RELATIONSHIPS BETWEEN TRUNK AND KNEE ACCELERATION AND THE GROUND REACTION FORCE DURING SINGLE LIMB LANDING

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The purpose of this study was to investigate the relationship between the ground reaction force and acceleration of the knee and trunk. We measured trunk and knee acceleration, as well as ground reaction force during single limb landing in 7 female basketball players. The associations between trunk and knee accelerations and vertical ground reaction force were analyzed by using correlation coefficients. Strong correlations were found between peak vertical ground reaction force and peak acceleration of the medial, vertical, and posterior trunk, trunk resultant, vertical knee, as well as knee resultant. It is possible to evaluate the variable movements during sports or sports-related activity by analyzing the acceleration of body segments.

KEY WORDS: accelometer, impact, injury risk

INTRODUCTION: Evaluating the movements during sports activities is essential for examining the physical load and risk of injury. The methods used in previous studies to evaluate sports movements are costly and require the use of expensive equipment, i.e., a 3dimensional motion capture system, as well as enormous amount of time. In contrast, measurements using an accelerometer are comparatively simple, with the measured acceleration also reflecting the impact applied to the segment. Peak accelerations occur for individual body segments, as the impact is transmitted through the skeletal system from the leg to the head. Therefore, acceleration measurements have been used in some studies. Moran and Marshall (2006) reported the effects of fatigue on tibial impact acceleration during a drop jump. Jarning, Mok, Hansen, and Bahr (2015) reported the possibility of using peak vertical acceleration or peak resultant acceleration measured by an accelerometer to estimate jump frequency as high jumping load for patellar tendinopathy. Setuain et al. (2015) reported biomechanical jumping differences in elite female handball players with previous anterior cruciate ligament (ACL) reconstruction, using accelerometer during bilateral and unilateral vertical jumps. In recent year, studies using accelerometer have been conducted and the device is useful for examining the physical load and risk of injury.
Acceleration of the body segment is influenced by the posture of the subject and ground reaction force. Derrick (2004) reported that the decrease in the impact increased when the knee was flexed. On one hand, this result suggested that greater flexion of the lower limb joint and trunk increases the decrease in the impact by joint rotation, stretching of elastic components of the muscle tendon complex, and muscular energy absorption (Derrick, 2004). On the other hand, greater ground reaction force could lead to greater moment to the lower limb joints and risk for injury. Previous study (Hewett et al., 2005) reported that greater knee abduction moment predicted ACL injury. However, the relation between the ground reaction force and acceleration of body segment was not known. The purpose of this study was to investigate the relationship between the ground reaction force and acceleration of the knee and trunk. One of the basic sports movements, the single limb landing, was selected for the measurements in this study to refer other studies (Nagano, Ida, Akai, & Fukubayashi, 2007; Schmitz, Kulas, Perrin, Riemann, & Shultz, 2007).

METHODS: A total of 7 female basketball players (age, 20.3 ± 1.4 years; body mass, 59.9 ± 3.4 kg; height, 1.67 ± 0.04 m; mean ± SD) at the national intercollegiate competition were recruited for the experiment. Measurements of trunk and knee acceleration were taken during single limb landing from a 30 cm platform. Upon landing, each subject was instructed to place their center of mass as far forward as possible in an attempt to limit horizontal motion and land without jumping up. Throughout the experiment, the participants wore basketball shoes of the same design (GELBURST RS Z, Adidas Corp., Japan). If the subject was unable to keep the landing position for 3 seconds, the trial was excluded. Measurements were recorded for 3 successful trials.

Linear acceleration was measured by using a lightweight (35 g) triaxial accelerometer (LP-WS0902, Logical Product, Fukuoka, Japan). The accelerometer was secured to the spinous processes of a participant's first and second thoracic vertebrae and the front of tibial tuberosity using double-sided adhesive tape (Figure 1). The three axes of the accelerometer were aligned close to the anatomical axes, i.e., the x-axis was aligned mediolaterally, the y-axis vertically, and the z-axis anteroposteriorly. Acceleration data were sampled at a frequency of 200 Hz and saved in the accelerometer's built-in memory (32 MB). After testing, the accelerometer was connected to a computer and the raw data were downloaded into a database for later analyses. Additionally, the ground reaction force data was recorded at 1000 Hz using a force plate (9287C, Kistler Japan Co., Ltd., Tokyo, Japan) synchronized with the accelerometer.

