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

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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.

Keywords: Lean mass | Landing | Energy absorption | Body composition | ACL injury

Article:

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 and Hootman et al., 2007). In particular, females typically exhibit a "stiff" landing strategy (Lephart et al., 2002 and 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 and 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 and 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 and 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 and 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 and 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 and Schmitz and 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).

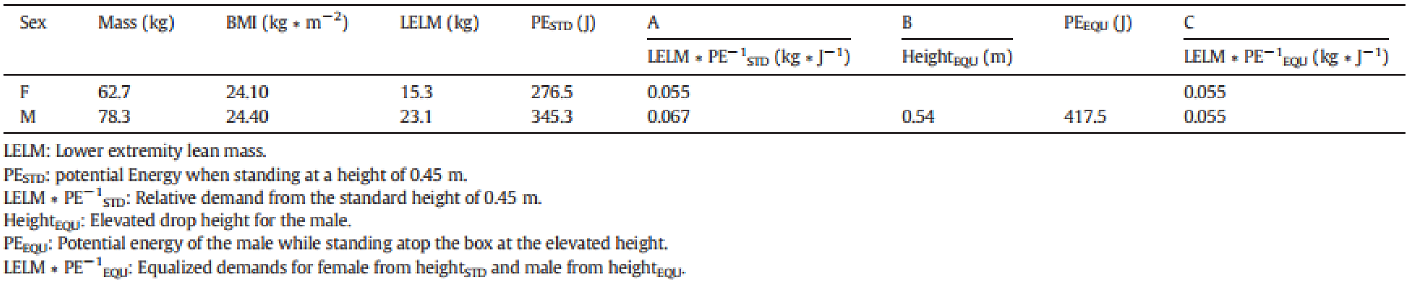
2.3. Biomechanical familiarization

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.

Table 1
Calculation of relative task difficulty ($LELM * PE^{-1}$) for BMI-matched males and females for the STD drop height of 0.45 m (column A). Drop height was increased for each male to match his task demand to his female counterpart ($height_{equ}$; column B), resulting in equalized relative task demands (column C).



Sex	Mass (kg)	BMI ($kg * m^{-2}$)	LELM (kg)	PE_{STD} (J)	A	B	PE_{EQU} (J)	C
					$LELM * PE^{-1}_{STD}$ ($kg * J^{-1}$)	$Height_{EQU}$ (m)		$LELM * PE^{-1}_{EQU}$ ($kg * J^{-1}$)
F	62.7	24.10	15.3	276.5	0.055			0.055
M	78.3	24.40	23.1	345.3	0.067	0.54	417.5	0.055

LELM: Lower extremity lean mass.
PE_{STD}: potential Energy when standing at a height of 0.45 m.
$LELM * PE^{-1}_{STD}$: Relative demand from the standard height of 0.45 m.
$Height_{EQU}$: Elevated drop height for the male.
PE_{EQU}: Potential energy of the male while standing atop the box at the elevated height.
$LELM * PE^{-1}_{EQU}$: Equalized demands for female from $height_{STD}$ and male from $height_{EQU}$.

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 calculated as the centroid of the medial and lateral femoral epicondyles and malleoli, respectively (Madigan and Pidcoe, 2003).

Participants performed 5 successful trials of the DJ landing for both conditions following the appropriate counterbalance order. Males performed the DJ from the EQU to represent the equalized condition, while females also performed the DJ at this height (EXG) to represent a task of exaggerated difficulty. For a trial to be considered successful, the participant had to keep their hands by both ears, drop off the box without stepping or jumping, land evenly on two feet with the test limb foot landing independently on the force platform, perform a maximal vertical jump and once again land evenly on two feet, as assessed by the investigator.

2.6. Data processing and reduction

2.6.1. Body composition data

The regions of interest (ROI) provided in the ENCORE 2007 software (GE Healthcare, Madison, WI, USA) were manually adjusted to partition total body composition into regional bone, lean, and fat mass so that the relative amounts and locations of lean mass could be determined. The lower extremity ROI was formed by a diagonal line which extended from the iliac crest through the femoral neck and then continued down to the tip of the longest toe, and laterally to include all soft tissue of the leg (Fig. 1). The amount of lean mass located in this ROI was designated as LELM (kg). The investigator established excellent day-to-day reliability ($ICC_{2,1}$ = 0.94–1.00) for manual lower extremity ROI placement in a group of 15 recreationally-active females (mean (S.D.) age = 20.3 (2.4) years, BMI = 23.2 (3.4) kg/m^2).

