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# Control of dynamic foot-ground interactions in male and female soccer athletes: Females exhibit reduced dexterity and higher limb stiffness during landing

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## Abstract

Controlling dynamic interactions between the lower limb and ground is important for skilled locomotion and may influence injury risk in athletes. It is well known that female athletes sustain anterior cruciate ligament (ACL) tears at higher rates than male athletes, and exhibit lower extremity biomechanics thought to increase injury risk during sport maneuvers. The purpose of this study was to examine whether lower extremity dexterity (LED) – the ability to dynamically control endpoint force magnitude and direction as quantified by compressing an unstable spring with the lower limb at submaximal forces – is a potential contributing factor to the “at-risk” movement behavior exhibited by female athletes. We tested this hypothesis by comparing LED-test performance and single-limb drop jump biomechanics between 14 female and 14 male high school soccer players. We found that female athletes exhibited reduced LED-test performance ($p$=0.001) and higher limb stiffness during landing ($p$=0.008) calculated on average within 51 ms of foot contact. Females also exhibited higher coactivation at the ankle ($p$=0.001) and knee ($p$=0.02) before landing. No sex differences in sagittal plane joint angles and center of mass velocity at foot contact were observed. Collectively, our results raise the possibility that the higher leg stiffness observed in females during landing is an anticipatory behavior due in part to reduced lower extremity dexterity. The reduced lower extremity dexterity and compensatory stiffening strategy may contribute to the heightened risk of ACL injury in this population.

### Keywords

Sensorimotor function; Leg stiffness; Sex difference; Lower extremity control; ACL injury



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FVC holds Unites States Patent 6,537,075 on a “Device for developing and measuring grasping force and grasping dexterity” but has no active or pending licensing agreements with any commercial entity.

## 1. Introduction

Controlling the dynamic interactions between the lower limb and the ground is requisite for success when performing skilled locomotor tasks. For example, the lower limbs must regulate the magnitude and direction of the ground reaction force to initiate, terminate, and/or redirect the body center of mass (COM) during locomotor tasks such as walking, running, rapid turning, and landing (Hass et al., 2008; Kaya et al., 2006; Liu et al., 2008; Mathiyakom et al., 2006). The ability to regulate the magnitude and direction of foot-ground interaction forces, previously defined as *lower extremity dexterity*, has been proposed as a potentially important attribute for tasks that require deceleration and redirection of the body COM (Lyle et al., 2013).

Although currently available methods are routinely used to characterize whole-body kinematics, kinetics and center of pressure dynamics, such methods do not quantify lower extremity dexterity. Thus, we developed the lower extremity dexterity test (LED-test) to assess the capability of the lower limb to regulate endpoint force magnitude and direction (Lyle et al., 2013). The LED-test, an adaptation of a test to quantify finger dexterity (Valero-Cuevas et al., 2003), evaluates the ability of an individual to compress an unstable spring with the lower limb at submaximal forces. The LED-test has been shown to be reliable and evaluates a dimension of dynamic lower limb function that is independent of isometric strength (knee extensors, knee flexors, hip extensors), height, and body mass (Lyle et al., 2013). Here, we examine whether limb dexterity could explain, in part, a serious and complex problem in sports medicine: why do young female athletes sustain non-contact anterior cruciate ligament (ACL) injuries at a rate 2–6 times greater than their male counterparts (Agel et al., 2005; Borowski et al., 2008; Yard et al., 2008)? This is an important clinical problem because most athletes that tear their ACL do not return to the same level of competitive play (Soderman et al., 2002), and it has been shown that approximately 50% of ACL injured athletes will experience knee osteoarthritis within 12–14 years of injury (Lohmander et al., 2004; von Porat et al., 2004).

