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Lower Extremity Landing Biomechanics in Both Sexes After a Functional Exercise Protocol

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Context: Sex differences in landing biomechanics play a role in increased rates of anterior cruciate ligament (ACL) injuries in female athletes. Exercising to various states of fatigue may negatively affect landing mechanics, resulting in a higher injury risk, but research is inconclusive regarding sex differences in response to fatigue.

Objective: To use the Landing Error Scoring System (LESS), a valid clinical movement-analysis tool, to determine the effects of exercise on the landing biomechanics of males and females.

Design: Cross-sectional study.

Setting: University laboratory.

Patients or Other Participants: Thirty-six (18 men, 18 women) healthy college-aged athletes (members of varsity, club, or intramural teams) with no history of ACL injury or prior participation in an ACL injury-prevention program.

Intervention(s): Participants were videotaped performing 3 jump-landing trials before and after performance of a functional, sportlike exercise protocol consisting of repetitive sprinting, jumping, and cutting tasks.

Main Outcome Measure(s): Landing technique was evaluated using the LESS. A higher LESS score indicates more errors. The mean of the 3 LESS scores in each condition (preexercise and postexercise) was used for statistical analysis.

Results: Women scored higher on the LESS (6.3 ± 1.9) than men (5.0 ± 2.3) regardless of time ($P = .04$). Postexercise scores (6.3 ± 2.1) were higher than preexercise scores (5.0 ± 2.1) for both sexes ($P = .01$), but women were not affected to a greater degree than men ($P = .62$).

Conclusions: As evidenced by their higher LESS scores, females demonstrated more errors in landing technique than males, which may contribute to their increased rate of ACL injury. Both sexes displayed poor technique after the exercise protocol, which may indicate that participants experience a higher risk of ACL injury in the presence of fatigue.

Key Words: anterior cruciate ligament, fatigue, Landing Error Scoring System

Key Points

- Women consistently demonstrated higher Landing Error Scoring System scores than men, committing more errors in landing technique both before and after exercise.
- The Landing Error Scoring System scores for both sexes increased after exercise, indicating that both males and females were more likely to demonstrate high-risk landing mechanics when fatigued.
- A relatively short period of intense exercise was sufficient to cause detrimental changes in landing mechanics.

An anterior cruciate ligament (ACL) tear is a common and debilitating injury in the athletic population.[1] Approximately 70% of ACL injuries during athletic activities result from a noncontact mechanism involving a deceleration task such as cutting, pivoting, or landing.[2] Female athletes continue to have a substantially (4 to 6 times) higher risk of noncontact ACL injury than male athletes participating in the same sports.[1,3] In addition to posing a financial burden, ACL injury has multiple long-term health consequences, including functional limitations and a markedly increased risk of disability and osteoarthritis.[4]

Researchers have established multiple intrinsic and extrinsic risk factors that may contribute to an individual's sustaining an ACL injury. It is widely believed that altered movement strategies may be most relevant to females' increased incidence of noncontact ACL injury.[2,5] Specific movement patterns commonly observed at the time of injury include increased knee valgus and tibial rotation in combination with decreased flexion at the knee, hip, and trunk.[2,5] Laboratory studies[6,7] and video analysis of actual ACL injuries in game situations[2,5] have shown that female athletes are more likely to demonstrate these potentially detrimental landing characteristics than their male counterparts. Individuals displaying these patterns are at greater risk of knee injury.[6,8] The Landing Error Scoring System (LESS) is a clinical movement-assessment tool that can be used to identify these patterns.[9,10]

An additional factor that may affect injury risk is neuromuscular fatigue.[11] Epidemiologic findings support the concept that fatigue may be a predisposing factor for injuries during athletic events.[12,13] Overall injury rates increase during the final minutes of competition[12,13] as well as in the later portions of the season[12] when the effects of fatigue are likely to become cumulative. Specifically, Hawkins and Fuller's data[13] indicated that a large percentage of noncontact knee injuries occurred in the last 15 minutes of the first half and the last 30 minutes of the second half of a soccer match. Fatigue has been hypothesized to alter neuromuscular-control factors associated with an increased risk of sustaining musculoskeletal injury. The combination of fatigue with an already high-risk movement pattern may further increase the chance of injury.[11,14,15] If females respond to fatigue differently than males do, this may be an additional risk factor for ACL injuries.[16] However, the specific movement patterns affected remain largely unknown because designs and results vary among studies.

