



## Full Length Article

## Focus of attention effects on lower extremity biomechanics during vertical jump landings

John R. Harry<sup>a,\*</sup>, Ryan Lanier<sup>a</sup>, Brandon Nunley<sup>a</sup>, Jarrod Blinck<sup>b</sup><sup>a</sup> Human Performance & Biomechanics Laboratory, Dept. of Kinesiology & Sport Management, Texas Tech University, 3204 Main Street, Lubbock, TX 79409, United States of America<sup>b</sup> Motor Behavior Laboratory, Dept. of Kinesiology & Sport Management, Texas Tech University, 3204 Main Street, Lubbock, TX 79409, United States of America

## ARTICLE INFO

## Keywords:

External focus  
Ground reaction forces  
Internal focus  
Joint work  
Landing

## ABSTRACT

This study examined biomechanical differences between external and internal foci of attention during vertical jump landings in males and females. Twenty-four healthy adults performed eight vertical jump landings using both internal and external foci while three-dimensional kinematic and ground reaction force (GRF) data were obtained. Two (focus) by two (sex) analyses of variance ( $\alpha = 0.05$ ) and Cohen's *d* effect sizes (ES) were used to compare differences in vertical GRF, joint angular positions and displacements, and lower limb joint angular work between foci and between sexes. Significantly greater knee contributions to total angular work occurred during external versus internal focus landings regardless of sex ( $p = .013$ ; ES = 0.30). Significantly smaller plantarflexion angles ( $p = .019$ ; ES = 0.53) and significantly greater knee flexion angles were observed at ground contact ( $p < .001$ ; ES = 1.11) in males during external focus landings. Females exhibited significantly smaller knee flexion angles at both ground contact during external versus internal focus landings ( $p = .031$ ; ES = 0.20) and compared to males during external focus landings ( $p < .001$ ; ES = 1.76). Both peak vertical GRF ( $p = .003$ ; ES = 1.54) and the ankle contributions to total angular work during loading ( $p = .026$ ; ES = 1.07) were greater in females versus males regardless of foci, whereas the knee contributions to total angular work during loading were smaller in women ( $p = .026$ ; ES = 1.07). Males and females might consider adopting an external focus during vertical jump landings to increase knee joint contributions to lower limb energy absorption. Females, in particular, might consider external focus use to decrease peak vertical GRF and increase the knee joint's contribution to total energy absorption to magnitudes similar to those exhibited by males.

## 1. Introduction

Focus of attention has been shown to influence motor skill learning and performance (Wulf, 2013; Wulf, McNevin, & Shea, 2001). Contemporary evidence suggests adopting an external focus (i.e., focus on the movement effect) yields superior results compared to an internal focus (i.e., focus on one's own body movements) during a number of motor skills, including basketball shots (Al-Abood, Bennett, Hernandez, Ashford, & Davids, 2002), golf chipping (Wulf & Su, 2007), lofted soccer kicks (Wulf, McConnel, Gärtner, & Schwarz, 2002), and dart throwing (Marchant, Clough, & Crawshaw, 2007). In addition to these types of sub-maximal effort motor skills requiring object manipulation and endpoint precision, performance of maximum-effort human-only movements, such as the

\* Corresponding author.

E-mail address: [john.harry@ttu.edu](mailto:john.harry@ttu.edu) (J.R. Harry).<https://doi.org/10.1016/j.humov.2019.102521>

Received 30 May 2019; Received in revised form 10 September 2019; Accepted 10 September 2019

Available online 11 October 2019

0167-9457/ © 2019 Elsevier B.V. All rights reserved.

countermovement vertical jump (CMVJ), can be enhanced through adoption of an external versus internal focus. For instance, enhanced CMVJ performance from use of an external focus is due, in part, to increased external force and lower-extremity joint torque productions (Wulf & Dufek, 2009). Independent of motor skill intensity, external foci appear to promote more efficient motor strategies (Vance, Wulf, Töllner, McNevin, & Mercer, 2004; Wulf, Dufek, Lozano, & Pettigrew, 2010) that maximize motor learning and performance by bolstering the automaticity of control processes governing movement execution (Wulf et al., 2001).

It seems clear that use of an external focus is favored over an internal focus during motor skill performance regardless of the task, the need for object manipulation, or both. However, the dominating theme among available investigations centers on focus of attention effects during the production of movement (e.g., throwing) rather than termination of movement. While positive external focus effects have been observed during tasks requiring performers to terminate postural sway movements (McNevin & Wulf, 2002; Wulf et al., 2001; Wulf, Höß, & Prinz, 1998), focus of attention effects have yet to be thoroughly examined during motor skills in which high-velocity body movements must be terminated, such as landing from a CMVJ.