The higher rate of ACL injuries in females is believed to result from them performing sport maneuvers with limb mechanics that increase ACL loading. For example, studies have shown that females decelerate body momentum by absorbing greater energy at the ankle and knee, whereas males tend to absorb more energy at the knee and hip (Decker et al., 2003; Schmitz et al., 2007; Sigward et al., 2011). In addition, the movement behavior exhibited by females has been characterized by smaller excursions of knee and hip flexion and higher ground reaction forces. This biomechanical pattern has been referred to as a “stiffening strategy” (Decker et al., 2003; Devita and Skelly, 1992; Pollard et al., 2010; Schmitz et al., 2007; Sigward et al., 2011) and shown to result in higher peak ACL forces when compared to a “soft landing strategy” (Laughlin et al., 2011). Moreover, there is evidence suggesting that limited joint excursions in the sagittal plane lead to greater frontal plane motion and moments at the knee (Pollard et al., 2010) which also has been linked to ACL injury risk (Hewett et al., 2005). In this study, we use average leg stiffness, defined as the ratio of peak vertical ground reaction force and COM displacement, as a global measure of multi-joint coordination to characterize the “stiffening strategy” described above (Butler et al., 2003; Farley et al., 1998; Kulas et al., 2006).

Several factors have been proposed to explain the movement behavior and higher ACL injury rates in females (e.g. hormonal, anatomical, environmental, neuromuscular) (Griffin et al., 2006). However, literature suggests that lower limb strength and anthropometry do not fully explain the sex disparity in movement behavior or injury rates (Beutler et al., 2009; Herman et al., 2008; Mizner et al., 2008; Shultz et al., 2009). Moreover, evidence demonstrating that exercise interventions emphasizing multiplanar jumping and landing drills reduce ACL injuries (Gilchrist et al., 2008; Kiani et al., 2010; Mandelbaum et al., 2005; Olsen et al., 2005) suggests modifiable factors other than strength may be responsible. For example, the ability to control dynamic foot-ground interactions as defined here (i.e. dexterity) is one potential factor that has yet to be examined.

The purpose of this study was to determine whether lower extremity dexterity is a potential factor underlying altered movement behavior in female athletes. We hypothesized that females would exhibit reduced LED-test performance when compared to the male athletes. Moreover, we hypothesized that the “stiffening strategy” used by females is due, in part, to reduced lower extremity dexterity. This hypothesis would be supported if female athletes exhibit both reduced dexterity and higher leg stiffness during a single-limb drop jump when compared to males. Because leg stiffness can be modulated by varying muscle activation before foot contact and/or limb kinematics at the time of foot contact (Farley et al., 1998; Fu and Hui-Chan, 2007; Moritz and Farley, 2004; Potthast et al., 2010), knee and ankle coactivation prior to foot contact and sagittal plane joint angles at foot contact were quantified. The time to peak vertical ground reaction force also was evaluated so that the landing behavior could be interpreted in terms of potential neural control mechanisms. For example, a finding of higher coactivation prior to foot contact and higher leg stiffness calculated at a time before reflex activity could likely influence limb mechanics (e.g. 50 ms) would be suggestive of a feedforward control strategy (Santello, 2005).

## 2. Methods

### 2.1. Subjects

Fourteen female and 15 male high school soccer athletes between the ages of 15–18 participated. To control for experience, the athletes were matched by age and skill level by recruiting players from the same competitive club or high school soccer division. Total years of soccer experience and club experience were similar between groups (Table 1). Participants were free of current lower extremity pain or injury. We excluded participants who reported any of the following: (1) history of previous ACL injury; (2) previous knee surgery; or (3) recent injury that had prevented them from participating fully in soccer for greater than 3 weeks within the last 6 months.

Participants attended a single session in which they completed the LED-test and a single-limb drop jump task. Prior to testing, subjects and their parent/guardian provided written informed assent and consent as approved by the Institutional Review Board of the University of Southern California. Participants were fitted with the same style of athletic shoe (New Balance Inc., Boston, MA). Only the dominant lower extremity was tested (i.e. preferred foot used to kick a ball).