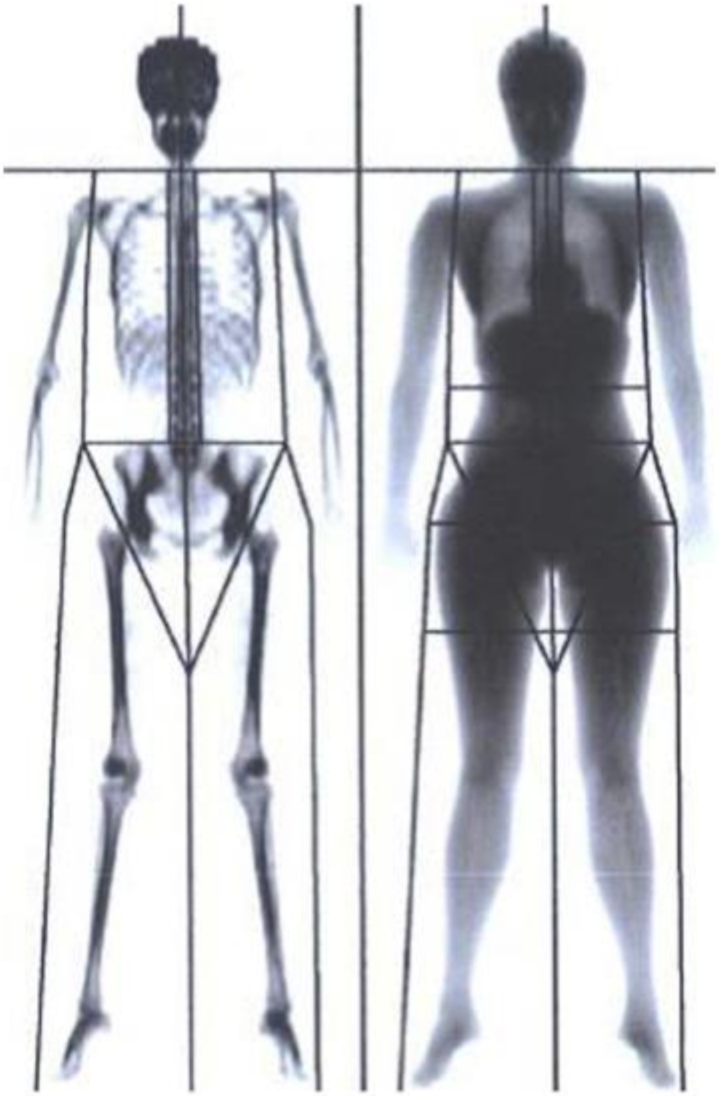


Fig. 1. Standard regions of interest (ROI) are manually-adjusted to define the lower extremity.

2.6.2. Biomechanical data

Kinematic and kinetic data were filtered with a 4th order, zero-lag 12 Hz low pass Butterworth filter. All processing was performed with Motion Monitor software (InnSports Training, Chicago, IL, USA). Data were then exported to Microsoft Excel 2007 (Microsoft Corp, Redmond, WA, USA) for further reduction. From these data, hip, knee, and ankle joint excursion were extracted from initial contact (vGRF > 10 N) to peak knee flexion to best represent the muscle actions over the entire deceleration period. Hip, knee, and ankle sagittal moments (Nm) were calculated with inverse dynamics solutions, while EA (eccentric work of hip extensors, knee extensors, and ankle extensors) were calculated as the areas under the negative joint power curves (Zhang et al., 2000, Decker et al., 2003 and Schmitz and Shultz, 2010). For all analyses, EA was calculated as the average value obtained across the 5 trials and then normalized to body weight and height ($J * N^{-1} * m^{-1}$).