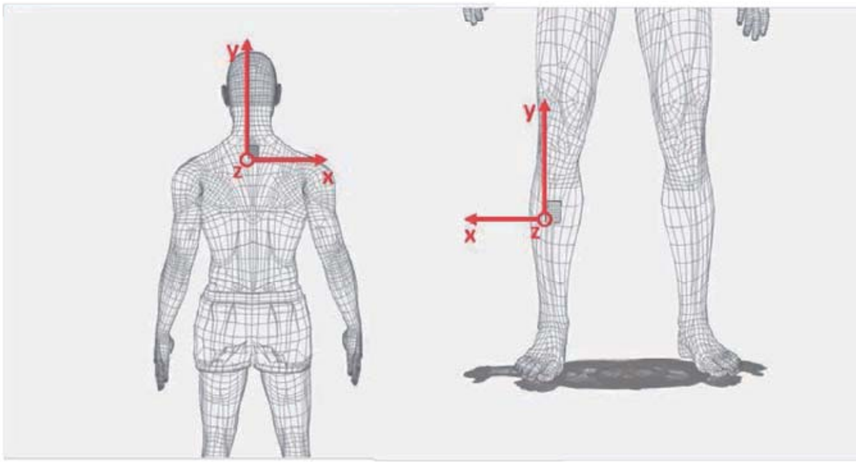

Figure 1: Accelerometer location

The peak acceleration in each direction and resultant acceleration were measured during landing. Peak accelerations were defined as the maximum acceleration in the medial, upward, and posterior directions. The peak vertical of the ground reaction force during landing was also measured and normalized by body mass (N/kg). The associations between trunk and knee accelerations and vertical ground reaction force were analyzed by using correlation coefficients. Significance was set at $p < 0.05$.

RESULTS : Table 1 shows average trunk and knee accelerations and vertical ground reaction force. Table 2 presents the correlation (r) values between trunk and knee accelerations and peak vertical ground force. Strong correlations were found between peak vertical ground reaction force and peak acceleration of the medial trunk ($r=.95$, $p<0.01$, figure 2a), vertical trunk ($r=.90$, $p<0.01$), posterior trunk ($r=.76$, $p<0.05$), trunk resultant ($r=.90$, $p<0.01$), vertical knee ($r=.82$, $p<0.05$), as well as knee resultant ($r=.89$, $p<0.01$, figure 2b).

DISCUSSION: In this study, we measured trunk and knee acceleration. Obtaining measurements using an accelerometer are comparatively simpler, with the measured acceleration also reflecting the impact applied to the segment. The results of this study showed a strong correlation between acceleration of the trunk and knee and vertical ground reaction force. These correlations indicate that those who demonstrated greater acceleration to the medial, vertical, posterior trunk, and resultant have greater vertical ground reaction force during landing. Additionally, those who demonstrated greater knee acceleration to the vertical and resultant have greater vertical ground reaction force during landing. It is possible that measuring the acceleration during sports movement could quantify the load to body segment.

Ground reaction force during landing was reported by previous studies that examined the sex-based differences or the risk of injury. Some previous studies have suggested that vertical ground reaction force is greater in female subjects than in male subjects during single leg (Schmitz et al., 2007) and double leg landings (Kernozek, Torry, H, Cowley, & Tanner, 2005). The results of this study indicated the strong relationships between acceleration of body segment and ground reaction force. Especially, trunk acceleration was correlated with all directions of acceleration. Moreover, there is little body restriction while measuring the acceleration of body segment. Therefore, it is possible to evaluate variable sports movements or real sports activity by using the acceleration of body segment. In this study, we have examined only the correlation of peaks. In the future study, the timing between the peaks should be examined.

