

Participants were high school-aged female basketball players; thus the generalizability of results is limited to this demographic. The high school summer league's short season with few practices limited the

dosage of the intervention (e.g., 36 exposures over three weeks). In addition, practice plans may have differed between teams and time spent for drills and scrimmage were not controlled. Shooting percentages during games were not tracked during the summer league, thus this study was not designed to ascertain whether scoring was affected by the intervention. Feedback was not faded over time. There was also no follow-up data collection to test retention and confirm that the athletes would maintain movement patterns once cuing ceased.

CONCLUSIONS

Providing female high school athletes with varied feedback during a jump shot drill is feasible and uses minimal time and resources. The feedback paradigm was provided during a double limb landing task at basketball practices but reductions in vertical ground reaction forces were noted when landing from a single limb drop jump. This intervention was easily integrated into the flow of practice. Combined auditory, written, pictorial, and delayed video feedback may be beneficial to learn proper movement techniques during jump landing for female basketball athletes at risk for ACL injury. Further investigation is needed to determine optimal cues to maintain performance and retention as cues are faded and removed.

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