2.6.3. Statistical analysis

For descriptive purposes and for comparison to previous work that used a standardized task when comparing sex differences in landing, independent t-tests compared males and females on hip, knee, and ankle EA during the STD condition. Then, to represent the sex difference in EA for each matched pair, difference scores (male's EA–female's EA) were calculated for each dependent variable. Then separate multivariate repeated measures ANOVAs compared the magnitude of the difference between males and females in absolute and relative joint EA (hip, knee, and ankle) between the 3 conditions (standardized (females STD vs. males STD), equalized (females STD vs. males EQU) and exaggerated (females EXG vs. males EQU)). If the overall multivariate test was significant, we examined the univariate (hip, knee, ankle) ANOVAs. Pairwise comparisons with Bonferroni corrections then determined the condition during which the larger sex difference existed. The level of significance was set a priori at $P \leq 0.05$.

3. RESULTS

Table 2 lists the demographic and body composition characteristics of participants who successfully completed data collection. For descriptive purposes, independent t-tests determined that, as expected, males were taller ($P < 0.01$) and heavier ($P < 0.01$) than their female counterparts, and the matching scheme was successful as there were no differences in BMI ($P = 0.60$). Males also had greater lower extremity lean mass (LELM) and relative total body mass ($P < 0.01$) than females.

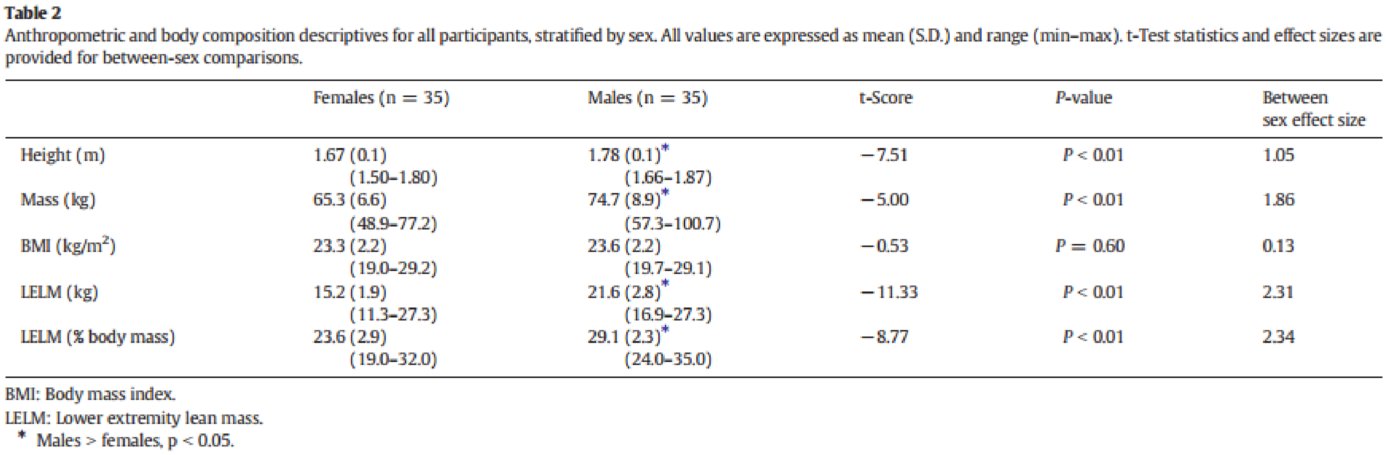


Table 2
Anthropometric and body composition descriptives for all participants, stratified by sex. All values are expressed as mean (S.D.) and range (min–max). t-Test statistics and effect sizes are provided for between-sex comparisons.

	Females (n = 35)	Males (n = 35)	t-Score	*P*-value	Between sex effect size
Height (m)	1.67 (0.1) (1.50–1.80)	1.78 (0.1)* (1.66–1.87)	−7.51	$P < 0.01$	1.05
Mass (kg)	65.3 (6.6) (48.9–77.2)	74.7 (8.9)* (57.3–100.7)	−5.00	$P < 0.01$	1.86
BMI (kg/m^2)	23.3 (2.2) (19.0–29.2)	23.6 (2.2) (19.7–29.1)	−0.53	$P = 0.60$	0.13
LELM (kg)	15.2 (1.9) (11.3–27.3)	21.6 (2.8)* (16.9–27.3)	−11.33	$P < 0.01$	2.31
LELM (% body mass)	23.6 (2.9) (19.0–32.0)	29.1 (2.3)* (24.0–35.0)	−8.77	$P < 0.01$	2.34

BMI: Body mass index.
LELM: Lower extremity lean mass.
* Males > females, $p < 0.05$.

