SEX-BASED DIFFERENCES IN TRUNK ACCELERATION AND LANDING POSTURE DURING THE DROP VERTICAL JUMP TEST

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The purpose of this study was to investigate sex-based differences in trunk acceleration and landing posture during the drop vertical jump test and to determine the relationships among relevant variables. Twenty college students (10 men and 10 women) performed drop vertical jumps from a 30-cm high box. Trunk acceleration and the trunk, limb, knee, and ankle angles in the sagittal plane were measured. The unpaired Student t-test and Pearson product-moment correlation coefficients were used for statistical analysis. Female participants demonstrated greater vertical trunk acceleration and smaller trunk angles than male participants did. In addition, vertical acceleration correlated with trunk and limb angles. Therefore, these parameters, which can be estimated by using wearable sensors, may be useful for checking athletes at high risk for injury.

KEY WORDS: accelerometer, kinematics, injury risk, screening

INTRODUCTION: Anterior cruciate ligament (ACL) injury is one of the most common and serious injuries for athletes, especially female athletes. Not only do ACL injuries often require surgery and long-term rehabilitation, but they are also well-known risk factors for the subsequent development of knee osteoarthritis.
Risk factors for ACL injuries include poor lower-extremity kinematics and uncontrolled trunk orientation. In a sagittal plane video analysis, participants who sustained ACL injuries showed the upright trunk position (Sheehan, Sipprell, & Boden, 2012) and had abnormalities in hip, knee, and ankle kinematics (Boden, Torg, Knowles, & Hewett, 2009). Additionally, peak vertical ground-reaction force (GRF) occurring within the first 40 ms after initial ground contact (IC) was observed in athletes with ACL injuries (Koga et al. 2010). Hewett et al. (2005) reported that, compared with uninjured athletes, athletes with ACL injuries exhibited 2.5-fold more knee abduction moments and 20% greater vertical GRF during the drop vertical jump (DVJ) test. The DVJ test has been previously used in training and lab-based studies; however, recently, it has been used as a clinic-based screening tool for ACL injury risk (Myer, Ford, & Hewett, 2011).
Body-mounted electronic accelerometers have recently been used to evaluate athletic movement. They can reflect vertical GRF in a several activities, such as walking, running, jumping, and box dropping (Rowlands & Stiles, 2012). Recent research by Setuain et al. (2015) showed that athletes who had previously undergone ACL reconstruction demonstrated significantly higher peak acceleration values in the vertical and mediolateral axes than did control athletes. However, sex-based differences in body acceleration and kinematics during DVJ tests are unknown. Therefore, we compared trunk acceleration and landing postures among young men and women. We also investigated the relationships among trunk acceleration and kinematic variables during DVJ tests.

METHODS: Ten young men (mean age, 21.3 ± 0.5 yrs; mean height, 1.73 ± 0.04 m; mean weight 68.3 ± 5.0 kg) and 10 young women (mean age, 20.7 ± 0.7 yrs; mean height, 1.58 ± 0.04 m; and mean weight 55.5 ± 3.7 kg) who were healthy college students participated in this study. They were informed in detail about the experimental procedures and the possible risks and benefits of the project, and informed consent was obtained.
A lightweight (41 g) tri-axial accelerometer (LP-WS1201, Logical Product, Japan) with a full-scale range of ±15*G* was attached over the T2-4 region of the subject's thoracic spine with a compression vest. Linear acceleration values were obtained at a sampling rate of 200 Hz. The three axes of the accelerometer were aligned close to the anatomical axes; that is, the x-, y-, and z-axes were aligned mediolaterally, vertically, and anteroposteriorly, respectively. Skin markers were placed on the left side of the body at the following six locations: the

acromion process, greater trochanter, lateral knee joint line, lateral malleolus, heel, and fifth metatarsal. Sagittal plane images were captured with a high-speed video camera at a sampling rate of 240Hz (EX-FC150, Casio, Japan).

Participants underwent DVJ tests based on the studies by Myer et al. (2011). They stood on a box (31-cm high) with their feet positioned 35 cm apart. They were instructed to drop off the box and immediately perform a maximum vertical jump with both arms raised. Prior to the test, subjects were allowed to perform three practice trials to familiarize themselves with the test maneuver. Once subjects were able to perform it, they completed three DVJ trials.

The vertical acceleration (y-axis) signal was used to distinguish the different phases during the DVJ test. The phase-C event, which was the first peak of vertical acceleration, was signaled by an abrupt positive change in vertical direction. This moment was determined as the start of the negative (eccentric) action during landing in the DVJ test. Trunk acceleration (each direction and resultant) at the moment of first peak vertical acceleration was measured, and the $trunk_G$, $limb_G$, knee, and ankle joint angles at the moment of first peak vertical acceleration were measured using two-dimensional video analysis (Figure1). The freely available software, Image J (National Institutes of Health), was used to obtain joint kinematics from the sagittal plane. An unpaired t-test was used to evaluate sex-based differences. Relationships between acceleration and kinematic variables were determined by Pearson's product-moment correlation coefficients. Significance was set at $p<0.05$.