Vertical landing is a commonly investigated motor skill that requires a performer to rapidly terminate downward momentum through negative angular power and work (i.e., energy dissipation) performed about the involved joints (Devita & Skelly, 1992; Harry, Barker, Eggleston, & Dufek, 2018). In light of these demands, landings are typically examined with respect to musculoskeletal overuse injury potential (Devita & Skelly, 1992; Dufek & Bates, 1990; Norcross et al., 2013; Zhang, Bates, & Dufek, 2000). Thus, it may not be surprising that the studies available on focus of attention effects during vertical landings aimed to determine whether adopting an external focus could improve movement technique and decrease musculoskeletal injury potential (Welling, Benjaminse, Gokeler, & Otten, 2016). It was suggested that qualitative technique improvements could be realized through adoption of an external focus, which might decrease overuse musculoskeletal injury potential to the anterior cruciate ligament (Welling et al., 2016). That working hypothesis was supported by a follow-up study in which males and females allocated to groups receiving either video instruction or an external focus demonstrated greater improvements in landing technique (e.g., greater knee flexion angles, more symmetrical movement patterns, smaller peak frontal knee moments and vertical GRF) than those receiving an internal focus following two training blocks of 10 drop vertical jump landings, and the improvements were retained during a 1-week retention test (Welling, Benjaminse, Gokeler, & Otten, 2017). In addition, a recent study investigating focus of attention effects during landing in male and female youth (14–17 years of age) rugby athletes observed a reduction in peak vertical GRF following two-weeks of both internal and external focus training (Widenhoefer, Miller, Weigand, Watkins, & Almonroeder, 2019). Importantly, the internal focus training coincided with increased impact forces when a secondary cognitive task was included (i.e., counting backward in 3's) but forces were negligibly effected by the secondary cognitive task following external focus training. While these studies collectively indicate adoption of an external focus can both qualitatively and quantitatively improve landing technique by altering discrete kinetic parameters, the landing movement performed tends to be completed from an elevated platform, which is known to require different mechanics and neural activations than the more generalizable CMVJ landings (Afifi & Hinrichs, 2012; Harry, Freedman Silvernail, Mercer, & Dufek, 2017). In addition, it remains unknown whether an external focus can also stimulate changes in time-dependent variables that might be better associated with the performance of a landing, such energy absorption about the involved joints (Norcross et al., 2013; Norcross, Blackburn, Goerger, & Padua, 2010; Yeow, Lee, & Goh, 2011).

Because of the need to study focus of attention effects during landing from a jump, sex differences should also be anticipated due to the unique landing mechanics employed by females versus males. For example, females exhibit greater knee valgus asymmetry than males during landings from a forward hop (Pappas & Carpes, 2012) in addition to greater knee flexion angles and angular accelerations during single-leg CMVJ landings (Fagenbaum & Darling, 2003). Furthermore, females exhibit greater peak vertical impact forces, knee extension moments, and ankle plantarflexion moments than males during sport-specific CMVJ landings from heights equal to 50% of their maximum vertical jump height (Butler, Willson, Fowler, & Queen, 2013). While a separate study identified smaller peak vertical impact forces in women versus men during more traditional maximum-effort CMVJ landings (Harry, James, & Dufek, 2019), females were also shown in that study to perform more angular work about the knee and ankle joints than males. Importantly, sex-specific responses to a novel focus of attention could be expected as slightly different focus-driven responses have been shown in both limbs during drop vertical jump landings (Welling et al., 2017). Furthermore, sex-specific responses to focus of attention interventions could be expected due to sex-specific combinations of biological, environmental, and sociocultural constraints that influence movement patterns (Bruton, O'Dwyer, & Adams, 2013). As such, thorough investigation into potential sex-specific responses to focus of attention interventions is warranted.

The purpose of this investigation was to examine differences in external impact forces and the organization of lower-extremity joint work during CMVJ landings between external and internal foci of attention in males and females. Based on the literature reviewed, we tested the following hypotheses: 1) greater peak vertical GRF magnitudes would occur when using an internal versus external focus regardless of sex, 2) different organizations of joint contributions to lower-extremity energy absorption would occur between internal and external foci regardless of sex, 3) females would exhibit greater peak vertical GRF magnitudes than males regardless of the focus adopted, and 4) lesser knee and greater ankle joint contributions to total lower limb work would be observed in females versus males regardless of the focus adopted.

## 2. Method

### 2.1. Participants

An a priori sample size estimation was conducted using G\*Power software (Faul, Erdfelder, Lang, & Buchner, 2009). The estimation was based on an F-test effect size of 0.3, power of 0.8, alpha level of 0.05, two within-subjects (focus) factors, and two

between-subjects (sex) factors. Accordingly, 12 men and 12 women were recruited for this study (demographics and anthropometrics described later in Section 2.4). Given the current lack of related literature from which an appropriate F-test effect size could be determined, we based our proposed F-test effect size on that which was used in recent work using a two-by-two condition-by-sex design (Smith, Paquette, Harry, Powell, & Weiss, 2018). Participants were classified as recreationally active due to their self-reported experience ( $\geq 2 \times$  per week during the previous six months) performing CMVJ landing movements that are common to recreational activities (e.g., basketball, soccer, volleyball, physical exercise training, etc.). Participants were free of any current or previous injury, ailment, or condition that would have affected their ability to perform maximum-effort CMVJ landing movements. Prior to completion of laboratory activities, informed written consent was provided to the researchers in accordance with the local Institutional Review Board.

## 2.2. Procedures

Participants visited the laboratory on one occasion. Age and sex were reported by the participants, while height and mass were measured. Participants completed a standardized warm up consisting of five minutes of stationary cycling at a self-selected pace, 10 body weight squats, 10 jump squats, and 20 forward step alternation walking lunges. Spherical 14-mm reflective markers were adhered to the participants using hypo-allergenic adhesive tape over the following locations bilaterally: acromion process, iliac crest, anterior superior iliac spine, posterior superior iliac spine, medial and lateral aspect of the knee joint, medial and lateral malleoli, and base of the second toe. Individual markers were adhered over the C7 vertebrae, sternum-jugular notch, and sacrum. Thermo-plastic shells with four non-collinear markers were secured bilaterally using elastic wraps and hypoallergenic adhesive tape over the lateral, mid-segment aspect of the thigh and leg segments, while three non-collinear markers were adhered bilaterally over the heel counter of the shoes.