The calculated drop height during the EQU condition resulted in an average drop height of 0.57 m (0.07 m) for the males, with the increase in height ranging from 0.00 to 0.23 m. An increase of 0.0 m indicates no difference in the LELM $* PE^{-1}$ ratio between the matched female and male. The calculated sex differences (male EA–female EA) for absolute and relative EA at all joints during all conditions are displayed in Fig. 2 and Fig. 3, respectively.

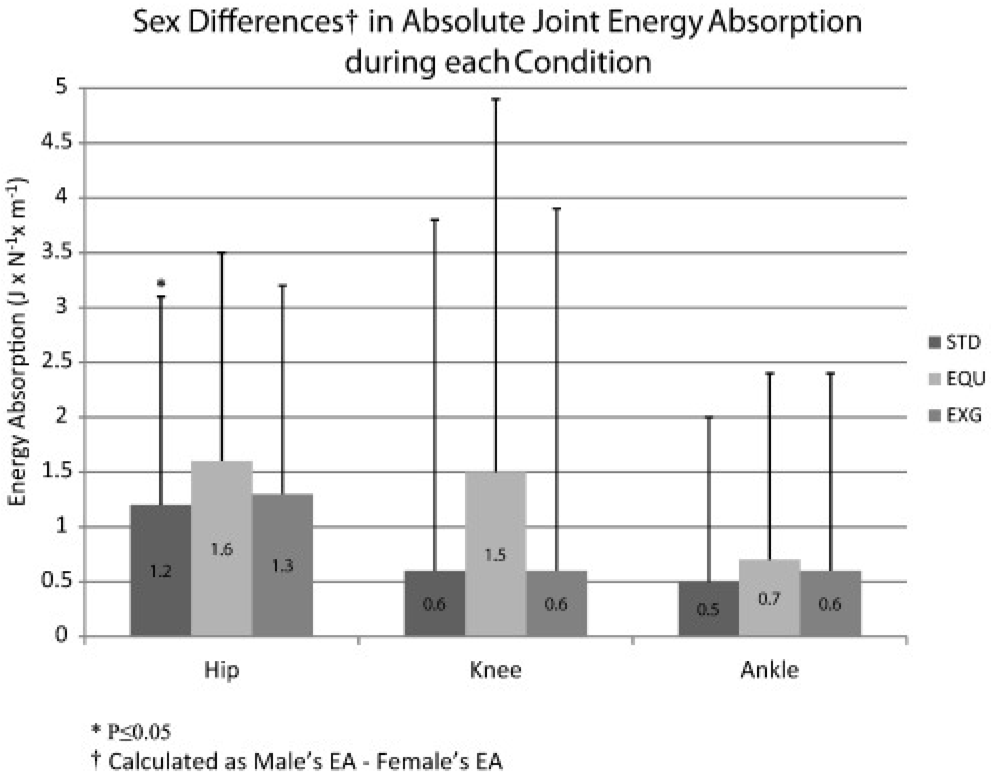
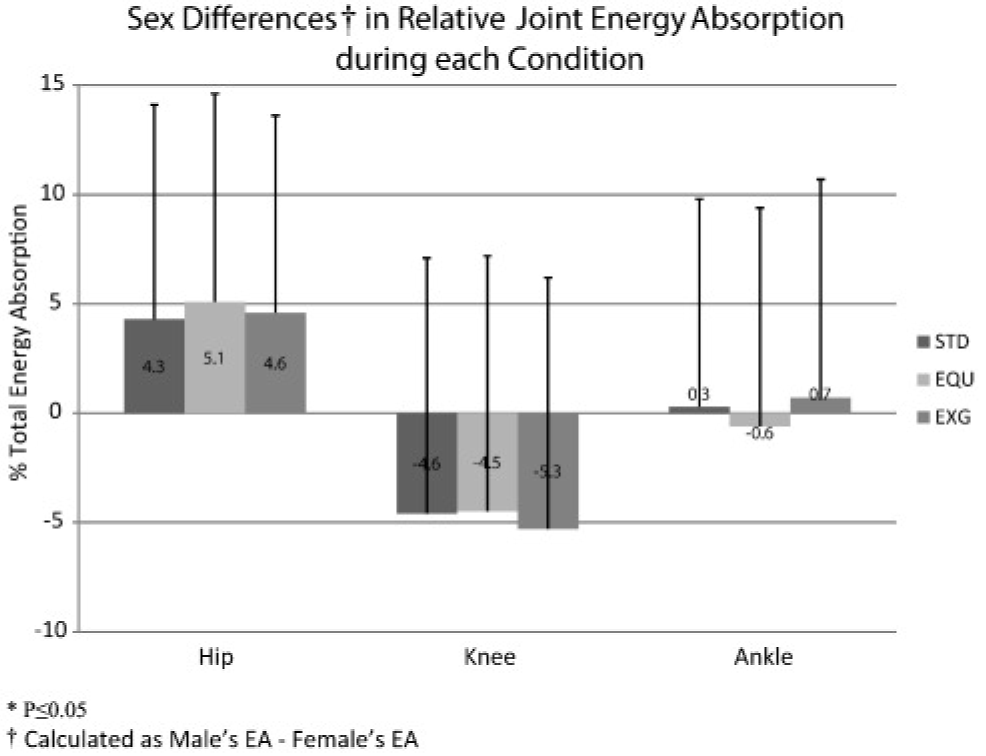


