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The effect of equalizing landing task demands on sex differences in lower extremity energy absorption

Melissa M. Montgomery [a,*], Sandra J. Shultz [b], Randy J. Schmitz [b]

[a] *Department of Kinesiology, California State University, Northridge, Northridge, CA, USA*
[b] *Applied Neuromechanics Research Laboratory, Department of Kinesiology, University of North Carolina at Greensboro, Greensboro, NC, USA*

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ABSTRACT

Background: Less lean mass and strength may result in greater relative task demands on females compared to males when landing from a standardized height and could explain sex differences in energy absorption strategies. We compared the magnitude of sex differences in energy absorption when task demands were equalized relative to the amount of lower extremity lean mass available to dissipate kinetic energy upon landing.
Methods: Male–female pairs ($n = 35$) were assessed for lower extremity lean mass with dual-energy X-ray absorptiometry. Relative task demands were calculated when landing from a standardized height. Based on the difference in lower extremity lean mass within each pair, task demands were equalized by increasing the drop height for males. Joint energetics were measured while landing from the two heights. Multivariate repeated measures ANOVAs compared the magnitude of sex differences in joint energetics between conditions.
Findings: The multivariate test for absolute energy absorption was significant ($P < 0.01$). The magnitude of sex difference in energy absorption was greater at the hip and knee (both $P < 0.01$), but not the ankle ($P = 0.43$) during the equalized condition compared to the standardized and exaggerated conditions (all $P < 0.01$). There was no difference in the magnitude of sex differences between equalized, standardized and exaggerated conditions for relative energy absorption ($P = 0.18$).
Interpretation: Equalizing task demands increased the difference in absolute hip and knee energy absorption between sexes, but had no effect on relative joint contributions to total energy absorption. Sex differences in energy absorption are likely influenced by factors other than differences in relative task demands.

1. Introduction

Sex differences in landing strategies are well-described and considered to be the major contributor to the 3–4× greater risk of injury to the anterior cruciate ligament (ACL) in females compared to males (Arendt and Dick, 1995; Hootman et al., 2007). In particular, females typically exhibit a “stiff” landing strategy (Lephart et al., 2002; Schmitz et al., 2007), which is thought to be associated with a reduced ability of the lower extremity muscles to absorb ground reaction forces during deceleration type maneuvers (Devita and Skelly, 1992; Zhang et al., 2000). Females have a tendency to absorb more absolute energy about the knee during terminal (Decker et al., 2003) and non-terminal (Schmitz and Shultz, 2010; Shultz et al., 2010b) landings and also typically favor the knee and ankle joints to absorb a relatively larger proportion of these forces (Zhang et al., 2000; Decker et al., 2003; Schmitz and Shultz, 2010), compared to males who tend to favor the hip and knee joints. As a more distal-to-proximal joint energy absorption (EA) strategy may expose passive structures to higher forces during landing and have also been associated with ACL injury risk (Norcross et al., 2010), a better understanding of the factors which drive joint energetic strategies is needed.

Body composition has been suggested as a risk factor for ACL injury (Uhorchak et al., 2003; Shultz et al., 2010a; Shultz et al., 2012a), yet has remained relatively unexplored. Females with an above average body mass index (BMI; an estimate of body composition (Smalley et al., 1990)) were reported to have a 3.5× greater risk of sustaining an ACL injury compared to those with an average BMI (Uhorchak et al., 2003). However, the mechanism by which BMI lends toward injury is unknown. Since a larger BMI is related to a larger proportion of body fat in females (Loomba-Albrecht and Styne, 2009), it is likely that this would lead to decreased relative muscle strength in females compared to males as a result of reduced available fat free mass relative to total body mass. As such, it is plausible that sex differences in joint stiffening and energy absorption strategies simply reflect a female's lessened ability to produce eccentric muscle torques, and thus energy absorption (Zhang et al., 2000; Decker et al., 2003) needed to perform safe landings.

To our knowledge, only one study has examined the relationship between body composition and landing biomechanics (Montgomery et al., 2012), while others have examined relationships between strength and landing biomechanics (Shultz et al., 2009; Schmitz and

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[*] Corresponding author at: Department of Kinesiology, California State University, Northridge, 18111 Nordhoff St., Northridge, CA 91330-8287, USA.

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Shultz, 2010). These studies all indicated that the relationships between lean body mass, strength and landing mechanics seem to be more pronounced in females than males, suggesting that strength in females is a more critical factor in performing controlled landings. However, these studies have typically compared males and females during a standardized task (i.e. drop landing from the same height) without regard for inter-participant differences in body composition or physical ability. This could result in relatively greater task demands for females who generally have less muscle mass available to decelerate their total body mass than males. While some investigators have scaled the task demands to account for inter-participant size differences (e.g. a forward hop equal to a percentage of body height) (Norcross et al., 2010); males are still relatively stronger than females after adjusting for differences in body size. Thus, this adjustment may not adequately account for differences in relative strength. One approach is to control the relative task demands by manipulating the height from which they drop, thus controlling the amount of energy that must be dissipated upon landing. By equalizing the task demands according to the available amount of lower extremity lean mass (LELM), it is possible that more accurate comparisons can be made between males and females, thus ensuring that some of the observed sex differences in neuromechanics are not the result of females performing a relatively more difficult task compared to males.