### 2.2. Lower extremity dexterity test

For a detailed description see Lyle et al., (2013). Briefly, the LED-test device consists of a 25.4 cm helical compression spring mounted on a 30.5 30.5 cm base with a 20×30 cm platform affixed to the free end. The spring characteristics were as follows: mean diameter: 3.08 cm, spring rate: 36.8 N/cm, hard drawn wire (#850, Century Spring Corp., Los Angeles, CA). The spring was chosen such that spring instability occurred at low force magnitude (i.e. minimize fatigue and influence of strength). The test device was positioned on a force platform and the vertical ground reaction force component recorded at 1500 Hz (AMTI, Waterton, MA). Vertical reaction forces were low-pass filtered at 15 Hz and displayed for participants as visual force feedback using LabVIEW (National Instruments Corp., Austin, TX).

Participants performed the LED-test in an upright partially supported posture with weight equally distributed on a bike saddle and the non-test limb, which rested on a step adjusted so that the hip and knee were extended and the pelvis was level. The trunk was supported by leaning forward approximately 20° against a strap at the level of the xiphoid process. The forearms rested on a crossbar adjusted to the level of the xiphoid process. At the beginning of each trial, the test limb was positioned with the foot on the device platform in a standardized posture (i.e. 75–80° of hip and knee flexion).

Participants were instructed to slowly compress the spring with their foot with the goal to raise the force feedback line as high as possible and keep it there. Participants were informed that it is natural for the spring to bend and become unsteady when force is applied. Despite the inherent instability, the goal was to sustain the highest vertical force possible during each 16 s trial. Subjects were instructed to avoid using the contralateral limb or arms to help direct the movement of the test limb.

Participants completed 5 practice trials. Then, subjects completed between 21 and 25 trials. Testing was stopped after trial 21 if performance on this trial was not among the best 3 of the previous 20 trials. Additional trials were completed up to 25 if performance on the 21st trial was one of the top 3 achieved. Thirty second rest periods were provided between trials and 2 min of rest was provided after every 5th trial. Verbal encouragement was provided to facilitate maximum performance.

**2.2.1. Data analysis—**The dependent variable for the LED-test was the highest average vertical force over a 10 s period during the sustained hold phase of each trial. Maximal values were identified for each trial using a point-by-point 10 s moving average calculated from the raw vertical ground reaction force (Lyle et al., 2013). Maximal values were considered for analysis if the coefficient of variation was ≤10% for each moving window time step. This criterion was chosen as an indicator that the dynamic interactions between the foot and spring-platform system (i.e. compression forces) were controlled (Lyle et al., 2013; Venkadesan et al., 2007). Participants had to complete at least 15 trials that met the coefficient of variation criterion. Failure to meet this criterion resulted in a subject being excluded from the analysis. The average of the best 3 trials was used for analysis. We have previously reported that the LED-test as described above has excellent test-retest reliability ($ICC_{(2,3)}$=0.94) (Lyle et al., 2013).

### 2.3. Biomechanical testing

For the single-limb drop jump task, participants were instructed to hop down from a 30 cm platform with their dominant limb, land in the middle of a force plate, and jump up as high as possible. Four trials were obtained from each subject. Three-dimensional kinematics were recorded at 250 Hz using an 11-camera system (Qualisys, Gothenburg, Sweden). Ground reaction forces were recorded from a force platform (AMTI, Newton, MA) at 1500 Hz. Electromyographic (EMG) signals were recorded at 1500 Hz with a MA-300 system (Motion Lab Systems, Baton Rouge, LA).

Self-adhesive surface electrodes (Norotrode 20, Myotronics Inc., Kent, WA) were placed over the rectus femoris (RF) proximally one-third the distance from the anterior superior iliac spine and superior patella and on the midpoint of the muscle bellies for lateral hamstring (LH), medial hamstring (MH), tibialis anterior (TA), and soleus (SOL). Electrodes and pre-amplifiers were secured to the skin with pre-wrap to minimize movement artifacts.