Fig. 2. Sex difference in absolute joint energy absorption for each of the three landing conditions. Differences were calculated as male's EA–female's EA.


Sex Differences† in Relative Joint Energy Absorption during each Condition

* P≤0.05

† Calculated as Male's EA - Female's EA

Fig. 3. Sex difference in relative joint energy absorption for each of the three landing conditions. Differences were calculated as male's EA–female's EA.

All descriptives and test statistics are in Table 3. These tests revealed that during STD, males absorbed more absolute energy ($J * N^{-1} * m^{-1}$) at the hip (3.9 (1.7) vs. 2.7 (1.3); $P < 0.01$), but not the knee ($P = 0.32$) or ankle ($P = 0.09$), compared to females. Males also absorbed a greater relative proportion of energy (%) about the hip (22.4 (9.6) vs. 18.1 (8.4); $P = 0.05$) compared to females, but not at the knee ($P = 0.08$) or ankle ($P = 0.88$).

The overall multivariate test for absolute EA was significant ($F_{6,29} = 11.97$, $P < 0.01$), indicating that the magnitude of sex difference in EA was different between conditions. When examining the univariate tests, the sphericity assumption was not met so the Greenhouse–Geisser correction was applied (Greenhouse and Geisser, 1959). The magnitude of sex difference in EA was apparent at the hip ($F_{1.5,51.7} = 8.10$, $P < 0.01$) and knee ($F_{1.5,50.9} = 12.74$, $P < 0.01$), but not at the ankle ($F_{1.5,50.2} = 0.77$, $P = 0.43$). The post-hoc analyses revealed that the larger sex differences in hip and knee EA occurred during the EQU condition compared to the STD and EXG conditions (all $P < 0.01$). The overall multivariate test for relative EA was not significant ($F_{4,31} = 1.69$, $P = 0.18$), indicating that the magnitude of sex difference in relative joint EA was similar across all conditions.