Few authors have examined the potential for such changes within the context of an exercise protocol that effectively simulates the demands of sport participation.[11,15] Previous researchers have used exercise protocols that have been short in duration,[11,17–19] consisted only of open kinetic chain tasks,[16] or required participants to repeat a single task such as parallel squats.[14,20] Investigators evaluating longer durations of exercise have used treadmill running or sprinting[18,21] rather than the multidirectional tasks inherent to most sports.

The few studies that have incorporated functional tasks have produced various results due to differences in duration and design. After 4 minutes of step-up and bounding tasks, McLean et al[11] found changes in only the frontal plane. Both sexes demonstrated increases in knee internal-rotation and abduction motion after exercise, and females demonstrated higher peak abduction moments than males.[11] Similarly, after a protocol of repeated vertical jumps and sprints until volitional exhaustion, Chappell et al[15] documented in both sexes an increase in knee-valgus moment and a decrease in knee-flexion angle. Although 4 minutes appears long enough to induce some alterations in landing mechanics, additional changes in sagittal-plane movement have occurred in a study with a slightly longer duration of exercise.[19] After 6 minutes of soccer drills, female National Collegiate Athletic Association Division I soccer players landed with increased knee internal-rotation and decreased knee- and hip-flexion angle. Both a longer duration and incorporation of multidirectional tasks may be necessary to truly assess changes.

Whereas such protocols may certainly have placed physical demands on the participants, they do not fully replicate the loading conditions sustained by the lower extremity during athletic activity. In order to obtain the most relevant findings and apply conclusions to the athletic population, we developed a functional exercise protocol consisting of a variety of multidirectional tasks and sought to extend the duration compared with that of previous studies.[11,15,19] To make our study as clinically relevant as possible, we chose the LESS to evaluate landing technique.[9] It is a valid and reliable clinical movement-assessment tool that allows for efficient evaluation of high-risk movement patterns.[9]

By using a sportlike protocol and the clinical assessment of a landing task, our exercise tasks and assessment tool are applicable to the athletic population and feasible for use by clinicians. Considering the relationship of landing mechanics to noncontact ACL injury, studying the effects of exercise on biomechanical characteristics while in a fatigued state may provide insight into injury risk.[11,14,15,17,20] Therefore, the purpose of this study was to assess the effects of fatigue induced by a functional exercise protocol on the landing biomechanics of males and females. We hypothesized that females would commit more landing errors than males in both the preexercise and postexercise conditions. Furthermore, we hypothesized that the exercise protocol would have a detrimental effect on all participants' landing biomechanics, causing them to commit more errors after the protocol. Last, we hypothesized that these exercise-induced changes would be more prominent in females than in males.

METHODS

We used a repeated-measures design in this study. The independent variables were sex (male and female) and exercise (preexercise and postexercise). The dependent variable was the LESS score.

Participants

Based on previous literature evaluating the effect of fatigue on landing mechanics,[11,17,22] we determined that a sample size of approximately 18 participants per group was needed for a power of 0.8, an α level of .05, and an anticipated effect size of 0.8. We recruited 36 healthy, active participants (18 men: age = 19.4 ± 1.4 years, height = 185.4 ± 6.5 cm, mass = 83.1 ± 13.2 kg; 18 women: age = 19.2 ± 0.9 years, height = 169.0 ± 7.8 cm, mass = 65.2 ± 7.1 kg) for this study. All were students at a large midwestern university and were currently involved in some form of organized sporting activity on campus; this included National Collegiate Athletic Association Division I, intramural, and club athletics. Participants were active in a variety of sports, with the most representation in basketball (12), soccer (7), flag football (3), and volleyball (3). Study participants were required to have at least 1 year of involvement in their respective sport (mean, 8.4 ± 4.7 years) and to report being active in their sport a minimum of 3 days per week for at least 1 hour each day. We excluded participants if they had experienced a lower extremity injury in the past 6 months, head injury in the past 6 months, or lower extremity surgery in the past year or had any history of ACL injury or surgery. We also excluded those who had previously been involved in an ACL injury-prevention program or received formal jump-landing instruction. Before the study, all participants read and signed an informed consent form approved by the university's Institutional Review Board for the Protection of Human Subjects.