Three-dimensional kinematic and GRF data were synchronously collected using a 12-camera motion capture system (Vicon Motion Systems, Ltd., Oxford, UK) sampling at 200 Hz and two force platforms (OPT464508; Advanced Mechanical Technology, Inc., Watertown, MA, USA) mounted flush with the laboratory floor and sampling at 1000 Hz. Following a static calibration trial, the markers adhered to the iliac crest, anterior superior iliac spine, medial and lateral aspects of the knee joint, medial and lateral malleoli, and base of the second toe were removed and the remaining markers were retained for motion tracking. Participants completed up to five practice trials of the CMVJ landing task to familiarize themselves with performing the movement within the laboratory environment. Participants were instructed to begin each trial by standing motionless with each foot on an individual force platform. A Vertec Jump Trainer (Sports Imports, Hilliard, OH, USA) was positioned adjacent to the participants on their preferred side to provide motivational support to jump with maximum-effort. The highest jump performed during the practice trials was recorded to control jump-landing height during experimental trials. After a “go” command, participants performed a maximum effort CMVJ using a self-selected arm swing and countermovement depth. Participants were instructed to reach with both hands to contact the highest rung possible on the Vertec device and all experimental trials were required to match the practice trial height within a  $\pm 1.27$  cm threshold, which has been shown to adequately control jump-landing height (Harry et al., 2017; Harry, Freedman Silvernaill, Mercer, & Dufek, 2018). During the landing, participants were instructed to land with each foot on an individual force platform, terminate downward motion, and return to a motionless standing position.

A total of sixteen CMVJ landing trials were recorded during which participants completed each trial as described previously. Eight trials were completed using an internal focus and eight trials were completed using an external focus, with the two foci presented to participants in a counterbalanced order (i.e., participant 1: internal, external; participant 2: external, internal). For the internal focus condition, participants were provided the following instructions: “after contacting the highest rung possible on the Vertec, concentrate on *flexing your knees* as rapidly as possible upon ground contact during landing”. For the external focus condition, participants were provided the following instructions: “after contacting the highest rung possible on the Vertec, concentrate on *pushing against the ground* as rapidly as possible upon ground contact during landing.” Focus instructions were provided for each repetition.

## 2.3. Data processing

Data were processed in the Visual3D software suite (version 6; C-Motion, Inc., Germantown, MD). A five-segment kinematic model was built from the marker trajectories to include the trunk, pelvis, and right thigh, leg, and foot segments. Raw kinematic and GRF data were smoothed using a fourth-order low pass Butterworth digital filter with cutoff frequencies of 8 Hz and 40 Hz, respectively. For joint kinetic analyses (described later), the raw GRF data were smoothed using an 8 Hz cutoff frequency matching that of the kinematic data to eliminate potential errors that could arise during Newtonian inverse dynamics calculations when separate filter cutoffs are used during impact movements (Bisseling & Hof, 2006; Kristianslund, Krosshaug, & Van den Bogert, 2012). The vertical position of the pelvis center of mass (COM) was calculated to represent the total body COM position, and vertical COM velocity was calculated as the first derivative of the vertical COM position data. Takeoff and ground contact were identified as the times when the summed vertical GRF data from the two force platforms decreased below and subsequently increased above 20 N, respectively. The summed vertical GRF was used since ground contact asymmetries are not significantly different during CMVJ landings (Harry et al., 2017).

Landing height was calculated as the square of COM vertical velocity at ground contact divided by two times gravitational acceleration. The peak vertical GRF magnitude was extracted as the largest magnitude observed in the summed GRF record, and the time between ground contact and the peak vertical GRF defined the “loading” phase (Harry, Barker, et al., 2018). Loading rate was calculated as the peak vertical GRF magnitude divided by loading time. The end of the landing was defined as the time when the

vertical COM velocity crossed zero after ground contact, and the time between the end of the loading phase and the end of landing defined the “attenuation” phase (Harry, Barker, et al., 2018).

A Cardan (*X-Y-Z*) rotation sequence was used to calculate the angular positions of the trunk segment and the hip, knee, and ankle joints, where *X* represents the medial-lateral axis, *Y* represents the anterior-posterior axis, and *Z* represents the longitudinal axis. The right-hand rule was used for rotational polarity (i.e., negative values indicate the trunk, hip, knee, and ankle joints were in flexed, extended, flexed, and plantarflexed positions, respectively). Angular velocities of the hip, knee, and ankle joints were calculated as the time-derivative of the joint angular positions. Trunk, hip, knee, and ankle angles were extracted at ground contact, and angular excursions were calculated during the loading and attenuation phases. Net internal joint moments were calculated using Newtonian inverse dynamics procedures, and joint angular powers were calculated as the dot product of the net joint moments and joint angular velocities. Joint angular work (i.e., joint energy absorption) was calculated as the time-integral of the joint angular power data during the loading and attenuation phases. The percent contributions of each joint to the total angular work performed by the lower extremity was calculated as the absolute value of joint angular work divided by the absolute sum of angular work performed about the hip, knee, and ankle joints (Hubley & Wells, 1983). All kinetic variables were normalized to the magnitude of kinetic energy developed at ground contact to account for the greater body mass and greater landing height (i.e., jump height) observed in males versus females. This normalization procedure facilitated control for between-group differences in addition to use of jump height as an outcome variable. This ensured that there were no undesirable effects of either focus on jump performance.