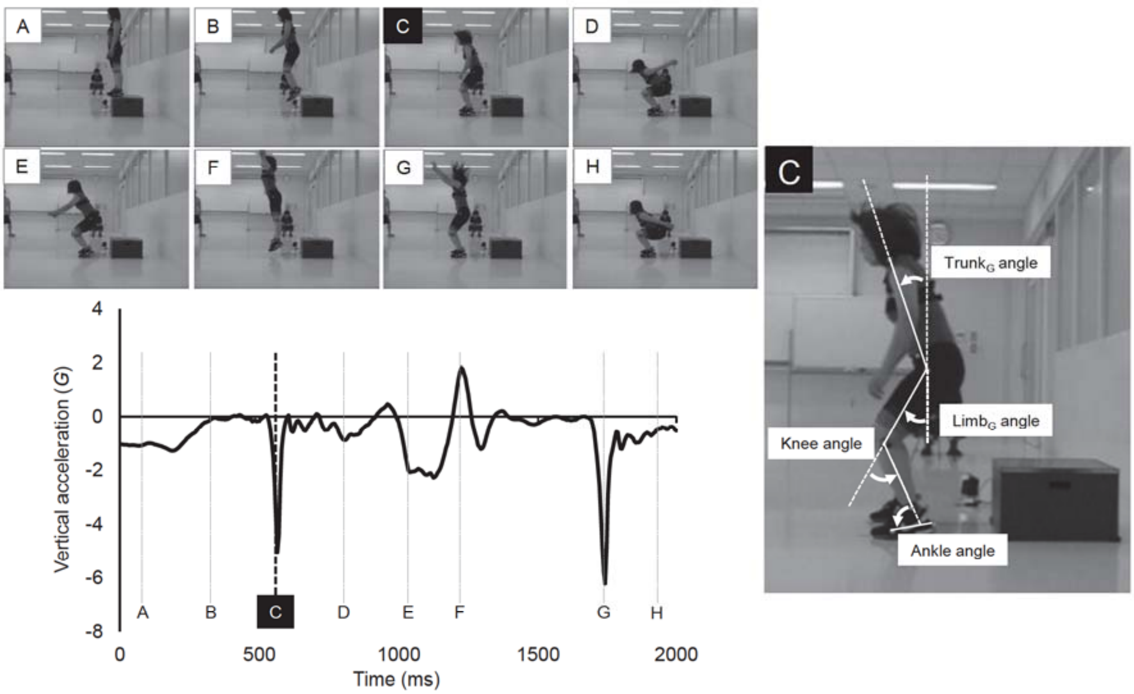

Figure 1: Y-vertical axis linear acceleration curve for a selected young woman (left panel) and the definition of each joint angle in sagittal plane video analysis (right panel).

RESULTS: Female participants demonstrated significantly greater vertical acceleration (-2.90 *G* versus -1.83 *G*, $p<0.01$) and smaller $trunk_G$ angles (21.9° versus 27.9°, $p<0.05$) than male participants did at the time of first peak vertical acceleration (Table 1). Table 2 displays the Pearson product-moment correlation coefficients among acceleration and kinematic variables at the first peak vertical acceleration moment. Moderate, positive correlations were found among vertical acceleration and $trunk_G$ (r=0.58, $p<0.01$) and $limb_G$ angles (r=0.49, $p<0.05$) (Figure 2). Acceleration values for anteroposterior direction were moderately correlated with $trunk_G$ (r=-0.66, $p<0.01$), $limb_G$ (r=-0.53, $p<0.05$), knee (r=-0.58, $p<0.01$), and ankle angles (r=0.62, $p<0.01$).

Table 1
Trunk acceleration, joint angles, and duration at the time of the first peak vertical acceleration

Valuables		Men (n=10)	Women (n=10)
Trunk acceleration	Medial-lateral (*G*)	0.00 (0.19)	-0.06 (0.23)
	Vertical (*G*)	-1.83 (0.54)	-2.90 (0.63) **
	Anterior-posterior (*G*)	-1.53 (0.89)	-0.82 (0.86)
	Resultant (*G*)	2.54 (0.78)	3.15 (0.60)
Joint angle	$Trunk_G$ (°)	27.9 (5.5)	21.9 (6.1) *
	$Limb_G$ (°)	38.6 (8.2)	32.9 (6.1)
	Knee (°)	64.6 (12.5)	58.5 (9.4)
	Ankle (°)	80.0 (5.3)	80.1 (6.4)
Duration	IC to phase-C (ms)	71.5 (15.2)	58.9 (12.5)

Note: Values are expressed as mean (standard deviation). Significant differences between male and female participants: ** p<0.01, * p<0.05. IC: Initial contact during vertical drop jump.