Three maximal voluntary isometric contraction (MVIC) trials lasting 3 s were recorded for each muscle group. The MVIC values for the RF and LH/MH were obtained during seated knee extension and flexion, respectively, with the knee flexed 60°. The MVIC value for SOL was obtained during an isometric single limb heel raise with resistance provided by a stable bar placed across the shoulders. The MVIC value for TA was obtained seated with subjects' dorsiflexing their foot against a rigid bar with the knee flexed to 90°.

Twenty-one reflective markers (14 mm spheres) were affixed to the following landmarks: distal second toes, first and fifth metatarsal heads, medial and lateral malleoli, medial and lateral femoral epicondyles, greater trochanters, iliac crests, anterior-superior iliac spines, and L5–S1. Non-collinear tracking marker clusters were placed on the shoe heel counter, lateral shank, and lateral thigh. The thigh and shank clusters were secured to elastic wraps, while the heel clusters were taped to the shoe. A standing calibration trial was obtained to establish the local segmental coordinate system. Following calibration, anatomical markers were removed. Tracking marker clusters, L5–S1, and iliac crest markers remained on during the jump trials.

**2.3.1. Data analysis—**The primary biomechanical variable of interest was average leg stiffness ($K_{\text{leg}}$). This was calculated as the ratio of the peak vertical ground reaction force ($F_{\text{peak}}$) to the COM displacement ($\text{COM}_{\text{disp}}$) from initial contact to the time of peak vertical ground reaction force (Farley et al., 1998; Farley and Morgenroth, 1999; Hughes and Watkins, 2008; Kulas et al., 2006):

$$K_{\text{leg}}=\frac{F_{\text{peak}}}{\text{COM}_{\text{disp}}} \quad (1)$$

COM displacement was calculated by double integration of the vertical acceleration (Cavagna, 1975; Farley et al., 1998; Ranavolo et al., 2008). The initial COM velocity was estimated from the kinematic trajectory of the pelvis segment COM at the time of foot contact. Leg stiffness values were normalized by body mass (Cone et al., 2011; Padua et al., 2005).

Additionally, sagittal plane joint angles and COM velocity at initial contact and time to peak vertical ground reaction force were examined. Joint angles and velocity at foot contact were reported to account for their potential influence on leg stiffness between sexes (Farley et al., 1998; Fu and Hui-Chan, 2007; Moritz and Farley, 2004; Potthast et al., 2010). All biomechanical variables evaluated occurred at or before the peak vertical ground reaction force. Therefore, the time to peak vertical ground reaction force was reported to enable interpretations of the biomechanical variables in the context of neural control. For the purpose of the current study, we distinguish broadly between feedforward control (≤50 ms after landing) and sensory feedback (≥30–50 ms after landing) (McDonagh and Duncan, 2002; Santello, 2005). Voluntary supraspinal commands are assumed to not influence the variables reported here (Taube et al., 2008).

Raw EMG signals were band-pass filtered (35–500 Hz), rectified, and smoothed with a 20 Hz zero-phase lag Butterworth low-pass filter. The smoothed EMG data were normalized to the highest EMG value recorded from either the MVIC or the drop jump (Besier et al., 2003; Rudolph et al., 2000; Voigt et al., 1998).

Coactivation was calculated during the 80 ms period prior to landing using the following equation (Schmitt and Rudolph, 2008),

$$\left[\sum_{i=1}^{n}\left(\frac{\mathrm{EMG}low_{(i)}}{\mathrm{EMG}high_{(i)}}\right)\times\left(\mathrm{EMG}low_{(i)}+\mathrm{EMG}high_{(i)}\right)\right]\div n \quad (2)$$

where *i* is timestep, n is total number of samples, EMG$low_{(i)}$ the lower of the two muscle amplitudes, and EMG$high_{(i)}$ the higher of the two muscle amplitudes. The ankle coactivation index was calculated using TA and SOL, while the knee index was calculated using RF and the average of the LH and MH muscles.