Before data collection, the lead author reviewed the LESS training materials and completed practice assessments, as described and provided by Padua et al.[9] In addition, we calculated intrarater reliability in determining LESS scores for the lead author using a pilot group of 5 participants. The intraclass correlation coefficient (ICC [2,k]) was 0.99 and the standard error of the measurement was 0.19.

Testing Procedures

All testing occurred in a single session and took place in a university gymnasium. We instructed participants to wear clothing and shoes they would normally wear during sport involvement, as well as to avoid physical activity for 12 hours preceding their data-collection session.

Upon arrival at the testing site, participants completed a questionnaire regarding their medical history and sports

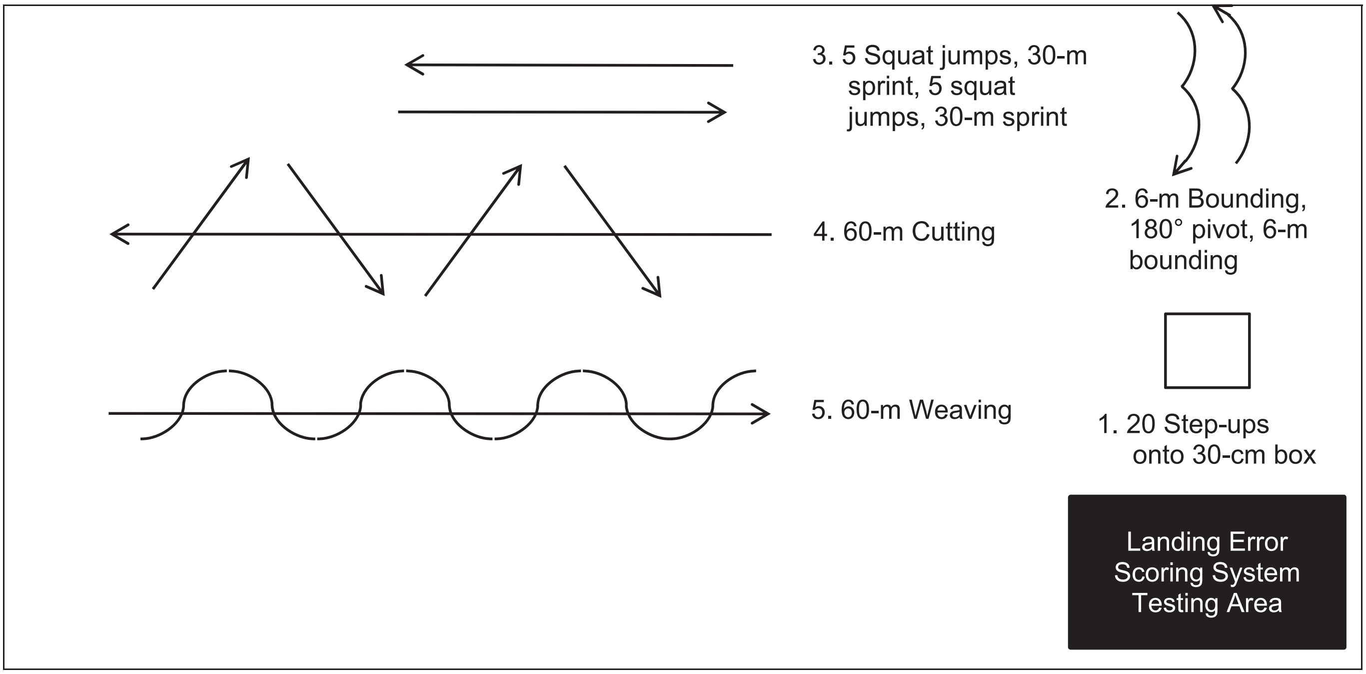

Figure 1. Exercise course design.

involvement. We placed a heart-rate monitor (Vantage XL; Polar USA Inc, Stamford, CT) around the chest of the participants and recorded resting heart rate. Similar to previous studies,[11,21] we monitored heart rate throughout the exercise protocol to evaluate the level of exercise intensity. To increase heart rate and prepare the body for exercise, participants performed a self-directed warm-up consisting of 5 minutes of stationary bicycle riding and 5 minutes of lower extremity stretches.