## 2.4. Statistical analysis

Processed data were imported to MATLAB (The Mathworks, Inc., Natick, MA) where participant mean values were calculated across trials for each of the described variables. Data were then organized and imported to SPSS (version 25; IBM Corp., Armonk, NY) where two (sex) by two (focus) analyses of variance ( $\alpha = 0.05$ ) were conducted for all variables, with sex (men, women) as the between factor and focus (internal, external) as the within factor. If a significant interaction was detected, simple main effects were conducted on each factor (i.e., independent samples *t*-tests were used to assess sex differences for each focus; paired-samples *t*-tests were used to assess focus of attention differences for each sex). If no significant interaction was detected, the Šidák adjustment was used for main effect comparisons. Cohen's *d* effect sizes (ES) were calculated to determine the magnitude of the differences for all comparisons. Hopkins' scale (Hopkins, 2006) was used for ES interpretations (small  $\leq 0.6 <$  moderate  $\leq 1.2 <$  large  $\leq 2.0 <$  very large).

## 3. Results

Two participants were excluded from the analysis due to marker digitizing errors after data collections were completed, resulting in a final sample of 11 males ( $21.7 \pm 1.6$  y;  $1.8 \pm 0.1$  m;  $73.8 \pm 11.5$  kg) and 11 females ( $22.5 \pm 2.7$  y;  $1.7 \pm 0.1$  m;  $67.7 \pm 12.8$  kg). Means and standard deviations, organized by sex and focus of attention, are presented for landing height, temporal durations, and vertical GRF data (Table 1), angular positions and excursions (Table 2), and lower limb angular work (Table 3).

### 3.1. Interaction effects

Significant sex by focus interactions were detected for the following variables: landing time ( $p = .045$ ), ankle joint angles at

**Table 1**  
Landing height, temporal durations, and vertical GRF data for men and women during internal and external foci of attenuation.

Variable	Internal Focus				External Focus			
	Men		Women		Men		Women	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Landing Height <sup>f</sup>	0.398	0.052	0.271	0.060	0.413	0.061	0.272	0.062
Landing Time <sup>a,b</sup>	0.380	0.084	0.308	0.079	0.306	0.114	0.311	0.058
Loading Time <sup>c,d,e</sup>	0.071	0.022	0.075	0.013	0.070	0.019	0.079	0.020
Attenuation Time	0.309	0.096	0.233	0.074	0.236	0.127	0.232	0.065
Loading Rate	146.70	43.13	193.79	66.38	189.07	132.55	188.08	74.25
Peak Vertical GRF <sup>f</sup>	9.44	2.09	13.58	2.76	10.09	2.46	13.36	3.17

Note: Unit of measure for landing height: meters; unit of measure for landing time, loading time, and attenuation time: seconds; unit of measure for loading rate: Newtons per second per Joule of kinetic energy; unit of measure for peak vertical GRF: Newtons per Joule of kinetic energy.

<sup>a</sup> Statistically significant difference between foci for men ( $p < .05$ ).

<sup>b</sup> Statistically significant difference between foci for women.

<sup>c</sup> Statistically significant difference between sexes for internal ( $p < .05$ ).

<sup>d</sup> Statistically significant difference between sexes for external ( $p < .05$ ).

<sup>e</sup> Statistically significant difference between foci regardless of sex ( $p < .05$ ).

<sup>f</sup> Statistically significant difference between sexes regardless of foci ( $p < .05$ ).

**Table 2**

Joint angular position and joint angular excursion data for men and women during internal and external foci of attenuation.

Phase/Event	Variable	Internal Focus				External Focus			
		Men		Women		Men		Women	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Ground Contact	Ankle Angle <sup>a</sup>	-21.80	8.55	-19.22	5.93	-16.15	13.32	-20.71	6.75
	Hip Angle	18.92	7.02	23.86	12.23	22.43	9.33	23.74	14.33
	Knee Angle <sup>a,b,d</sup>	-18.18	7.83	-15.46	8.29	-26.01	6.95	-13.98	7.35
	Trunk Angle	6.74	7.02	7.39	7.18	3.03	10.02	7.51	7.05
Loading	Ankle Excursion	40.27	10.58	41.13	5.92	35.74	10.73	43.11	7.55
	Hip Excursion	14.40	6.36	16.03	5.66	13.20	5.70	16.48	7.94
	Knee Excursion	-35.29	9.17	-33.57	6.04	-31.26	8.04	-35.82	8.38
	Trunk Excursion	-5.50	2.87	-4.66	2.91	-5.47	3.68	-4.92	3.80
Attenuation	Ankle Excursion <sup>f</sup>	8.28	17.75	4.97	3.09	8.18	13.80	4.96	3.35
	Hip Excursion <sup>e</sup>	46.33	16.37	37.59	13.05	36.16	16.17	36.19	11.98
	Knee Excursion <sup>e</sup>	-47.88	23.51	-34.37	9.61	-38.42	19.10	-31.40	8.53
	Trunk Excursion <sup>a,c</sup>	-40.14	19.16	-22.62	9.80	-28.48	15.58	-22.80	11.98

Note: unit of measure for all variables: degrees; negative angles indicate ankle dorsiflexion, hip extension, knee flexion, and trunk flexion; negative excursions indicate ankle plantarflexion, hip, extension, knee flexion, and trunk flexion.

<sup>a</sup> Statistically significant difference between foci for men ( $p < .05$ ).

<sup>b</sup> Statistically significant difference between foci for women.

<sup>c</sup> Statistically significant difference between sexes for internal ( $p < .05$ ).