### 2.4. Statistical analysis

A one-way multivariate analysis of variance (MANOVA) was used to examine sex differences for LED-test performance, leg stiffness, time to peak vertical ground reaction force, body and joint kinematics, and ankle and knee coactivation. If a significant sex difference was found for the MANOVA, the results from univariate ANOVAs were reported for each dependent variable. The one-way MANOVA and post-hoc univariate ANOVAs were justified as the data were normally distributed with homogeneity of covariances and variances between groups. Statistical analyses were conducted with SPSS software (IBM, Armonk, NY) using $p \leq 0.05$.

## 3. Results

One male participant was excluded from all analyses because he did not complete the minimum of 15 LED-test trials that met the coefficient of variation criterion of 10%. Leg stiffness from an additional male subject exceeded 1.5 times the inter-quartile range when both groups were combined. Therefore, his single limb landing data were excluded. The ankle coactivation index could not be calculated for 1 female participant due to technical issues.

The multivariate test of overall differences was statistically significant ($p=0.005$). ANOVAs show that LED-test performance was significantly lower in the females than the males (99.6±5.5 vs. 109.3±7.9 N, $p=0.001$, Fig. 1). In addition, leg stiffness was significantly higher in the female athletes (395.7±101.6 vs. 304.8±54.9 N/m/kg, $p=0.008$, Fig. 2). Furthermore, the time to peak vertical ground reaction force occurred significantly earlier in females and coactivation of the ankle and knee was significantly greater in the female group (Table 2). Joint angles at initial contact and COM velocity were not different between sexes (Table 2).

## 4. Discussion

The purpose of this study was to determine whether lower extremity dexterity is a potential factor underlying altered movement behavior in female athletes. In support of our hypothesis, females exhibited reduced lower extremity dexterity and higher leg stiffness during a drop jump task when compared to age and skill matched male soccer athletes. Although the absolute difference between groups was relatively small in magnitude (10 N), the sex disparity was almost two times the previously reported minimal detectable difference of 5.5 N (Lyle et al., 2013).

Lower extremity dexterity was quantified as the ability to compress a spring prone to buckling as far as possible with the goal of finding the maximal instability that can be controlled. The spring-platform system becomes increasingly unstable and harder to control when compressed with increasing force; therefore, we reported the highest compression forces achieved as a surrogate to the maximum instability controlled. Importantly, we designed the LED-test to reach the limits of instability at submaximal forces (approximately

16% of body weight) to negate potential influences of lower extremity anthropometry and strength (Lyle et al., 2013). Thus, we interpret the lower forces achieved by females on the LED-test as reduced sensorimotor ability to regulate dynamic foot-ground interactions.

Apart from differences in LED-test performance, the female athletes landed with higher leg stiffness, which is characteristic of a movement behavior thought to increase the risk for ACL injury (Hewett et al., 2005; Laughlin et al., 2011; Schmitz et al., 2007; Sigward et al., 2011). The higher leg stiffness observed in females was attributed to both a higher vertical ground reaction force (4.1±0.55 vs. 3.7±0.47 body weights, $p$=0.03) and decreased COM displacement (10.6±0.01 vs. 12.2±0.02 cm, $p$=0.01). Our findings are consistent with a previous study that reported female athletes exhibit higher vertical ground reaction forces and less hip and knee flexion compared to males during single-limb landing (Schmitz et al., 2007).