Therefore, the objective of this study was to compare the magnitude of sex differences in energy absorption strategies when landing from the same height, when landing from a height that is equalized relative to the amount of lean mass available to dissipate kinetic energy upon landing, and when females landed from an exaggerated height (further exaggerating task demands for females). We expected that the magnitude of sex differences in EA, particularly at the knee, would be greatest in the exaggerated condition, and least when the task demands were equalized (i.e. landing height increased in males) as compared to when landing from the same height as males.

2. Methods

2.1. Participant recruitment and selection

We primarily recruited NCAA Division I and club soccer and basketball athletes for participation. Participants were eligible to participate if they regularly participated in athletic activities consisting of jumping, landing, and rapid decelerations with a change of direction. Participants were excluded if they had current lower extremity injury or pain, or a history of lower extremity orthopedic surgery or knee ligament injury. In order to maintain consistency with our population of interest (i.e. healthy athletes), we also chose to exclude those who were classified as obese ($BMI > 30\ kg/m^2$). Additionally, females were excluded if they were pregnant or thought they could be pregnant. Once a male and female with similar BMIs (within $1.0\ kg/m^2$) were identified, they were enrolled in the study as a pair. At that time, participants provided their informed consent according to university IRB protocol.

2.2. Body composition testing and calculation of relative task demands

Each participant's body composition was assessed with the Lunar Prodigy Advance (GE Healthcare, Madison, WI, USA) fan-beam DXA. All participants received standard instructions to prepare for their scan which required that they: 1) did not exercise or drink alcohol within 24 h of testing, 2) drank at least 1 l of water the evening before their scan, 3) did not intake caffeine or food within 2 h, and 4) voided their bladder within 15 min prior to measurement. Additionally, females were required to submit a urine sample so that a pregnancy test (CVS Early Result Pregnancy Test; CVS Caremark, Woonsocket, RI, USA) could confirm that they were not pregnant before testing could be performed. Body height (in) and mass (lb) were measured with a wall-mounted stadiometer and digital scale, respectively. These data were entered into the patient database in the EnCORE 2007 software (GE Healthcare, Madison, WI, USA) to calculate body composition. While wearing light athletic clothing void of any metal, participants were positioned on the DXA table per manufacturer's instructions and asked to lie still for the duration of the total body scan. EnCORE 2007 software (GE Healthcare, Madison, WI, USA) was then used to quantify lower extremity lean mass (LELM).

2.3. Biomechanical familiarization

Following body composition testing, participants performed a standardized 12-minute dynamic flexibility warm-up before being familiarized to the drop jump (DJ) landing task. This protocol included landing from 0.45 m to represent the standardized (STD) condition and then from a greater height of 0.55 m, which was used to represent the equalized (EQU) condition for males and the exaggerated (EXG) condition for females. We familiarized everyone to a height of 0.55 m because their actual EQU height could not be calculated until each male–female pair was tested for body composition. In the event that the actual EQU was more than 0.08 m from the practice height, the participants were asked to return to the lab for re-familiarization. The order of conditions was counterbalanced between pairs, but identical within each pair. While atop the box, participants were asked to assume an initial position whereby they aligned their 1st MTP joint (i.e. ball of foot) with the edge of the box and placed their hands at the level of their ears. They were then asked to drop straight down off the box, land evenly on both feet, perform a maximal vertical jump, and land once again on both feet. They were instructed to perform the drop landing and subsequent jump in one fluid motion (i.e. land, load, jump), rather than two separate motions (i.e. land, pause, load, jump). Each participant performed the entire task as many times as needed in order to be comfortable and consistent with the investigator emphasizing the importance of performing a maximal vertical jump each trial.

2.4. Calculation of relative task demands

Per the Law of Conservation of Energy, the potential energy (PE; body mass (kg) × gravity (m/s^2) × drop height (m)) of the person standing on the top of the box (PE_{box}) is theoretically equal to the sum of the kinetic energy (KE_{land}) and potential energy (PE_{land}) at the moment of landing. Thus, the relative task demand during the DJ was calculated for each participant based on the amount of LELM relative to their PE at the $height_{std}$ of 0.45 m ($LELM * PE^{-1}{}_{STD}$; Table 1, column A). Based on the difference in relative difficulty within matched female–male pairs, the drop height was increased for the male ($height_{EQU}$, Table 1, column B) to equalize the task demands to their matched female ($LELM * PE^{-1}{}_{EQU}$; Table 1, column C). We also used the calculated height for the male's EQU for the female's EXG.

2.5. Biomechanical testing

Approximately 7 days following familiarization, participants returned for biomechanical testing. They were outfitted in standardized shoes (Uraha 2; Adidas North America, Portland, OR, USA), compression shorts and shirt. Participants performed the dynamic flexibility warm-up in an identical fashion to that during familiarization. Following the warm-up, participants were instrumented with three optical LED markers (Phase Space, San Leandro, CA, USA) on each segment (foot, shank, thigh, and pelvis) for biomechanical analysis. Body mass and height were measured using the force platform (Type 4060-NC, Bertec Corporation, Columbus, OH, USA) and the digitizing stylus, respectively, to enable anthropometric modeling in Motion Monitor software (InnSports Training, Chicago, IL, USA) as well as normalization of the energetics data. Hip joint centers were calculated using the Leardini method (Leardini et al., 1999), while the knee and ankle joint centers were