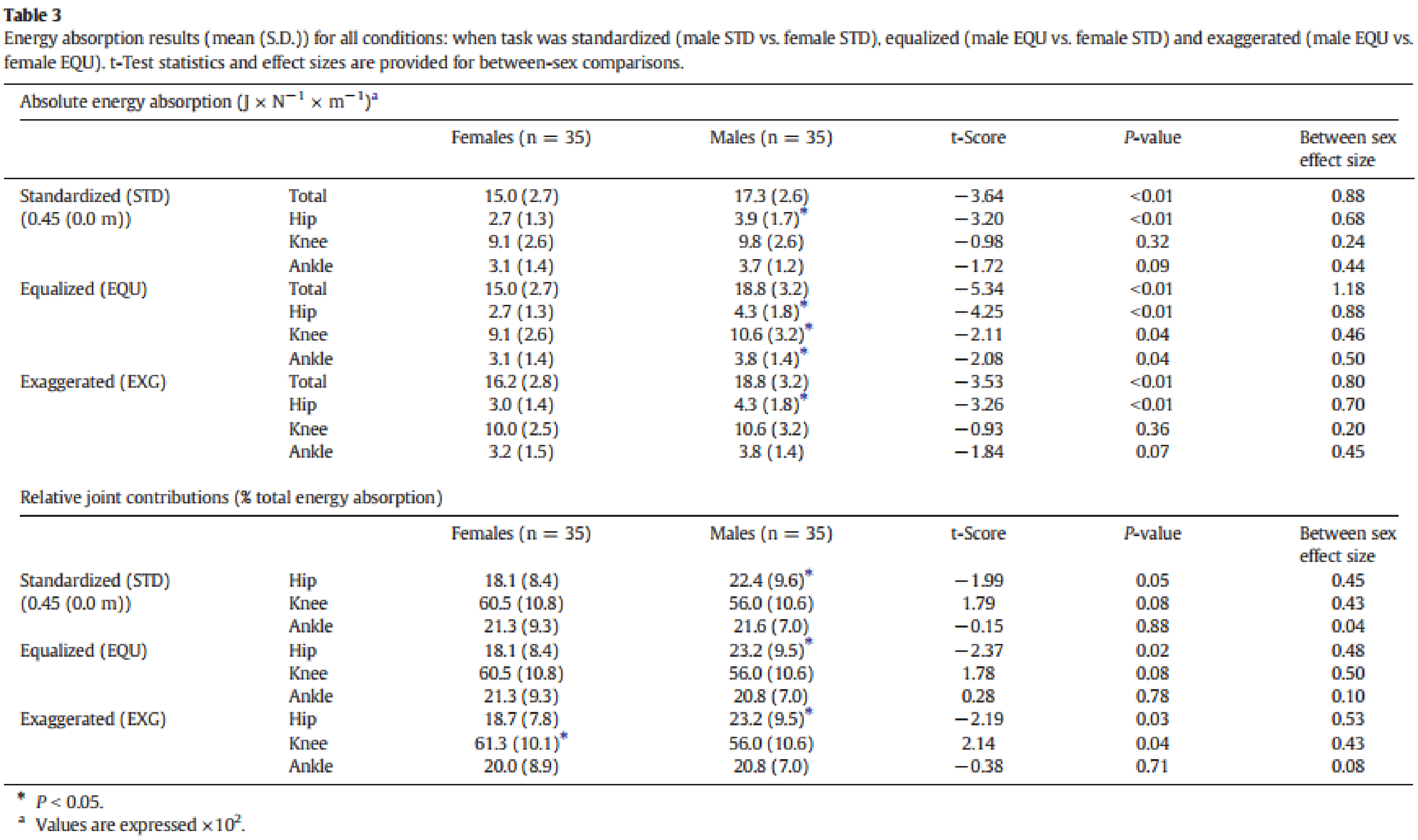


Table 3

Energy absorption results (mean (S.D.)) for all conditions: when task was standardized (male STD vs. female STD), equalized (male EQU vs. female STD) and exaggerated (male EQU vs. female EQU). t-Test statistics and effect sizes are provided for between-sex comparisons.

Absolute energy absorption (J × N^{-1} × m^{-1})[a]

		Females (n = 35)	Males (n = 35)	t-Score	*P*-value	Between sex effect size
Standardized (STD) (0.45 (0.0 m))	Total	15.0 (2.7)	17.3 (2.6)	−3.64	<0.01	0.88
	Hip	2.7 (1.3)	3.9 (1.7)*	−3.20	<0.01	0.68
	Knee	9.1 (2.6)	9.8 (2.6)	−0.98	0.32	0.24
	Ankle	3.1 (1.4)	3.7 (1.2)	−1.72	0.09	0.44
Equalized (EQU)	Total	15.0 (2.7)	18.8 (3.2)	−5.34	<0.01	1.18
	Hip	2.7 (1.3)	4.3 (1.8)*	−4.25	<0.01	0.88
	Knee	9.1 (2.6)	10.6 (3.2)*	−2.11	0.04	0.46
	Ankle	3.1 (1.4)	3.8 (1.4)*	−2.08	0.04	0.50
Exaggerated (EXG)	Total	16.2 (2.8)	18.8 (3.2)	−3.53	<0.01	0.80
	Hip	3.0 (1.4)	4.3 (1.8)*	−3.26	<0.01	0.70
	Knee	10.0 (2.5)	10.6 (3.2)	−0.93	0.36	0.20
	Ankle	3.2 (1.5)	3.8 (1.4)	−1.84	0.07	0.45