The reduced dexterity exhibited by female athletes offers a potential explanation for the differences in movement behavior between males and females. Muscle activity observed prior to landing in cats (McKinley et al., 1983; Prochazka et al., 1977) and humans (Duncan and McDonagh, 2000; McDonagh and Duncan, 2002; McKinley and Pedotti, 1992; Santello, 2005) is believed to provide an initial level of muscle stiffness that controls, in part, the limb dynamics immediately after impact (Moritz and Farley, 2004). Bursts of muscle activity starting approximately 30–50 ms after impact are attributed to sensory feedback (e.g., muscle spindle, golgi tendon organ) (Duncan and McDonagh, 2000; McDonagh and Duncan, 2002; McKinley et al., 1983; Taube et al., 2008). For this reason, the sex differences in leg stiffness, calculated on average within 51 ms of impact (Table 2), can be attributed largely to preparatory regulation of leg stiffness from feedforward control (Fu and Hui-Chan, 2007; Hobara et al., 2007; Moritz and Farley, 2004). The higher ankle and knee coactivation observed in the female athletes support this premise as higher coactivation prior to landing has been shown to contribute to higher ground reaction forces and higher leg stiffness during similar tasks (Arampatzis et al., 2001; Fu and Hui-Chan, 2007; Hobara et al., 2007; Hortobagyi and DeVita, 2000). Although COM velocity and joint angles at impact could have influenced leg stiffness (Farley et al., 1998), these variables were similar between groups and therefore could not account for the sex differences observed here. Collectively, the findings raise the possibility that the female movement behavior observed in this study could represent a heightened feedforward muscle activation strategy to compensate for reduced lower extremity dexterity.

Behavioral and biomechanical lines of evidence suggest that reduced lower extremity dexterity may provide an explanation for higher ACL injury rates and a potential mechanism by which exercise interventions reduce these injuries. The lower LED-test scores achieved by the females in this study were interpreted as reduced ability to control dynamic foot-ground interactions. It is known that agility (i.e. ability to change direction quickly), which represents a functional domain related to dynamic foot-ground interactions, is enhanced in male athletes compared to female athletes (Meylan and Malatesta, 2009; Mujika et al., 2009; Pauole et al., 2000). Females also exhibit limb mechanics considered to increase ACL injury risk during landing and cutting maneuvers (Beutler et al., 2009; Sigward et al., 2011; Sigward and Powers, 2006). Importantly, anthropometry or strength does not appear to explain the sex differences in agility (Brughelli et al., 2008), at-risk movement behavior (Beutler et al., 2009; Herman et al., 2008; Mizner et al., 2008) or LED-test performance (Lyle et al., 2013). In addition, exercise interventions that only include muscle strengthening have not been shown to reduce ACL injury rates (Hewett et al., 2006). Instead, intervention programs shown to reduce injury rates in females incorporate multiplanar jumping and landing and agility tasks (Gilchrist et al., 2008; Kiani et al., 2010; Mandelbaum et al., 2005; Olsen et al., 2005). We propose that these tasks, which include technique instruction, could be viewed as opportunities for athletes to practice using their lower limbs to control and/or redirect their COM by dynamically regulating the magnitude and direction of foot-ground interactions. We speculate that lower extremity dexterity is an attribute that could be enhanced from these exercise interventions. Further study is necessary to examine whether LED-test performance is predictive of injury risk, performance on physical function tests for agility, or improved following injury prevention training.

Several physiological mechanisms could influence performance during the LED-test. The task goal specifies that participants direct force into an unstable surface with the lower limb, which necessitates concurrent dynamic stabilization. This goal could be accomplished by using sensory feedback and/or feedforward pathways that may include voluntary coactivation. It is well known that these options increase limb impedance but have inherent compromises in isolation (Hogan, 1984; Shemmell et al., 2010). Sensory feedback is metabolically efficient but suffers from delays due to signal transmission. Voluntary coactivation has no response delays but is metabolically inefficient and adds sensorimotor noise that could be destabilizing (Harris and Wolpert, 1998). Furthermore, voluntary limb stiffening by coactivation is influenced by strength and muscle activation levels (Hogan, 1984). Previously, we reported that LED-test scores are poorly correlated with lower extremity strength (Lyle et al., 2013). Thus, it is unlikely that whole limb stiffening is the primary strategy during the LED-test.

