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Knee Joint Laxity and Neuromuscular Characteristics of Male and Female Soccer and Basketball Players*

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ABSTRACT

Anterior cruciate ligament injuries are occurring at a higher rate in female athletes compared with their male counterparts. Research in the area of anterior cruciate ligament injury has increasingly focused on the role of joint proprioception and muscle activity in promoting knee joint stability. We measured knee joint laxity, joint kinesthesia, lower extremity balance, the amount of time required to generate peak torque of the knee flexor and extensor musculature, and electromyographically assessed muscle activity in 34 healthy, collegiate-level athletes (average age, 19.6 ± 1.5 years) who played soccer or basketball or both. Independent *t*-tests were used to determine significant sex differences. Results revealed that women inherently possess significantly greater knee joint laxity values, demonstrate a significantly longer time to detect the knee joint motion moving into extension, possess significantly superior single-legged balance ability, and produce significantly greater electromyographic peak amplitude and area of the lateral hamstring muscle subsequent to landing a jump. The excessive joint laxity of women appears to contribute to diminished joint proprioception, rendering the knee less sensitive to potentially damaging forces and possibly at risk for injury. Unable to rely on ligamentous structures, healthy female athletes appear to have adopted compensatory mechanisms of increased hamstring activity to achieve functional joint stabilization.

The participation of women in intercollegiate athletics has been increasing and continues to do so. The National Collegiate Athletic Association (NCAA) reported a 9% increase in the number of female participants in its athletic programs from 1989 to 1992, with even greater gains being seen in specific sports, such as soccer.[51] With the number of female intercollegiate athletes increasing, epidemiologic injury surveillance continues to demonstrate the high incidence of knee injuries occurring among female athletes compared with their male counterparts. This sex discrepancy is evident when comparing knee injury patterns of men and women participating in the intercollegiate sports of soccer and basketball.[5,18,24,43,46,54] Compared with their male counterparts, female athletes participating in these sports have been sustaining a significantly higher number of severe knee injuries, specifically injury to the ACL.[30,32] Injury to the ACL of female soccer players while playing soccer is reportedly occurring at a rate two to five times the rate of injury to the ACL occurring in men's soccer.[43,51,54] Female basketball players are two to eight times more likely to sustain an ACL tear while playing basketball than are their male counterparts.[18,24,46,51,68]

In an attempt to explain the disproportionate incidence of ACL injury among female athletes, various causative factors have been presented and investigated. Shoe-surface interface, distal femur dimensions, muscle strength, knee joint laxity, proprioception, balance, neuromuscular activation patterns, and muscle fatigue have been suggested as causes of ACL injury.[3,12,17,24,29,34,44,45,55,61] Research in the area of ACL injury has increasingly focused on the role of joint proprioception and muscle activity in promoting knee joint stability. Proprioceptive deficits resulting in motor reflex insufficiencies, possibly secondary to excessive joint laxity, may render a joint unable to sense and respond to joint stress, thereby resulting in connective tissue and ligament injury. Although

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muscle reflex activation may be deficient in these joints, McNair and Marshall[48] have suggested that muscle-activation patterns, typically evaluated through EMG, may develop to enhance the joint stabilization provided by static restraints or may function to compensate for inherent joint laxity or deficits in joint proprioception, or both.

Joint-stabilizing muscle activity is influenced by proprioceptive, kinesthetic, visual, and vestibular-system information as well as by cortical and spinal-nerve motor commands. In addition to this sensory information, there appears to be a developed muscle "program" that results in preactivated muscle tension in anticipation of expected joint load. Previously experienced muscle-activation patterns and joint motions, such as routinely practiced sport-specific activities, may "preprogram" or "feed-forward" muscle activity. By repeating and practicing muscle-activation patterns, the learned information can be applied to the programming of future muscle patterns.[19,21,25,63] This preprogrammed muscle activity may have a crucial role in functional joint stabilization, particularly for knee joints with inherent joint laxity or proprioceptive deficits that result in reflex deficiencies. Since women often incur ACL injuries during routine noncontact activities, one might speculate that the coordinated motor program that provides dynamic stability fails as a result of some external influence such as fatigue or loss of motor control.

The purpose of this study was to examine and compare knee joint laxity, joint proprioception, balance, peak torque production time, and EMG-assessed muscle activity of male and female soccer and basketball players during functional tasks.