Relative joint contributions (% total energy absorption)

		Females (n = 35)	Males (n = 35)	t-Score	*P*-value	Between sex effect size
Standardized (STD) (0.45 (0.0 m))	Hip	18.1 (8.4)	22.4 (9.6)*	−1.99	0.05	0.45
	Knee	60.5 (10.8)	56.0 (10.6)	1.79	0.08	0.43
	Ankle	21.3 (9.3)	21.6 (7.0)	−0.15	0.88	0.04
Equalized (EQU)	Hip	18.1 (8.4)	23.2 (9.5)*	−2.37	0.02	0.48
	Knee	60.5 (10.8)	56.0 (10.6)	1.78	0.08	0.50
	Ankle	21.3 (9.3)	20.8 (7.0)	0.28	0.78	0.10
Exaggerated (EXG)	Hip	18.7 (7.8)	23.2 (9.5)*	−2.19	0.03	0.53
	Knee	61.3 (10.1)*	56.0 (10.6)	2.14	0.04	0.43
	Ankle	20.0 (8.9)	20.8 (7.0)	−0.38	0.71	0.08

* $P < 0.05$.

[a] Values are expressed ×10^2.

4. DISCUSSION

In the current study, we examined the effect of equalizing task demands within BMI-matched pairs in order to examine the theory that previously-observed sex differences in landing biomechanics when landing from the same height are partly attributed to females possessing less lean mass and strength than males (Shultz et al., 2009 and Schmitz and Shultz, 2010). By equalizing the task demands between BMI-matched males and females, we hypothesized that the sex differences in joint-specific EA would be smaller. Additionally, when differences in task demands were exaggerated we thought we would observe greater sex difference in landing energetics due to an even greater overall difficulty for females, compared to the standardized condition. These hypotheses were not upheld.

In the current study, when comparing males and females during a standardized task, we did not see the typical sex differences in joint energetics as expected from previous work. Namely, when examining individual joint contributions just during the standardized condition, we found that males absorbed more energy at the hip, but there were no sex differences at the knee or ankle. These findings are in partial agreement with previous reports that males absorb more absolute energy about the hip during a terminal landing (Decker et al., 2003) but are contrary to previous findings that females absorb more absolute energy about the knee during terminal (Decker et al., 2003) and non-terminal (Schmitz and Shultz, 2010 and Shultz et al., 2010b) landings. However, when looking at relative joint contributions, it was noted that although not statistically-significant ($P = 0.08$), females absorbed 4.5% more energy about the knee than males, while males absorbed 4.3% more energy about the hip than females ($P = 0.05$), which is consistent with previous work. (Schmitz and Shultz, 2010 and Shultz et al., 2010b) While this “knee-dominant” strategy in females has been suggested to be reflective of hip extensor weakness (Zhang et al., 2000 and Pollard et al., 2010) we did not examine hip strength in the current study.

When examining the effect of equalizing the task demands by increasing the difficulty of the task for males, they absorbed more overall energy with a similar increase in EA across the joints, which increased the sex difference in absolute EA. The increase in EA with greater drop height is consistent with previous studies that have investigated the effects of increased landing heights on EA (Mcnitt-Gray, 1993, Zhang et al., 2000 and Zhang et al., 2008) and is also consistent with the basic premise that an increase in drop height is concomitant with the generation of a greater amount of kinetic energy which must be dissipated upon landing. However, of greater interest to the current investigation were the relative joint contributions to EA where we observed sex differences in relative joint contributions only at the hip (M > F), although the females trended towards a greater proportion of EA at the knee (Table 3). When the task demands were equalized, males absorbed more total energy when landing from a greater height; but contrary to our hypothesis, hip and knee energy absorptions did not change (< 1%).