Several lines of evidence favor the interpretation that control during the LED-test is largely dependent on sensorimotor processing. First, the ability to compress a slender spring with the thumb has been shown to be compromised after decreasing thumbpad sensibility with a Lidocaine nerve block, but not by occluding vision (Venkadesan et al., 2007). Second, a differential increase in cortico-striatal-cerebellar networks has been observed when compressing springs with increasing levels of instability, and not just increased primary motor cortex drive as would be anticipated for a strategy based on finger stiffness (Mosier et al., 2011). Lastly, it has been shown that task specific reflex modulation can regulate multi-joint limb mechanics and stability when interacting with a compliant environment (De Serres et al., 2002; Krutky et al., 2010; Perreault et al., 2008). Therefore, we speculate that the participants used involuntary neural mechanisms (e.g. spinal, subcortical), as opposed to voluntary coactivation strategies, to stabilize the leg during the LED-test. Voluntary muscle activation, even at these low levels, naturally produces some stiffness and damping, but it is likely not a dominant strategy. Additional research is needed to identify the neuromuscular mechanisms responsible for the sex differences observed in this study.

As this is the first step toward examining the importance of lower limb dexterity as a potential factor contributing to the movement behavior considered to increase the risk of ACL injury, there are several limitations that should be noted. The small sample precluded statistical analyses to establish predictive relations. Future studies are needed that incorporate larger samples and longitudinal designs to evaluate the potential causal relations among limb dexterity, movement behavior and ACL injury risk. Moreover, the LED-test in its current form takes 30–40 min to complete. Thus, this test may not be feasible for screening purposes on a large scale at this time.

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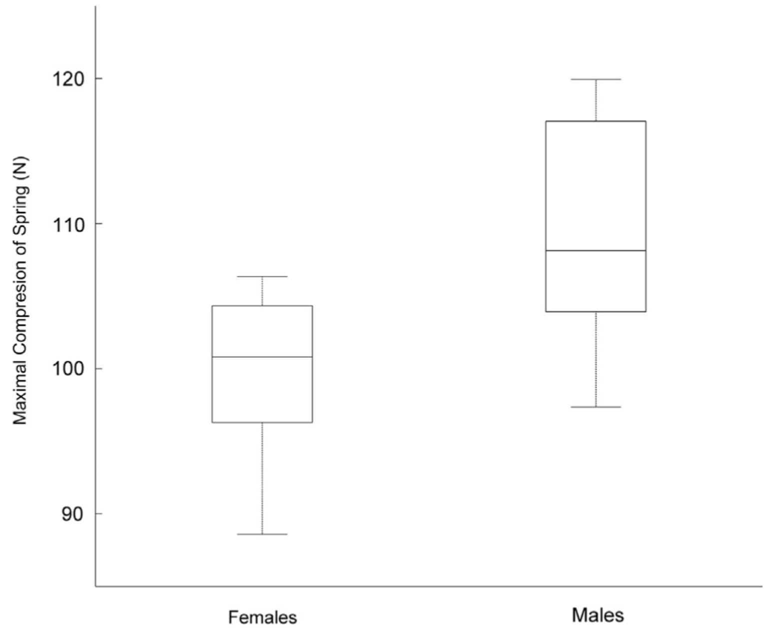


**Fig. 1.**
LED-test performance between sexes. Male soccer athletes achieved significantly greater forces when compared to female soccer athletes during the LED-test ($n$=14 per group, $p$=0.001). The forces achieved reflect the maximal instability that could be controlled. The central horizontal line within the box represents the median value, the box edges represent 25th and 75th percentile, and the whiskers represent the outermost data points.