MATERIALS AND METHODS

Thirty-four (17 male, 17 female) healthy, collegiate-level athletes who played soccer, basketball, or both (average age, 19.6 ± 1.5 years; average height, 175.0 ± 9.0 cm; average weight, 72.9 ± 11.9 kg) from the University of Pittsburgh and nearby universities participated in this study. Subject characteristics are detailed by sex in Table 1. No subjects enrolled in the study had a significant history of ligament trauma to either knee joint, and all said their ankle joint on the test side was functionally stable. In addition, no subject reported suffering from any systemic or vestibular-system disorders known to impair cutaneous sensation or balance. All subjects gave written consent to participate in this study, which was approved by the University of Pittsburgh Investigatory Review Board.

TABLE 1
Subject Characteristics (Means ± SD)

Group	Age (years)	Height (cm)	Weight (kg)	Sports participation (years)
Women ($N = 17$)	18.9 ± 0.9	168.5 ± 4.9	65.6 ± 8.3	10.8 ± 2.6
Men ($N = 17$)	20.4 ± 1.7	181.5 ± 7.2	80.3 ± 10.3	13.9 ± 2.4

Testing Procedure

Before testing, subjects completed a detailed questionnaire designed to ensure compliance with the subject inclusion criteria and to determine the subjects' sport-participation history. Subjects were assigned a randomized order for data collection on the following five dependent variables: knee joint laxity, knee joint proprioception, single-legged balance ability, amount of time required to generate peak torque of the knee flexor and extensor musculature, and reactive muscle activity in response to landing. The dominant lower limb served as the test limb for all data collection. Dominance was established by ascertaining which lower extremity the subject would prefer to land on when dropping from a 25.4-cm-high step.

Anterior Tibial Translation

To quantify knee joint laxity, the KT-1000 instrumented knee arthrometer (MEDmetric, San Diego, California) measured anterior tibial translation during the application of a 30-pound (133-N) anterior displacement force. Compared with other commercially available arthrometers, the KT-1000 arthrometer has been shown to most closely approximate the findings of the clinical examination.[2] Research has established this device as both a valid[15] and reliable[2,6,16,56,62] instrument for measuring the anteroposterior displacement of the tibia on the femur. Reliability of this test device was enhanced by ensuring data collection by a single researcher.

Subjects were tested in the supine position with the legs placed on thigh supports and the feet secured with VELCRO (VELCRO USA, Inc., Manchester, New Hampshire) straps to the foot rest. In this position, the knee joint was flexed to 20° of flexion, as confirmed by a goniometric reading, while the feet were maintained in the neutral position. Manufacturer's specifications were employed for placement of the KT-1000 arthrometer onto the test limb as well as for collection of all data. Three test trials were performed and a mean test value was calculated.

Proprioception Assessment

Assessment of proprioception via the afferent neuromuscular pathway was conducted by measuring knee joint kinesthesia. To do so, we measured threshold to detection of passive motion using a proprioception testing device designed and manufactured by the Department of Engineering at the University of Pittsburgh. The device moved the knee joint into flexion and extension through the axis of the joint, while a rotational transducer interfaced with a digital microprocessor counter (Red Lion Controls, York, Pennsylvania) provided angular displacement values. The proprioception testing device moved the knee at a constant angular velocity of 0.5 deg/sec. Test-retest reliability of the proprioception testing device has previously been established, with correlation coefficients of $r = 0.92$.[41]

Subjects were tested in the seated position with both feet placed in pneumatic boots inflated to 30 mm/Hg, with the eyes blindfolded, and with a headset placed over the ears, all in an effort to negate cutaneous, visual, and auditory cues that contribute to joint kinesthesia. All testing was performed at the starting position of 15° of knee flexion. When the subject gave the investigator a thumb-up signal, the investigator responded with a tap to the subject's contralateral leg to begin the test. At a random point during the subsequent 10 seconds, knee movement was engaged. The subject had been previously instructed to disengage the device on sensation of knee joint movement. Six randomized trials, three trials moving into flexion and three trials moving into extension, were performed with the degrees of angular motion recorded for each. A mean value for the three trials was calculated for both test directions.