Preexercise

The LESS. We collected LESS data using procedures described by Padua et al.[9] Participants performed 3 trials of a double-legged jump-landing task from a 30-cm box. Participants jumped forward from the box to a distance equivalent to 50% of their body height, landing on both feet, and immediately jumped upward as high as possible. To eliminate coaching effects, we explained the task but did not provide a physical demonstration of or instruction in a proper landing technique. We permitted up to 3 practice attempts to allow participants to become comfortable with the task. We then videotaped 3 trials of the task, with a 10-second rest period between repetitions. We placed 2 standard 30-Hz video cameras (Sony DCR-SR42 Handycam; Sony Corp, Tokyo, Japan) on tripods set to a height of 40 cm and positioned 2 m from the front and left sides of the landing area.

Vertical Jump. We measured the participants' maximal vertical-jump height using the Vertec device (Sports Imports Inc, Columbus, OH). We incorporated this measurement in order to have an objective measure of fatigue as directly related to lower extremity power.[23]

Participants performed a countermovement jump from a stationary position; they squatted down, swung their arms, and jumped upward as high as possible, touching the highest possible point on the Vertec with their dominant hand. They performed 3 trials of the jump for maximal vertical height, with a 10-second rest period between trials.[21] The average of the 3 maximal jumps was recorded as the participant's maximum vertical-jump height (cm).[18]

Exercise Protocol

After completing the 3 jump-landing trials and maximal vertical-jump height measurements, participants took part in our functional exercise protocol, which consisted of 5 tasks compiled from previous research.[11,14,15] We set up the tasks as a circuit in the gymnasium (Figure 1) so that participants could quickly move from one exercise to the next. Participants first performed a series of 20 step-up/step-downs onto a box 30 cm in height.[11,18] Then they performed a plyometric bounding task for 6 m, pivoted, and repeated the bounding task for an additional 6 m.[11] In the next task, participants alternated 5 squat jumps, a 30-m sprint, a second series of 5 jumps, and a 30-m sprint back to the starting point.[15] They then performed right-to-left diagonal cutting over a distance of 60 m and last, weaving ("carioca") over a distance of 60 m.[24] We instructed participants to exercise at a high intensity, using the term *game speed* to provide them with an idea of their expected pace. They continued at a fast pace but one that would allow them to complete multiple repetitions. To encourage high-intensity exercise, we informed them that we were measuring heart rate and encouraged them to go at a fast pace because their heart rate would increase with more intense exercise. We did not inform participants that we were measuring vertical-jump height, to deter bias during jumps. After each repetition of the course, we recorded vertical-jump height, heart rate, and time required to complete the repetition.

Table 1. Landing Error Scoring System, Vertical-Jump, and Heart-Rate Values Before and After Exercise Protocol (Mean ± SD)

	Landing Error Scoring System Score		Vertical Jump, cm		Heart Rate, bpm	
Group	Pretest	Posttest	Pretest	Posttest	Pretest	Posttest
Males	4.2 ± 2.1	5.6 ± 2.3	50.4 ± 5.0	42.3 ± 7.4	79.4 ± 10.0	182.8 ± 16.2
Females	5.7 ± 1.9	6.9 ± 1.7	42.8 ± 5.6	37.2 ± 5.3	79.6 ± 8.9	187.1 ± 10.3
Overall	5.0 ± 2.0	6.3 ± 2.0	46.6 ± 5.3	39.8 ± 6.3	79.5 ± 9.4	185.0 ± 13.2

We considered the onset of fatigue to occur when participants demonstrated a decrease in vertical-jump height of at least 5 cm (2 in) on 2 consecutive course repetitions. This was based on previous research; after a fatiguing effort similar to ours, Chappell et al[15] documented a mean decrease in vertical-jump height of 5 cm and considered this an indication of lower extremity fatigue for all participants. In order to allow participants to progress further into a fatigued state and create a stronger differentiation between the 2 test conditions, we required our participants to complete 1 additional repetition of the exercise course after they reached the 5-cm decrease in jump height. We informed them when they had 1 repetition remaining and encouraged them to give maximum effort on this final repetition.

Postexercise

Immediately after completion of the exercise protocol, we recorded final heart rate and measured maximal vertical-jump height using the Vertec. Participants returned immediately, without rest, to the LESS testing area. We collected LESS data through 3 trials of the jump-landing task in the same manner as during the preexercise testing but without the rest period between trials. Last, we encouraged participants to cool down by walking or stretching.