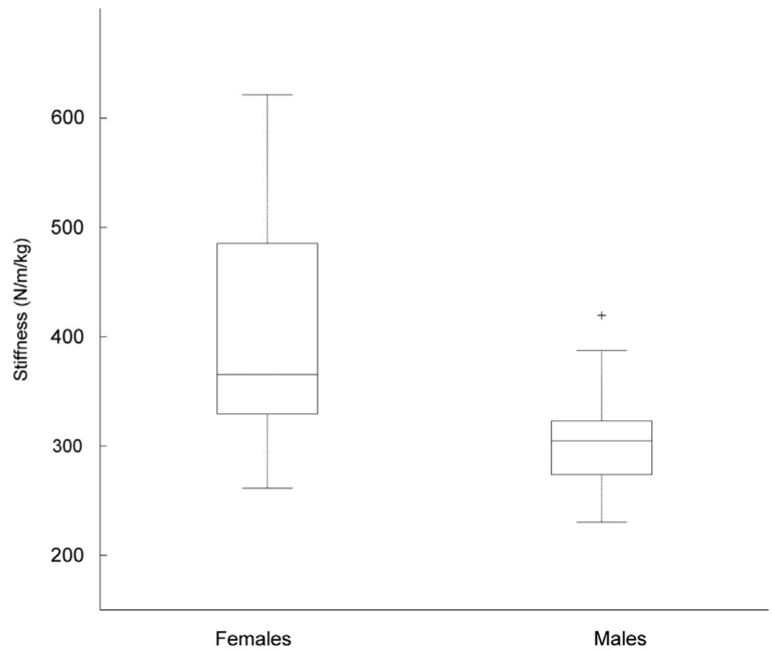


**Fig. 2.**

Average leg stiffness during a single-limb drop jump between sexes. Female soccer athletes ($n$=14) had significantly greater leg stiffness when compared to male soccer athletes ($n$=13) during the single limb drop jump ($p$=0.008). The central horizontal line within the box represents the median value, the box edges represent 25th and 75th percentile, the whiskers represent the outermost data points up to 1.5 times the interquartile range and the + represents data points exceeding the whiskers (i.e. outlier).

## Table 1

Participant characteristics (values are mean ± SD).

| | **Females *n*=14** | **Males *n*=14** | ***p*** |
|---|---|---|---|
| Age, yr | 16.2 ± 0.8 | 15.9 ± 0.7 | 0.33 |
| Height, m | 1.67 ± 0.06 | 1.79 ± 0.07 | <0.001 |
| Body mass, kg | 63.9 ± 11.6 | 67.8 ± 8.9 | 0.34 |
| Total soccer experience, yr | 10.9 ± 1.8 | 10.3 ± 2.1 | 0.46 |
| Club soccer experience, yr | 5.4 ± 1.9 | 4.5 ± 1.8 | 0.24 |

**Table 2**

Sex comparison of biomechanical variables during the single limb drop jump. (values are mean ± SD).

| | Females | Males | *p* |
|---|---|---|---|
| Time to peak force (ms)[a] | 47.8 ± 7.4 | 54.1 ± 7.7 | 0.04 |
| Initial contact ankle angle[a] | 29.5 ± 5.7 | 29.1 ± 6.9 | 0.86 |
| Initial contact knee angle[a] | 14.7 ± 2.9 | 15.7 ± 5.9 | 0.56 |
| Initial contact hip angle[a] | 29.7 ± 8.9 | 31.3 ± 5.5 | 0.59 |
| Center of mass velocity[a] | 2.27 ± 0.13 | 2.32 ± 0.14 | 0.37 |
| Ankle coactivation[b] | 14.9 ± 4.5 | 8.5 ± 3.7 | 0.001 |
| Knee coactivation[a] | 11.6 ± 3.9 | 7.9 ± 3.4 | 0.02 |

[a]Females: *n*=14, males: *n*=13.

[b]Females: *n*=13, males: *n*=13.