Single-Legged Balance Assessment

Assessment of lower extremity balance ability provides information about both the afferent and efferent neuromuscular pathways. To assess lower extremity balance, this study used a commercially available balance device, the Biodex Stability System (Biodex, Inc., Shirley, New York). This system consists of a movable balance platform that provides up to 20° of surface tilt in a 360° range of motion. The platform is interfaced with computer software (Biodex, Version 3.1, Biodex, Inc.) that enables the device to perform as an objective assessment of balance. Reliability of the Biodex Stability System has been established with an interclass correlation coefficient ranging from 0.6 to 0.95.[52]

To begin the lower extremity balance assessment, subjects were asked to stand on one leg on the central area of the locked balance platform. Using the permanent grid system of the platform, the subject's heel position coordinates were noted and entered into the microcomputer. Testing position required subjects to fold both arms across the chest and hold the unsupported limb in a position of 0° of hip flexion and 90° of knee flexion while slightly abducted so as not to contact the test limb. The platform was set at instability level 2, indicating the degree of platform instability, which ranged from 1 to 6, with 1 representing the greatest amount of instability. This setting remained constant throughout testing.

For a period of 20 seconds, subjects attempted to maintain the unstable platform in a level position. For each test of balance, the Biodex software generated a stability index value that was calculated by assessing the amount of time and the degree to which the platform was off level. Three practice trials and three test trials were performed, and a mean test value was calculated from the three test trials.

Time to Peak Torque

The time, in milliseconds, to generate peak torque of the knee joint flexor and extensor musculature was quantified using the Biodex Isokinetic Dynamometer. The test arm was set at a constant angular velocity of 180 deg/sec, while the resistance accommodated to the torque produced by the subject. Before data collection, subjects completed five submaximal and three maximal warm-up repetitions. Data were collected on five maximal test repetitions. Strong verbal encouragement was given to each subject throughout the test time.

EMG Assessment

Muscle activity in response to a landing task was determined with the use of surface EMG. The muscle activity of six knee joint muscles was simultaneously measured as subjects jumped from a step and landed on the floor while using only the test limb. After data collection, the onset time, amplitude, and area of the first contraction subsequent to landing were calculated for each of the six muscles.

Before testing, the skin surrounding the knee joint was abraded with a pumice stone and cleaned with isopropyl alcohol to ensure adequate surface contact for the electrodes. Self-adhesive silver/silver electrodes (Multi Bio Sensors, Inc., El Paso, Texas) were placed in pairs over the muscle bellies of the following muscles: the vastus medialis, the vastus lateralis, the medial hamstring, the lateral hamstring, the medial head of the gastrocnemius, and the lateral head of the gastrocnemius. A ground electrode was mounted on the patella. Each electrode was 10 mm in diameter and the electrodes were placed 25 mm apart. Electrical impedance, measured with a digital multimeter, was determined, and a resistance value of 2 kΩ was considered as the maximum value of acceptable electrical impedance.

The levels of the maximal voluntary contractions of the six test muscles were established for each subject by collecting 5 seconds of EMG data during a single maximal-effort isometric contraction. After collection of these data, the subject was asked to perform the single-legged landing test. The landing test required the subject to use the test limb to stand on one leg atop a 25.4-cm-high bench and to jump from the bench to the floor, landing on the test limb. To determine the stages of the landing task, a footswitch secured to the floor within the landing area signaled foot contact with the floor. The footswitch was connected to an EMG channel so that contact with the ground was synchronized with measurement of muscle activity. Testing required the subject to begin the jump standing on one leg on the bench and to land the jump on the floor footswitch. Before each test, the subject was asked to stand motionless to establish the baseline EMG activity. Then the EMG activity was sampled from the time the subject stood on one leg on the bench until approximately 5 seconds after floor contact. Two practice trials preceded the three test trials. A trial was not considered for data collection if the subject landed on the contralateral limb or was unable to maintain balance upon landing.

For each test trial, the analog data from the six EMG leads was sampled and processed with the Noraxon Telemyo System (Noraxon USA, Inc., Scottsdale, Arizona). Muscle signal activity was collected by the surface electrodes and passed to a battery-operated FM transmitter (Noraxon USA, Inc.) worn by the subject. The transmitter contained a single-ended amplifier that filtered at a bandwidth of 15 to 500 Hz and had a common-mode rejection ratio of 130 dB and a receiver that converted the signal from analog to digital data with an analog-to-digital card. From the transmitter, the signal was passed to the computer where the raw EMG data were sampled at a frequency of 2500 Hz and analyzed by Myoresearch software (Noraxon USA, Inc.).