The acceleration of body segment is possibly affected by other factor but ground reaction force. Peak accelerations occur for individual body segments as the impact is transmitted through the skeletal system, from the leg to the head. The accelerations of these segments depend on geometry of the segments, apparent stiffness of the joints, segment deformations, segment masses, and segment moments of inertia (Derrick, 2004). The results of this study showed that knee accelerations to mediolateral and anteroposterior were not correlated with ground reaction force. Knee kinematics during landing on frontal and horizontal plane was complex (Nagano et al., 2007). Therefore, these kinematics possibly affected the knee acceleration during landing, and in future studies, the relationship between kinematics and acceleration should be examined.

Table 1
Mean (SD) of trunk and knee acceleration and vertical ground reaction force (GRF)

	Mean (SD)
Peak trunk acceleration (G)	
Medial	1.21 (0.43)
Vertical	7.39 (2.76)
Posterior	2.95 (0.80)
Resultant	7.51 (2.76)
Peak knee acceleration (G)	
Medial	-15.47 (4.77)
Vertical	21.93 (9.76)
Posterior	-7.44 (2.20)
Resultant	26.79 (10.15)
Peak vertical GRF (N/kg)	48.74 (6.04)

Table 2
R values for the association with trunk and knee acceleration and vertical ground reaction force

	Trunk Acceleration			
	Medial peak	Vertical peak	Posterior peak	Resultant peak
Peak vertical GRF	.95**	.90**	.76*	.90**

	Knee Acceleration			
	Medial peak	Vertical peak	Posterior peak	Resultant peak
Peak vertical GRF	-.60	.82*	-.43	.89**

*: $p < 0.05$, **: $p < 0.01$

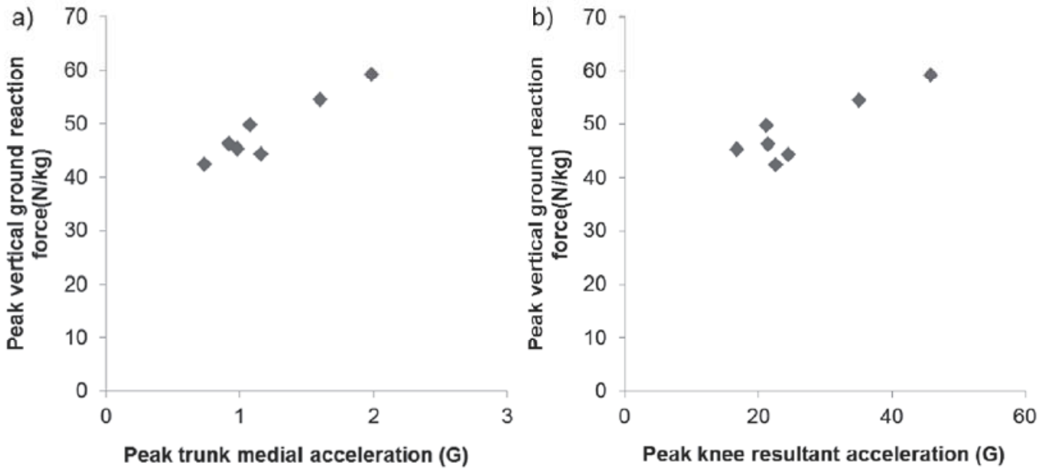

Figure 2: Relationship between peak vertical ground reaction force, peak trunk medial acceleration (a) and peak knee resultant acceleration (b)

CONCLUSION: The purpose of this study was to investigate the relationships between the ground reaction force and acceleration of the knee and trunk. The results of this study showed a strong correlation between acceleration of trunk and knee, and vertical ground reaction force. Especially, trunk acceleration was correlated with all directions of acceleration. There is little body restriction while measuring the acceleration of body segment. Therefore, it is possible to evaluate the variable sports movements or real sports activity by using the acceleration of body segment.

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