Data Processing

After all data collection, the lead author reviewed the video of each participant using Adobe Premiere Version 4.0 software (Adobe Systems Incorporated, San Jose, CA) and scored the jumps using the LESS rubric. Scoring is based on multiple characteristics observed: knee-flexion angle, knee-valgus angle, trunk-flexion angle, ankle-joint plantar-flexion angle, foot position, stance width, timing of foot contact, sagittal-plane joint motion, and the rater's overall impression of the quality of the landing motion. A higher LESS score indicates more errors, high-risk landing technique, and a potentially higher risk of noncontact ACL injury.[9] To prevent bias, we randomly selected participant numbers to determine the order in which videos were scored. The lead author reviewed videos and scored each trial. The mean of the 3 scores for each participant in each condition (preexercise and postexercise) was used for statistical analysis.[10,25]

Table 2. Course Repetition Data (Mean ± SD)

Group	Time to Fatigue, min	Repetitions of Course	Time per Repetition, min
Males	12:03 ± 3:52	6.0 ± 2.0	2:00
Females	15:56 ± 4:35	7.7 ± 2.6	2:13
Overall	13:52 ± 4:13	6.8 ± 2.3	2:06

Statistical Analysis

We performed statistical analysis of LESS scores, heart rate, vertical-jump height, and course duration using SPSS statistical software (version 16.0; SPSS Inc, Chicago, IL). All data were treated as continuous variables.[26] For each dependent variable, we examined data using a 2 × 2 repeated-measures analysis of variance (ANOVA) with 1 within-subject factor (test at 2 levels) and 1 between-subjects factor (sex at 2 levels). Alpha was set a priori at $P \leq .05$.

RESULTS

Means and standard deviations for LESS scores, vertical jump, and heart-rate data are reported in Table 1. Data related to completion of the exercise protocol are presented in Table 2.

For the LESS scores, results of a 2 × 2 repeated-measures ANOVA revealed no significant test-by-sex interaction ($F_{1,34} = .25$, $P = .62$), as presented in Figure 2. However, significant main effects for sex ($F_{1,34} = 4.40$, $P = .04$) and test ($F_{1,34} = 24.65$, $P < .001$) were identified. Women scored significantly higher on the LESS (6.3 ± 1.8) than their male counterparts (4.9 ± 2.2), regardless of time. Overall, postexercise scores were significantly higher than preexercise scores (mean difference = 1.3, 95% CI = 0.8, 1.8).

In analyzing jump height, we identified no test-by-sex interaction ($F_{1,34} = 1.79$, $P = .19$). We discovered a significant difference between sexes ($F_{1,34} = 13.54$, $P = .001$), with men jumping higher than women (46.4 ± 6.2 cm and 40.0 ± 5.5 cm, respectively). In addition, both male and female participants had a significant reduction in jump height after the exercise intervention ($F_{1,34} = 53.81$, $P =$

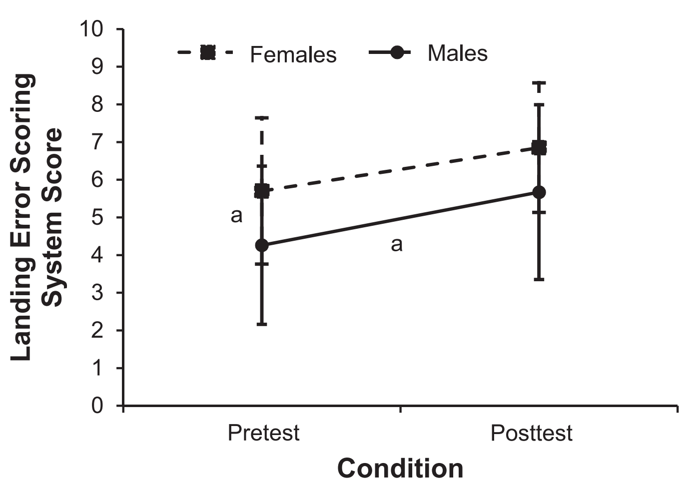

Figure 2. Influences of sex and exercise status on Landing Error Scoring System score. [a] Significant differences between females and males and between pretest and posttest.

.001). Specifically, both sexes had a decreased ability to generate power after the exercise protocol (preexercise to postexercise mean difference = 6.8 cm, 95% CI = 4.9, 8.7).