For each muscle, the onset time, amplitude, and area of the first contraction subsequent to landing was determined using a program of the Myoresearch software called a Marker Exhaustive Analysis. Onset time was defined as the time in milliseconds from landing, indicated by contact with the footswitch, until the first muscle contraction. A muscle signal was considered a contraction if it exceeded the set trigger level of 10% of the maximal voluntary contraction (Fig. 1). The analysis also determined the amplitude and area of this first contraction. Calculation of the contraction's area was truncated at 1 second. Mean test data were calculated from the results of the three test trials.

RESULTS

Individual means and standard deviations for each dependent variable are presented by sex in Tables 2 and 3. To determine the presence of a statistically significant sex difference, an independent t-test analysis was conducted for each dependent variable. A preset alpha level of $P < 0.05$ was selected to determine statistical significance in this study. The results of these statistical analyses are presented by individual dependent variable in the following sections.

Anterior Tibial Translation

Results revealed a significant difference in anterior tibial translation scores between the female athletes and the male athletes (Table 2). The significantly higher anterior tibial translation scores of the women demonstrate a higher degree of knee joint laxity in female subjects compared with the men.

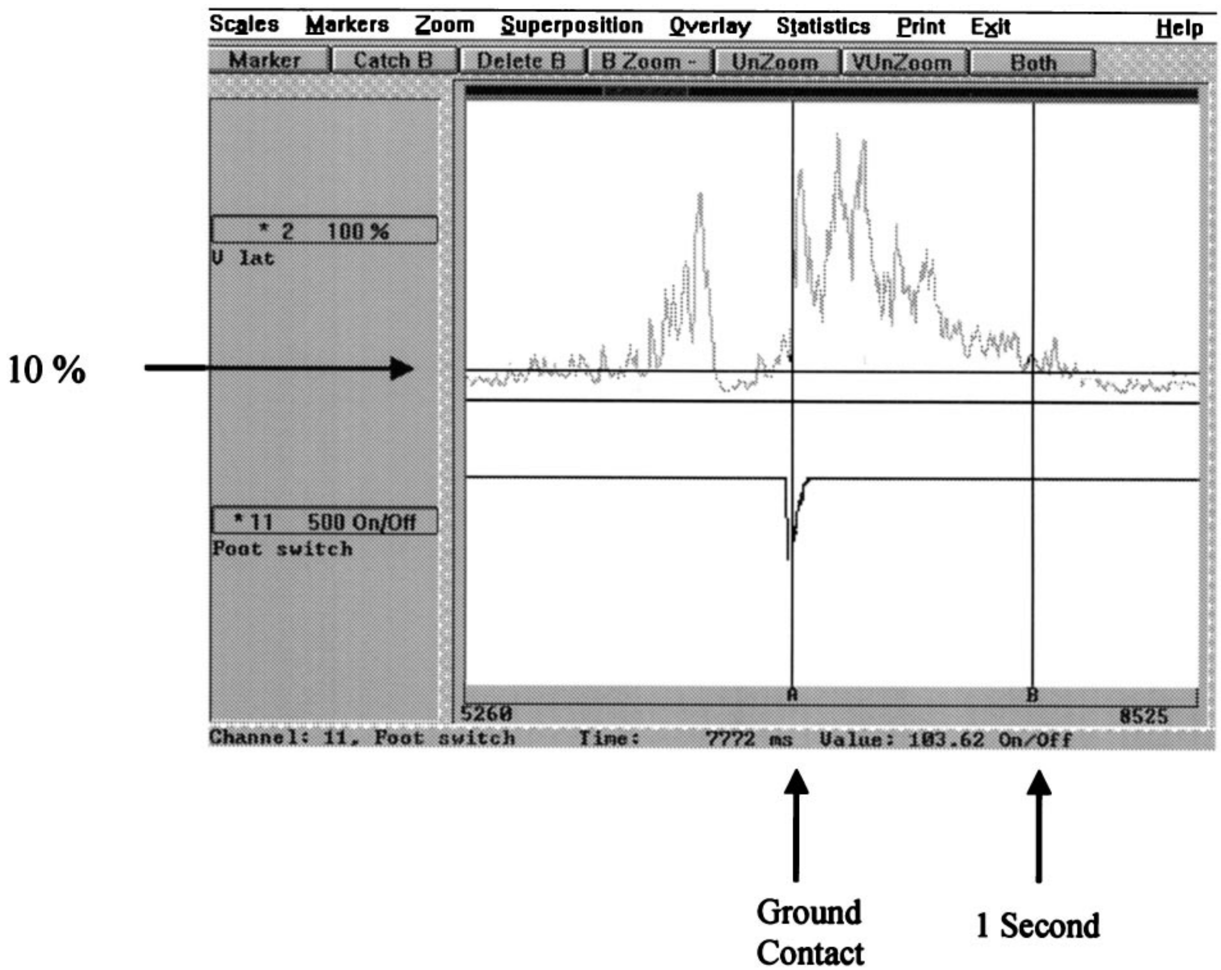

Figure 1. EMG data analysis illustrating synchronization of muscle activity and footswitch contact.

TABLE 2
Knee Joint Laxity and Neuromuscular Characteristics by Sex (Mean ± SD)

Group	Anterior tibial translation (mm)	TTDPM[a] (deg angular motion)		Stability index	Time to peak torque (msec)	
		Flexion	Extension		Flexion	Extension
Women (N = 17)	6.05 ± 1.46	2.81 ± 2.54	2.95 ± 1.47	3.27 ± 1.43	220.63 ± 51.83	371.88 ± 154.67
Men (N = 17)	4.80 ± 1.53	1.89 ± 0.57	2.11 ± 0.63	6.00 ± 3.06	214.71 ± 46.38	338.23 ± 124.16
P value	0.021	0.155	0.039	0.002	0.733	0.495

[a] Threshold to detection of passive motion.

TABLE 3
Electromyography Measurements (Means ± SD) of Six Sampled Lower Extremity Muscles by Sex

Group	Muscle					