Table 2
Correlation coefficients among trunk acceleration and kinematic variables at the time of the first peak vertical acceleration

	$Trunk_G$ angle	$Limb_G$ angle	Knee angle	Ankle angle
Medial-lateral acceleration	0.17	-0.01	-0.10	0.12
Vertical acceleration	0.58**	0.49*	0.13	-0.02
Ant-posterior acceleration	-0.66**	-0.53*	-0.58**	0.62**
Resultant acceleration	-0.18	-0.14	-0.03	-0.39

Note: ** p<0.01, * p<0.05. Ant-posterior: Anterior-posterior.

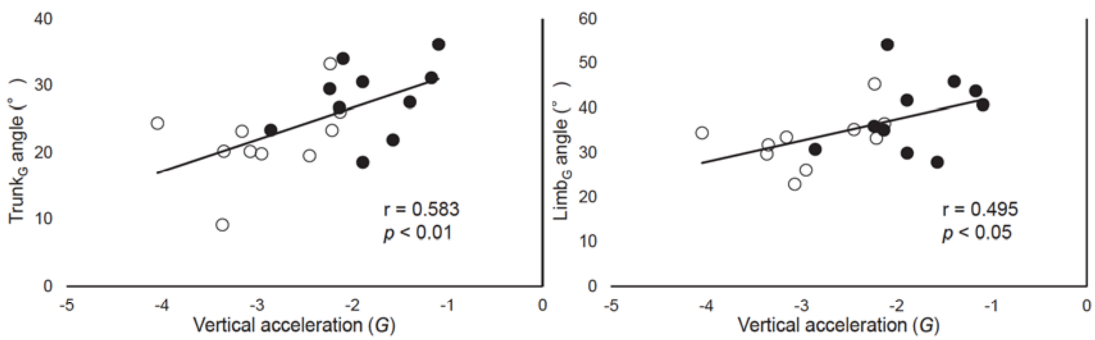

Figure 2: Relationships among vertical acceleration and $trunk_G$ (left panel) and $limb_G$ angles (right panel) at the first peak vertical acceleration moment. Young men are represented by filled circles, whereas young women are represented by open circles.

DISCUSSION: We described trunk acceleration and sagittal plane kinematics during DVJ tests, especially for the first negative (eccentric) action in landing. Vertical acceleration and trunk kinematics differed by sex, and vertical and anteroposterior trunk accelerations were correlated with kinematic variables. These results explain how tri-axial trunk acceleration occurs during the DVJ test landing phase and can be used to evaluate high-risk athletes.

We focused here on the first peak vertical acceleration moment variables. The duration between initial ground contact and phase-C events tended to be shorter for women than for men (58.9 ms vs. 71.5 ms, p=0.58). Non-contact ACL injuries may occur within 40 ms of IC (Koga et al. 2010) since data were relatively similar to the first peak vertical acceleration for women. Further, compared with men, women here demonstrated significantly greater vertical acceleration and smaller $trunk_G$ angles. Previous research showed that women applied significantly higher GRF during landing than men did (Salci, Kentel, Heycan, Akin, & Korkusuz, 2004), consistent with the present data, because vertical GRF was correlated with vertical acceleration (Rowlands & Stiles, 2012; Nagano et al. unpublished data). In addition, Nagano, Ida, Akai, and Fukubayashi (2011) reported that women showed smaller trunk-forward inclination during shuttle run cutting than men did; this posture resembles ACL injury. They also argued that decreased trunk-forward inclination was moderately correlated with increased excursion of internal tibia rotation. We could not confirm tibial rotation here because of the simple video analysis; however, women may experience more tibial excursion immediately following ground contact in the DVJ test.

Vertical trunk acceleration was moderately correlated with $trunk_G$ and $limb_G$ angles, whereas anteroposterior direction was correlated with all kinematic variables, suggesting that trunk and hip joint control is essential for reducing vertical trunk acceleration during DVJ tests. A previous video-based study also showed that the $trunk_G$ and $limb_G$ angles, but not the knee angle, were correlated with center of mass placement at IC (Sasaki et al. 2015). This knowledge is essential for understanding postural adjustment at landing. Upright trunk position and shallow hip flexion encourage vertical trunk acceleration, which may increase ACL injury risk.

CONCLUSION: The purpose of this study was to investigate sex-based differences in trunk acceleration and landing posture during DVJ tests and determine relationships among variables. Women demonstrated significantly greater vertical trunk acceleration and smaller $trunk_G$ angles. Vertical acceleration correlated with $trunk_G$ and $limb_G$ angles. These parameters, estimated by wearable sensors, may be useful for evaluating high-risk athletes.

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