Females increasing their EA in a nearly identical fashion with regard to individual joint contributions was unexpected since the EXG condition represented an especially exaggerated increase in task difficulty compared to the males; hence, larger changes in joint-specific EA were expected in the females from the STD to EXG conditions. Another unexpected finding was the absence of a “shift” in relative joint contributions to total energy absorption from the distal musculature (i.e. ankle) at the lower height to the larger, more proximal musculature (i.e. hip) at the higher height, which has been previously documented (Zhang et al., 2000 and Zhang et al., 2008) and theorized to be reflective of the larger muscle groups' capacity for greater energy absorption (Zhang et al., 2000). Given these findings in drop landings, it was reasonable to expect that energy dissipation demands would be met with larger muscle groups (i.e. a shift in EA to the hip). However, since the previous observations were made during a drop landing, the relationship of height to joint-specific demands may differ with the current drop jump task. Since the drop jump is typically characterized by larger contributions from the hip compared to the drop landing (Shultz et al., 2012b), the distal-to-proximal effect previously observed in drop landings may have been negated during the current task as the participants were already utilizing their hip to absorb energy at the lower height in preparation for subsequent utilization of the stored energy for a maximal vertical jump.

Collectively, our findings were unexpected, as we hypothesized that energy absorption demands about the knee during landing in females would increase as a function of the increased kinetic energy associated with landing from a greater height. The most likely explanation for the lack of sex differences in knee energy absorption at either height is that the females in this study were more highly trained, experienced, and likely stronger than the recreationally-active college students used in previous studies (Zhang et al., 2000, Decker et al., 2003, Zhang et al., 2008, Norcross et al., 2010, Schmitz and Shultz, 2010 and Shultz et al., 2010b). By including a group of females who were very skilled and experienced jumpers, it appears that it narrowed the big differences between the males and females in jumping and landing ability, which likely provides a partial explanation for the lack of expected sex differences in the current study (e.g. greater vertical ground reaction forces (Decker et al., 2003, Lephart et al., 2002 and Schmitz et al., 2007), peak knee extensor moments (Chappell et al., 2002 and Salci et al., 2004), and knee energy absorption (Decker et al., 2003 and Schmitz and Shultz, 2010)), compared to previous work that compared males and females during a standardized task. Further, the increased drop height during the EQU condition may have still been well within their strength capabilities; thus, their accommodation strategy looked similar to the males. Anecdotally, the majority of females in our study reported that the EXG condition did not feel more difficult to them. This may point to a need to account for additional factors above those used in this study when matching relative demands. Since eccentric strength correlates slightly better with EA than lower extremity lean mass (Montgomery et al., 2012), matching relative difficulty on the basis of strength rather than lean mass may better capture true functional differences in relative task difficulty experienced by males and females. However, as strength is likely not the sole factor in determining energy absorption capabilities, other factors which are difficult to quantify and manipulate, such as coordination, should be taken into consideration.

Another observation in this study that became evident during the matching scheme was that matched males and females who had larger BMIs typically had larger differences in drop height (EQU-STD). Because the equalized condition was essentially based on the ratio of LELM to body mass, and larger differences in LELM result in larger equalized drop heights, this confirmed previous findings that larger BMIs are primarily attributed to greater lean mass in males and greater fat mass in females (Loomba-Albrecht and Styne, 2009). The participants in this study represented a seemingly large range of BMIs: 19.0 to 29.2 kg/m^2, which accordingly represented a large range of LELM values (11.3–19.8 kg in females; 16.9–27.3 kg in males). This was met with disproportionately larger drop heights during the EQU condition for those with larger BMIs. It is possible that those males and females who had to drop from greater heights (due to a higher BMI) experienced larger changes in EA than those with smaller BMIs. In future work, we will consider more closely examining those with above average BMIs since those females have specifically been identified as being more at-risk for ACL injury (Uhorchak et al., 2003).

5. CONCLUSIONS

Equalizing the relative task demands between BMI-matched males and females did not induce the expected alterations in energy absorption strategies. During a standardized task where sex differences in knee EA are typically present, the males and females in the current study performed similarly. When the task difficulty was increased to account for sex differences in LELM relative to total body mass, the males responded by increasing total EA without the preferential reliance on the knee that was expected. When females were also asked to land from the increased height, which represented an exaggerated increase in relative task difficulty compared to the males, the females responded to the greater height in a manner nearly identical to that of the males. These findings may suggest that the relative task difficulty was underestimated in this highly athletic and skilled population and that further work is needed to determine the most appropriate equalizing scheme for creating parity in task difficulty between males and females.

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