	Vastus medialis	Vastus lateralis	Medial hamstring	Lateral hamstring	Medial gastrocnemius	Lateral gastrocnemius
			Onset time[a]			
Women	39.20 ± 56.66	40.51 ± 28.21	175.57 ± 108.56	187.01 ± 133.19	241.10 ± 141.57	193.90 ± 155.33
Men	30.60 ± 51.98	52.94 ± 70.59	182.44 ± 91.88	217.63 ± 108.95	289.09 ± 177.96	144.19 ± 98.58
P	0.648	0.505	0.843	0.469	0.396	0.274
			Amplitude[b]			
Women	361.65 ± 255.49	315.82 ± 162.25	163.49 ± 84.45	156.00 ± 72.59	225.86 ± 223.35	131.72 ± 64.90
Men	290.87 ± 173.62	298.00 ± 231.27	134.20 ± 66.33	84.84 ± 43.47	134.13 ± 74.70	161.45 ± 73.82
P	0.352	0.796	0.269	0.002	0.129	0.221
			Area[c]			
Women	35.36 ± 18.93	27.75 ± 14.00	7.91 ± 6.04	10.78 ± 8.34	12.63 ± 15.43	6.24 ± 5.80
Men	36.05 ± 33.53	28.59 ± 27.81	7.40 ± 6.20	2.82 ± 2.66	6.47 ± 5.42	9.76 ± 10.43
P	0.941	0.912	0.806	0.001	0.141	0.234

[a] Time (in milliseconds) from ground contact when landing a jump until onset of muscle contraction.
[b] Peak amplitude (in millivolts) of the first contraction subsequent to landing a jump.
[c] Area (in millivolt · seconds) of first contraction subsequent to landing a jump.

Proprioception

Proprioception was tested by measuring knee joint kinesthesia as the threshold to detection of passive motion while moving into either the direction of knee flexion or of knee extension. The ability to detect joint motion while moving into the direction of knee flexion was not significantly different between the sexes; however, there were significant mean differences between the sexes for measurement of kinesthesia moving into knee extension. The women took significantly longer than the men to detect joint motion moving in the direction of knee joint extension (Table 2).

Single-Legged Balance

There was a statistically significant difference in single-legged balance ability scores between the female athletes and the male athletes (Table 2). The lower stability index measurements of the women reflects their statistically superior single-legged balance ability compared with the men.

Time to Generate Peak Torque

The time, in milliseconds, to generate peak torque of the flexor and extensor musculature was quantified using the Biodex Isokinetic Dynamometer. Results revealed no significant sex differences in the time to generate peak torque when considering either the knee flexor musculature or the knee extensor musculature (Table 2).