<sup>d</sup> Statistically significant difference between sexes for external ( $p < .05$ ).

<sup>e</sup> Statistically significant difference between foci regardless of sex ( $p < .05$ ).

<sup>f</sup> Statistically significant difference between sexes regardless of foci ( $p < .05$ ).

**Table 3**

Lower limb joint work and joint contributions to lower limb work data for men and women during internal and external foci of attenuation.

Phase	Variable <sup>a,b,c,d</sup>	Internal Focus				External Focus			
		Men		Women		Men		Women	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Loading	Lower Limb Work	34.3%	15.3%	36.5%	10.3%	29.4%	13.4%	38.7%	13.3%
	Ankle Contribution <sup>f</sup>	42.4%	12.4%	53.8%	15.3%	38.5%	13.7%	53.2%	12.0%
	Hip Contribution	10.5%	6.8%	10.0%	5.8%	8.7%	5.4%	8.9%	4.7%
	Knee Contribution <sup>e,f</sup>	47.1%	11.0%	36.2%	11.9%	52.9%	12.3%	37.9%	10.4%
Attenuation	Lower Limb Work	49.5%	20.4%	48.0%	12.6%	44.6%	14.0%	44.3%	12.0%
	Ankle Contribution	6.7%	4.7%	7.7%	4.1%	7.3%	6.2%	8.3%	2.9%
	Hip Contribution	25.7%	12.5%	23.5%	8.9%	26.7%	16.2%	21.5%	13.6%
	Knee Contribution	67.6%	10.5%	68.8%	7.6%	66.0%	13.2%	70.2%	13.4%

Note: unit of measure for lower limb work: percentage of kinetic energy at ground contact; unit of measure for joint contributions: percentage of lower limb work.

<sup>a</sup> Statistically significant difference between foci for men ( $p < .05$ ).

<sup>b</sup> Statistically significant difference between foci for women.

<sup>c</sup> Statistically significant difference between sexes for internal ( $p < .05$ ).

<sup>d</sup> Statistically significant difference between sexes for external ( $p < .05$ ).

<sup>e</sup> Statistically significant difference between foci regardless of sex ( $p < .05$ ).

<sup>f</sup> Statistically significant difference between sexes regardless of foci ( $p < .05$ ).

ground contact ( $p = .005$ ), knee angles at ground contact ( $p < .001$ ), knee joint excursion during the loading phase ( $p = .025$ ), trunk excursion during the attenuation phase ( $p = .043$ ), and total lower limb angular work during the loading phase ( $p = .048$ ). No statistically significant interaction was detected for any other variable ( $p \geq .054$ ).

Landing time (Table 1) was significantly longer with an internal focus than with an external focus for males ( $p = .029$ ;  $ES = 0.78$ ). Landing time was also significantly longer for males than females with an external versus internal focus ( $p = .050$ ;  $ES = 0.93$ ). Males landed with significantly greater plantarflexion at ground contact (Table 2) when using an internal focus compared to an external focus ( $p = .019$ ,  $ES = 0.53$ ).

Males landed with greater knee flexion at ground contact when using an external focus ( $p < .001$ ;  $ES = 1.11$ ), whereas females landed with greater knee flexion when using an internal focus ( $p = .031$ ;  $ES = 0.20$ ; Table 2). Males also had greater knee flexion at ground contact than females when using an external focus ( $p = .001$ ;  $ES = 1.76$ ). Males exhibited significantly greater trunk excursion during the attenuation phase when using an internal focus compared to an external focus ( $p = .035$ ;  $ES = 0.70$ ). Additionally,

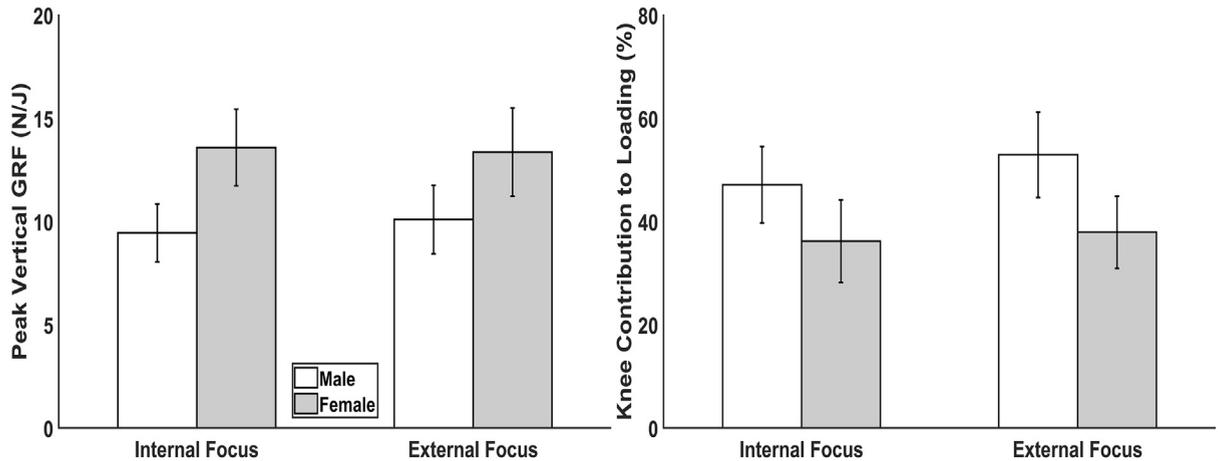


Fig. 1. Peak vertical ground reaction force (left) and knee contribution to lower limb energy absorption during the loading phase (right) of landings with internal and external foci.