For heart rate, we did not identify a test-by-sex interaction ($F_{1,34}$ = .60, P = .45). We also found no differences in heart rate between the male and female participants ($F_{1,34}$ = .58, P = .45), but both sexes were significantly affected by the exercise intervention ($F_{1,34}$ = 1615.29, P = .001). Heart rates increased from an average of 79.5 ± 9.4 to 185.0 ± 13.2 beats per minute, indicating exertion by both sexes.

DISCUSSION

The purpose of this study was to examine the effects of a high-intensity exercise protocol on landing mechanics as quantified by the LESS. We also sought to determine whether these effects would be more pronounced in females. A key finding was that women scored higher on the LESS, both before and after fatigue, indicating that overall, they committed more movement errors than men.

Sex differences in LESS scores are well supported in the literature, with females consistently scoring higher than males.[9,10,27] Use of the LESS allows researchers to efficiently screen for movement patterns associated with ACL injury risk that could previously have been evaluated only with complex motion-analysis systems. Specifically, research using the LESS has documented that females are more likely to land with less hip and knee flexion at initial ground contact.[27] In addition, throughout the landing task, females use less overall hip- and knee-flexion motion[9,27] and more valgus motion.[9] In a study by Padua et al,[9] females were more likely than males to be placed in the "poor" landing technique category (defined as a LESS score greater than 6). In a study of more than 2700 military cadets, the mean LESS score was 5.3 ± 1.5 for females and 4.7 ± 1.7 for males, a difference that was statistically significant.[27] Our participants scored within similar ranges (6.3 for women and 5.0 for men), and our findings support the existence of sex differences in LESS scores across several active populations.

The second key finding of our study was that LESS scores increased in both sexes after the exercise intervention, from an average of 5.0 ± 2.3 to 6.3 ± 1.9. Our results support previous research[11,17,18,21] demonstrating that both sexes exhibit altered and potentially more harmful landing mechanics during a variety of tasks when in a fatigued condition. In terms of the LESS, this means that participants' postexercise scores of greater than 6 placed them in the category of high-risk jump-landing technique.[10] Before our study, such changes had not been assessed using the LESS.

Motion analysis revealed increased knee abduction in both males and females after exercise protocols similar to ours.[11,14] Several authors[6,16,18] have documented fatigue-induced decreases in hip and knee flexion, resulting in a more extended, "stiff" landing position. This relates to injury risk because landing in a more extended position is believed to increase anterior tibial translation and strain on the ACL.[15,18,21] Potentially increasing ACL strain further, Chappell et al[15] discovered that at the time of peak anterior tibial shear force, females demonstrate a valgus moment, whereas males demonstrate a protective varus moment. When this increased valgus moment demonstrated by females is combined with the increased anterior tibial translation that also occurs with fatigue,[28] a particularly hazardous loading state for the ACL may occur.[15] In other words, the combination of a knee-valgus moment with decreased hip or knee flexion may result in a greater risk of ACL injury than any of these characteristics on their own.[29] Repetitive loading in this manner, such as would occur during sustained exercise, may increase the risk of ACL injury.[15]

We sought to replicate the sustained, high-intensity effort required of athletes in sports with the highest risk of ACL injury (ie, basketball and soccer). Our exercise protocol was based on previous research,[11,15,18,24] but the combination of tasks and effort duration are unique to our study. We incorporated forward sprints and jumps, lateral and diagonal movements through cutting and carioca, and rotational movements through pivoting. These tasks required a variety of muscle-recruitment patterns, including acceleration and deceleration in different planes of motion.[18] Our purpose in placing these demands on our participants was to fatigue them in a way that is similar to athletic activity, thereby giving our findings greater applicability outside the laboratory setting. Previous authors have required participants to run on a treadmill,[18,21] repeat a single task such as vertical jumps,[23] or exercise for only a short time (less than 5 minutes).[11,17] In contrast, our participants performed 5 different exercises continuously at a high intensity for an average of 14 minutes before reaching our baseline criteria for fatigue. This protocol simulated the demands of a moderate-length intense competition, when injuries are likely to occur.[13,21]

We also sought to monitor and assess exercise-related changes in a clinically applicable manner. Previous researchers[15,21] have concluded that decreased performance in the task of interest, such as maximum vertical jump, may be used to indicate fatigue. We considered the minimal baseline for fatigue to be when participants demonstrated a decrease in vertical-jump height of at least 5 cm on 2 consecutive course repetitions.[15] Although male participants had higher overall maximum vertical-jump heights than female participants, both sexes had significant reductions in jump height after the exercise intervention. The mean decrease after fatigue was 6.8 cm, suggesting that the level of fatigue was similar in both sexes. We also evaluated the cardiovascular effect of our protocol by collecting heart-rate data. We documented a mean postexercise value of 185 beats per minute, equivalent to 94% of participants' maximum heart rate. We effectively elicited fatigue in both sexes, as evidenced by the consistent and substantial increase in heart rates after the exercise intervention.