Electromyography Assessment

The time, in milliseconds, from ground contact when landing from a jump until the onset of a muscle contraction was obtained for each of the six sampled lower extremity muscles. Results revealed no significant differences between the men's and women's mean onset times for any of the following sampled muscles: the vastus medialis, the vastus lateralis, the medial hamstring, the lateral hamstring, the medial gastrocnemius, or the lateral gastrocnemius (Table 3).

A significant mean difference for peak amplitude of the first contraction subsequent to landing between groups was revealed for the lateral hamstring muscle amplitude. The women had a significantly greater peak amplitude in the first contraction subsequent to landing than did the men (Table 3). Results revealed no significant mean differences between groups for either the vastus medialis muscle, the vastus lateralis muscle, the medial hamstring muscle, the medial gastrocnemius muscle, or the lateral gastrocnemius muscle (Table 3).

For each of the six sampled lower extremity muscles the area of the first contraction subsequent to landing was recorded. Comparisons of group means for each muscle revealed a statistically significant difference between groups for the lateral hamstring muscle. The women recorded a significantly greater area of the first contraction subsequent to landing compared with the men. There were no significant differences between sexes for the following muscles: the vastus medialis, the vastus lateralis, the medial hamstring, the medial gastrocnemius, and the lateral gastrocnemius (Table 3).

DISCUSSION

This study was conducted to examine sex differences in knee joint laxity, knee joint proprioception, lower extremity balance, amount of time for knee musculature to generate peak torque, and reactive muscular activity in athletes participating in the collegiate sports of soccer and basketball. Results revealed that, compared with the male athletes, the female athletes inherently possessed greater knee joint laxity, demonstrated a longer time to detect knee joint motion moving into extension, and possessed superior single-legged balance ability. Most interestingly, female athletes demonstrated greater EMG peak amplitude and area of the lateral hamstring when landing from a jump.

Since the subjects for our study were healthy athletes with no history of ACL injury, the demonstrated muscle-activation patterns appeared to routinely achieve functional joint stabilization. For the female athletes, these muscle-activation patterns appear to achieve joint stabilization in the presence of excessive joint laxity and proprioceptive deficits. These muscle-activation patterns may be adaptive or learned in an attempt to compensate for inherent joint laxity and proprioceptive deficits. Able to rely on compensatory muscle-activation patterns, female athletes may potentially perform numerous injury-causing activities, such as deceleration maneuvers or landing tasks, without sustaining ACL trauma. However, subsequent to fatigue or some other adverse mechanism, interruption of the compensatory muscle-stabilizing activity may produce a joint unable to resist imparted joint forces and may result in ligament trauma. In the female athlete, ligament trauma may result from failure of preactivated motor activity since women, with decreased joint proprioception, may lack the reflex capability for joint protection or may be unable to generate muscle force rapidly enough to absorb the joint forces and protect the ligament.

For this study, the assessment of muscle activity required subjects to jump from a bench and land on the ground using only the test limb. This task was selected based on epidemiologic injury data that suggest that the primary mechanism of ACL injury in basketball and soccer players is a noncontact type mechanism, such as decelerating or landing from a jump.[5] McNair and Marshall[48] used a similar task for their study investigating the landing characteristics of uninjured and ACL-deficient subjects. They suggested that this task was "novel" and stated that it was not a task their subjects would have previously experienced or practiced. For the subjects in our study however, this was a frequently practiced skill and was reflective of activities routinely performed while participating in their sport.

The results of our study revealed that when landing a jump, female athletes produced significantly greater EMG peak amplitude and area of the lateral hamstring muscle than did male athletes. This greater quantity of muscle activity demonstrated by the female athletes may lend support to the supposition that female athletes possessing inherent joint laxity achieve joint stabilization through increases in muscle activity. Interestingly, the increased muscle activity was revealed in the lateral hamstring musculature which, by virtue of its insertion onto the fibular head and its posterolateral orientation, has a significant influence on protecting the knee from anterolateral subluxations.[47] It is well documented that the hamstring muscles assist the ACL in controlling anterior tibial translation.[20,27,28,53,60,64] These findings appear to demonstrate that consciously, or perhaps subconsciously, female athletes may have adopted compensatory protective muscle-activation patterns in an attempt to achieve joint stabilization.