Note: Data are presented as mean  $\pm$  95% confidence interval.

males displayed significantly greater trunk excursion during the attenuation phase than females when using an internal focus ( $p = .014$ ; ES = 1.21; Table 2).

Despite significant interactions, none of the simple main effects on knee joint excursion (Table 2) or total limb angular work during the loading phase (Table 3) were significantly different. No other statistically significant simple main effects were detected ( $p > .05$ ; Tables 1–3).

### 3.2. Focus effects

Hip joint excursion during the attenuation phase was significantly larger with an internal focus than with an external focus ( $p = .014$ , ES = 0.41; Table 2). Knee joint excursion during the attenuation phase was significantly greater during internal versus external focus landings ( $p = .008$ ; ES = 0.37; Table 2). The contribution of the knee to total lower limb angular work during the loading phase was significantly greater during external versus internal focus landings ( $p = .013$ ; ES = 0.30; Table 3; Fig. 1, right). No other statistically significant focus effects were detected ( $p \geq .052$ ; Tables 1–3).

### 3.3. Sex effects

Landing height was significantly higher for males than for females ( $p < .001$ , ES = 2.50; Table 1). Peak vertical GRF was significantly greater in females versus males ( $p = .003$ ; ES = 1.54; Table 1; Fig. 1, left). Females displayed a significantly greater ankle contribution to the total lower limb angular work than males during the loading phase ( $p = .026$ ; ES = 1.07; Table 3). Males displayed a significantly greater knee contribution to the total lower limb angular work than females during the loading phases ( $p = .012$ ; ES = 1.24; Table 3; Fig. 1, right). No other significant sex effects were detected ( $p \geq .141$ ; Tables 1–3).

## 4. Discussion

The purpose of this investigation was to examine differences in external impact forces and the organization of lower-extremity joint angular work between external and internal foci of attention in men and women during CMVJ landings. Contrary to our first hypothesis (greater vertical GRF with an internal versus external focus), peak vertical GRF, along with loading rate and loading time, was not different between foci for males nor females. This suggests the maximum amount of external stress and the rate at which that stress is experienced during a CMVJ landing is not impacted by whether a performer is focused on internal versus external factors. This result contradicts previous studies in which males exhibited greater peak vertical GRF after adopting an internal focus during drop vertical jump landings and females exhibited lesser peak vertical GRF after adopting an external focus (Welling et al., 2017) and generally smaller peak vertical GRF were observed during external versus internal focus landings (Widenhoefer et al., 2019). The difference between study outcomes appears to center mainly on the landing task performed (Harry et al., 2017) with the two foci, since we utilized CMVJ landings and they utilized drop vertical jump landings and drop landings from elevated platforms, respectively.

In partial support of our second hypothesis (different organizations of joint energy absorption between internal and external foci), the contribution of the knee joint to total lower limb angular work performed during the loading phase was greatest when using an external versus internal focus regardless of sex, whereas the hip and knee joint contributions were unchanged. While this increase at the knee was small in magnitude, it does suggest adoption of an external focus can encourage augmented knee joint dominance with respect to mechanical energy dissipation in both males and females without changing the magnitude of total lower limb work

performed. Such an increase in the knee joint contribution may be desired since the knee joint is the dominant contributor to energy absorption during landing (Harry, Barker, et al., 2018) and an external focus seems to encourage appropriate organizations of joint work during loading without altering the total amount of work performed by the lower limb. Interestingly, the similar lower extremity angular work and corresponding joint contributions between foci during attenuation coincided with smaller hip and knee flexion excursions when adopting the external focus. This indicates greater hip and knee extension torques were produced when using the external focus to absorb the remaining mechanical energy from impact. When the current work is considered alongside previous work on external focus-related increases in CMVJ height through increased lower extremity mechanical output (Wulf & Dufek, 2009), adoption of specific jumping and landing external foci seem ideal when performing the CMVJ because enhanced jump performance should precede an ideal organization of lower limb joint work during landing.

In support of our third (greater vertical GRF for females versus males) and fourth (lesser knee and greater ankle contributions to angular work during the loading phase for females versus males) hypotheses, females exhibited greater peak vertical GRF, lesser knee contributions and greater ankle contributions to lower limb work during loading than men did regardless of the focus adopted. Our peak vertical GRF results are not consistent with the smaller peak vertical GRF magnitudes Butler et al. (2013) observed in females versus males during stop jump landings because the jump landings in that study were performed below functional capacity (i.e., 50% of maximum jump height) and the current landings were performed for maximum effort, thereby requiring potentially different landing mechanics. The current GRF differences observed between sexes appear due to the fact that men exhibited greater knee flexion and ankle plantarflexion angles at ground contact with an external focus, while the opposite was true for women. As landing with a more extended knee joint (Devita & Skelly, 1992) and/or a less plantarflexed ankle (Rowley & Richards, 2015) can increase the peak vertical GRF, it is likely that the females' knee and ankle joint kinematic strategies at ground contact contributed to the greater peak vertical GRF magnitudes. In addition, the current GRF results were likely influenced by the joint work contributions during loading, since they support prior conclusions that women employ an ankle dominant energy absorption strategy (Weinhandl & O'Connor, 2010) that can reduce the involvement of the knee joint musculature during the loading phase. Since these sex-specific differences occurred largely independent of the focus adopted, the aforementioned sex-specific combinations of biological, environmental, and sociocultural constraints that influence movement patterns (Bruton et al., 2013) do not appear exacerbated by use of a specific attentional focus during CMVJ landings.