Our findings have important implications for injury risk assessment and prevention. After exercise, nearly twice as many women (7) as men (4) transitioned from the low-risk to the high-risk category[10] according to LESS scores. This suggests that these individuals' initially low scores may not provide the full picture of their landing mechanics during sport. Because a relatively short duration of intense exercise was sufficient to cause these detrimental changes, this may be a factor currently missing from the initial assessment of injury risk. Once identified, there may be significant benefit to implementing injury-prevention programs with these athletes in particular.

In our study, both sexes scored higher on the LESS after fatigue, with more women moving into the high-risk group. Such information may be relevant to the clinical application of our results. DiStefano et al[10] concluded that participants who had the largest number of LESS errors at baseline achieved the greatest improvements after completing an injury-prevention program. In their study,[10] participants in the poor-technique (high-risk) group improved their score by more than 2 points (3 times the average change of 0.66 points). Individuals whose scores transition to high risk with exercise may have a significant potential for improvement and risk reduction. Current injury-prevention programs are typically performed as a warm-up before activity and have been effective in correcting faulty mechanics and reducing ACL injury risk in isolated populations.[10,30] However, to be considered truly effective, any intervention program must train athletes to maintain proper technique and landing strategies throughout sport participation, when they will experience various levels of exercise intensity and fatigue. To our knowledge, no authors have examined the effects of an injury-prevention program performed after exercising. There may be a yet unrealized potential for even greater effect if the timing of the intervention is changed.

In conclusion, our protocol created equal fatigue effects for our participants. Heart rates and vertical-jump heights were affected to a similar degree regardless of sex; therefore, we do not feel the lack of interaction was due to unequal amounts of induced fatigue. Our participants' increases in LESS scores suggest that both sexes are likely to demonstrate high-risk mechanics and therefore potentially increased injury risk when fatigued.

Limitations

Although we attempted to standardize the level of exercise across participants, the exact degree of fatigue experienced by each participant remains unknown. In an attempt to investigate this, other authors[14] have examined incremental changes in biomechanics at various points during an exercise protocol and have reported on the relationship of time to the onset of fatigue effects. This may be an important direction for future study.

Future Research

Investigators should continue to examine the specific biomechanical components that are altered by fatigue and how these changes relate to the noncontact ACL injury mechanism in both sexes. The LESS should continue to be a valuable tool in the assessment of individuals (of both sexes) who may be at a higher risk of ACL injury and, thus, candidates for intervention programs. In our study, more women than men transitioned into the poor-technique category after exercise. Future researchers should focus on the specific LESS items that show some level of change after exercise. This level of detail was beyond the aim of our study but may provide insight into identifying and modifying these factors. It is also important to evaluate the responses of male athletes to injury-prevention programs because this has yet to be studied.

When injury-prevention programs are implemented may be a factor in their effectiveness. It may be beneficial to have athletes perform injury-prevention exercises after a short duration of exercise or after practice as a cool-down, rather than a warm-up, as is common. This would allow clinicians to observe athletes who may demonstrate movement errors only in a postexercise state and provide feedback so the athletes can correct such errors. This would allow participants to make changes when most needed and potentially carry the effects into game and practice situations.[18]

Finally, to determine the clinical effectiveness of such programs, it will be important to apply research findings to the design of injury-prevention programs and prospectively monitor ACL injury rates. The ultimate goal will be to improve such programs to substantially decrease the risk of ACL injury in all athletes.

CONCLUSIONS

Women demonstrated higher LESS scores than men, indicating that they committed more errors in landing technique before and after exercise. The LESS scores for both sexes increased after a period of intense lower extremity exercise. Both males and females were more likely to demonstrate high-risk landing mechanics when in a fatigued state, which may indicate a higher risk for ACL injury. The influence of a single variable such as fatigue did not affect the landing patterns of females to a greater degree than in males. Thus, fatigue plays a role in promoting high-risk landing patterns in both sexes, which may contribute to the risk of noncontact ACL injury.

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