Our findings of excessive joint laxity in female athletes compared with male athletes appears to conflict with some researchers' findings,[2,4,15,16,65,66] while being similar to the findings of the Huston and Wojtys study[31] of the neuromuscular performance characteristics of elite female athletes. Although our study and that of Huston and Wojtys determined that female athletes inherently possess significantly greater joint laxity than do male athletes, we can only speculate that this inherent joint laxity is related to ligament injury. As of yet, researchers have been unable to establish a relationship between excessive ligament laxity and frequency or type of joint ligament injury.[22,23,36,49,50] However, the excessive joint laxity demonstrated by the female athletes in our study appears to contribute to diminished joint proprioception, rendering the knee less sensitive to potentially damaging forces and possibly at increased risk for injury.

In this study, the assessment of proprioception via the afferent neuromuscular pathway was conducted by measuring knee joint kinesthesia. The central nervous system interprets joint kinesthetic signals at both the conscious and unconscious levels of motor control. Unconscious joint stabilization is achieved, in part, by gathering and processing kinesthetic information gained from the afferent system. The ability of the somatosensory system to detect forces imparted on articular structures and mediate protective muscle responses is especially important in providing for joint stabilization.[7–9,37–42,57–59] Our finding of no significant sex differences in the ability to detect motion when determined from the starting position of 15° of knee flexion and moving into the direction of knee flexion is supported by the work of Barrett[10] and Barrett et al.[11] Barrett et al.[11] suggested that knee joint proprioception in normal knees does not appear to differ by sex. However, our study did reveal significant sex differences when the ability to detect motion moving into the direction of knee extension was assessed.

Our testing start position of 15° of flexion is near the end range of the joint's motion. As the knee further extends from this position, the ACL becomes increasingly taut, which may be why we found differences between men and women in joint kinesthesia. Even though this test joint angle was consistent for all subjects, the significantly greater knee joint laxity inherent to the female athletes may have caused them to have less taut, and therefore less sensitive, ligaments at the initiation of testing. Allegrucci et al.[1] investigated joint kinesthesia in healthy athletes participating in upper extremity sports and suggested that excessive joint laxity may result in decreased joint motion sensibility because of the lack of stimulation of these lax tissues. In their study, the dominant, and significantly more lax, shoulder of athletes in sports that require more use of the dominant arm exhibited poorer kinesthetic awareness at an extreme position of external rotation compared with the nondominant shoulder. At this position of external rotation the ligaments of the dominant arm were more lax and therefore less able to detect joint motion.[1]

Even though our study did not investigate reflexive muscle activity to sudden joint loading, it did measure the time for knee joint musculature to generate peak torque and revealed no sex differences for either the knee flexor or extensor musculature. However, Huston and Wojtys[31] reported that female athletes took significantly longer than male athletes to generate hamstring muscle peak torque. These results, although contrary to the findings of our study, may aid in explaining the greater incidence of ACL injury in female athletes.

The statistically superior single-legged balance ability demonstrated by the female athletes compared with the male athletes should be cautiously interpreted. Investigators agree that both balance and muscle activity measurements provide a direct determination of the efferent muscle response to afferent stimulation.[13,14,35] However, unlike measurements of muscle activity, balance assessment values result from input originating from not only the peripheral somatosensory system but also from both the visual and the vestibular systems.[26,33]

SUMMARY

This study was conducted in an attempt to explain the disproportionate incidence of ACL injuries in female athletes compared with males athletes participating in the same sports. We suggested, and then demonstrated, that female athletes participating in the collegiate sports of soccer and basketball inherently possess excessive knee joint laxity and proprioceptive deficits that may predispose them to ligament injury. The excessive joint laxity of the women appears to contribute to diminished joint proprioception, rendering their knees less sensitive to potentially damaging forces and possibly at increased risk for ligament injury. In addition, this study suggests that female athletes may have adopted a compensatory muscle-activation pattern of increased lateral hamstring activity to achieve functional joint stabilization. Although this strategy should, theoretically, aid female athletes in accomplishing joint stability, its effectiveness over time and in response to varying joint conditions and forces is yet unknown.

We recommend that future research continue to focus on joint laxity and neuromuscular characteristics of athletes who participate in sports in which a disproportionate number of ACL injuries occur. Although not feasible for this investigation, researchers may find that conducting prospective studies in which multiple measurements can be taken over time may aid in identifying potential risk factors. In addition, studies of different training methods that address proprioceptive and neuromuscular deficits should be conducted so that sex-specific and sport-specific training and rehabilitation protocols can be established.

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