A possible limitation of this study was the focus-specific instructions provided to the participants, since they are somewhat dissimilar to those described in related literature and might not reflect what is typically used by clinicians during injury prevention training (e.g., land softly [external]; flex your knees [internal]). Although we aimed to both keep the instructions as similar as possible and avoid potential increases in the overall loading magnitudes that could occur by promoting a longer-than-necessary impact duration, we must acknowledge that the current instructions differ from typical instructions. Another possible limitation was the absence of a control condition that was independent of internal or external focus instructions. Despite the typical study outcome that performance during the control condition is worse than with an external focus and comparable to an internal focus in recreationally active or non-expert samples (Wulf et al., 1998; Wulf & McNevin, 2003; Wulf & Su, 2007; Wulf, Zachry, Granados, & Dufek, 2007), it remains speculative to theorize what could have occurred had we included a control condition. Another possible limitation was our choice to control jump-landing height in real-time using a Vertec jump training. While this procedure accurately controls jump-landing height (Harry et al., 2017; Harry, Freedman Silvernail, et al., 2018), the required act of reaching the hands/fingers to touch the vanes was an external focus during the jumping and early portion of the flight phase. It is unknown whether this could have impacted when the prescribed foci were employed as well as the requisite landing mechanics. One could manipulate the focus of attention during the jumping phase and during the landing phase with a factorial design, which would require participants to complete four different conditions (internal and external focus during both jumping and landing). However, changing the focus instruction so frequently might confuse or overwhelm participants and cause them to ignore the instructions. We chose to avoid these issues by manipulating only the focus of attention of the landing. Finally, the loss of two participants was a possible limitation, since the overall statistical power of the study might have been slightly compromised. Still, our use of effect sizes to supplement the statistical probabilities compensates for the loss of statistical power (Sullivan & Feinn, 2012).

## 5. Conclusions

We determined that the contribution of the knee joint to total lower limb angular work performed was greatest during the loading phase of CMVJ landings when using an external focus. In addition, females exhibited greater peak vertical GRF magnitudes than males did, which coincided with lesser knee joint flexion at ground contact and lesser knee joint contributions to total lower limb work than men regardless of the focus adopted. Both males and females might consider adopting an external focus of attention during CMVJ landings to increase the contribution of the knee joint to total lower limb angular work and encourage optimal organization of lower limb joint contributions to energy absorption, though external focus use may be more critical for females due to aforementioned sex-specific mechanics.

## Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

## Declaration of Competing Interest

None.

## Acknowledgements

We would like to thank all of the participants who volunteered for this study. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

## References

- Afifi, M., & Hinrichs, R. N. (2012). A mechanics comparison between landing from a countermovement jump and landing from stepping off a box. *Journal of Applied Biomechanics*, 28, 1–9.
- Al-Abood, S. A., Bennett, S. J., Hernandez, F. M., Ashford, D., & Davids, K. (2002). Effect of verbal instructions and image size on visual search strategies in basketball free throw shooting. *Journal of Sports Sciences*, 20, 271–278.
- Bisseling, R. W., & Hof, A. L. (2006). Handling of impact forces in inverse dynamics. *Journal of Biomechanics*, 39, 2438–2444.
- Bruton, M. R., O'Dwyer, N., & Adams, R. (2013). Sex differences in the kinematics and neuromuscular control of landing: Biological, environmental and sociocultural factors. *Journal of Electromyography and Kinesiology*, 23, 747–758.
- Butler, R. J., Willson, J. D., Fowler, D., & Queen, R. M. (2013). Gender differences in landing mechanics vary depending on the type of landing. *Clinical Journal of Sport Medicine*, 23, 52–57.
- Devita, P., & Skelly, W. A. (1992). Effect of landing stiffness on joint kinetics and energetics in the lower extremity. *Medicine & Science in Sports & Exercise*, 24, 108–115.
- Dufek, J. S., & Bates, B. T. (1990). The evaluation and prediction of impact forces during landings. *Medicine & Science in Sports & Exercise*, 22, 370–377.
- Fagenbaum, R., & Darling, W. G. (2003). Jump landing strategies in male and female college athletes and the implications of such strategies for anterior cruciate ligament injury. *The American Journal of Sports Medicine*, 31, 233–240.
- Faul, F., Erdfelder, A., Lang, A.-G., & Buchner, A. (2009). G\*power: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, 39, 175–191.
- Harry, J. R., Barker, L. A., Eggleston, J. D., & Dufek, J. S. (2018). Evaluating performance during maximum effort vertical jump landings. *Journal of Applied Biomechanics*, 34 (403–309).
- Harry, J. R., Freedman Silvernail, J., Mercer, J. A., & Dufek, J. S. (2017). Comparison of pre-contact joint kinematics and vertical impulse between vertical jump-landings and step-off landings from equal heights. *Human Movement Science*, 56, 88–97.
- Harry, J. R., Freedman Silvernail, J., Mercer, J. A., & Dufek, J. S. (2018). Bilateral comparison of vertical jump landings and step-off landings from equal heights. *The Journal of Strength & Conditioning Research*, 32, 1937–1947.
- Harry, J. R., James, C. R., & Dufek, J. S. (2019). Weighted vest effects on impact forces and joint work during vertical jump landings in men and women. *Human Movement Science*, 63, 156–163.
- Hopkins, W. G. (2006). A new view of statistics: A scale of magnitudes for effect statistics. Retrieved from <http://sportssci.org/resource/stats/effectmag.html>.
- Hubley, C., & Wells, R. (1983). A work-energy approach to determine individual joint contributions to vertical jump performance. *European Journal of Applied Physiology and Occupational Physiology*, 50, 247–254.
- Kristianslund, E., Krosshaug, T., & Van den Bogert, A. J. (2012). Effect of low pass filtering on joint moments from inverse dynamics: Implications for injury prevention. *Journal of Biomechanics*, 45, 666–671.
- Marchant, D. C., Clough, P. J., & Crawshaw, M. (2007). The effects of attentional focusing strategies on novice dart throwing performance and their task experiences. *International Journal of Sport and Exercise Psychology*, 5, 291–303.
- McNevin, N. H., & Wulf, G. (2002). Attentional focus on supra-postural tasks affects postural control. *Human Movement Science*, 21, 187–202.
- Norcross, M. F., Blackburn, J. T., Goerger, B. M., & Padua, D. A. (2010). The association between lower extremity energy absorption and biomechanical factors related to anterior cruciate ligament injury. *Clinical biomechanics*, 25, 1031–1036.
- Norcross, M. F., Lewek, M. D., Padua, D. A., Shultz, S. J., Weinhold, P. S., & Blackburn, J. T. (2013). Lower extremity energy absorption and biomechanics during landing, part I: Sagittal-plane energy absorption analyses. *Journal of Athletic Training*, 48, 748–756.
- Pappas, E., & Carpes, F. P. (2012). Lower extremity kinematic asymmetry in male and female athletes performing jump-landing tasks. *Journal of Science and Medicine in Sport*, 15, 87–92.
- Rowley, K. M., & Richards, J. G. (2015). Increasing plantarflexion angle during landing reduces vertical ground reaction forces, loading rates and the hip's contribution to support moment within participants. *Journal of Sports Sciences*, 33(18), 1922–1932.
- Smith, R. E., Paquette, M. R., Harry, J. R., Powell, D. W., & Weiss, L. W. (2018). Footwear and sex differences in performance and joint kinetics during maximal vertical jumping. *The Journal of Strength & Conditioning Research* (Epub ahead of print).
- Sullivan, G. M., & Feinn, R. (2012). Using effect size or why the P value is not enough. *Journal of Graduate Medical Education*, 4, 279–282.
- Vance, J., Wulf, G., Töllner, T., McNevin, N., & Mercer, J. (2004). EMG activity as a function of the performer's focus of attention. *Journal of Motor Behavior*, 36, 450–459.
- Weinhandl, J., & O'Connor, K. M. (2010). Gender comparisons between unilateral and bilateral landings. *Journal of Applied Biomechanics*, 26, 444–453.
- Welling, W., Benjaminse, A., Gokeler, A., & Otten, B. (2016). Enhanced retention of drop vertical jump landing technique: A randomized controlled trial. *Human Movement Science*, 45, 84–95.
- Welling, W., Benjaminse, A., Gokeler, A., & Otten, B. (2017). Retention of movement technique: Implications for primary prevention of ACL injuries. *International Journal of Sports Physical Therapy*, 12, 908.
- Widenhofer, T. L., Miller, T. M., Weigand, M. S., Watkins, E. A., & Almonroeder, T. G. (2019). Training rugby athletes with an external attentional focus promotes more automatic adaptations in landing forces. *Sports Biomechanics*, 18, 163–173.
- Wulf, G. (2013). Attentional focus and motor learning: A review of 15 years. *International Review of Sport and Exercise Psychology*, 6, 77–104.
- Wulf, G., & Dufek, J. S. (2009). Increased jump height with an external focus due to enhanced lower extremity joint kinetics. *Journal of Motor Behavior*, 41, 401–409.
- Wulf, G., Dufek, J. S., Lozano, L., & Pettigrew, C. (2010). Increased jump height and reduced EMG activity with an external focus. *Human Movement Science*, 29, 440–448.
- Wulf, G., Höls, M., & Prinz, W. (1998). Instructions for motor learning: Differential effects of internal versus external focus of attention. *Journal of Motor Behavior*, 30, 169–179.
- Wulf, G., McConnel, N., Gärtner, M., & Schwarz, A. (2002). Enhancing the learning of sport skills through external-focus feedback. *Journal of Motor Behavior*, 34, 171–182.
- Wulf, G., & McNevin, N. (2003). Simply distracting learners is not enough: More evidence for the learning benefits of an external focus of attention. *European Journal of Sport Science*, 3, 1–13.
- Wulf, G., McNevin, N., & Shea, C. H. (2001). The automaticity of complex motor skill learning as a function of attentional focus. *The Quarterly Journal of Experimental Psychology: Section A*, 54, 1143–1154.
- Wulf, G., & Su, J. (2007). An external focus of attention enhances golf shot accuracy in beginners and experts. *Research Quarterly for Exercise and Sport*, 78, 384–389.
- Wulf, G., Zachry, T., Granados, C., & Dufek, J. S. (2007). Increases in jump-and-reach height through an external focus of attention. *International Journal of Sports Science and Coaching*, 2, 275–284.
- Yeow, C. H., Lee, P. V. S., & Goh, J. C. H. (2011). An investigation of lower extremity energy dissipation strategies during single-leg and double-leg landing based on sagittal and frontal plane biomechanics. *Human Movement Science*, 30, 624–635.
- Zhang, S. N., Bates, B. T., & Dufek, J. S. (2000). Contributions of lower extremity joints to energy dissipation during landings. *Medicine & Science in Sports & Exercise*, 32, 812–819.