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Original Article

Effects of different oral instructions on kinematic and kinetic parameters during drop vertical jump

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Abstract. [Purpose] This study aimed to examine the impact of changing the drop vertical jump stance time on kinematic and kinetic parameters by ordering to high jump or quick jump for consistent stance time and a more accurate assessment of anterior cruciate ligament injury risk. [Participants and Methods] The participants were 20 healthy female students. The drop vertical jump was started by instructing the participants to stand on a 30-cm platform with both legs stationary. The task was performed while the participants were instructed to perform high jump or quick jump. [Results] Stance time was significantly shorter with quick jump than with high jump. Quick jump showed significantly higher knee abduction angles at initial contact and peak vertical ground reaction force, and lower hip flexion, knee flexion, and ankle dorsiflexion angles at the lowest point of the center of mass. Quick jump showed a significantly higher peak vertical ground reaction force. The knee abduction moment at initial contact was not significantly different between the 2 conditions. [Conclusion] Quick jump was better than high jump for making stance time consistent, and the differences in kinematic and kinetic characteristics by oral instructions should be considered when using drop vertical jump.
Key words: Anterior cruciate ligament, injury, Drop vertical jump, Stance time

INTRODUCTION

Anterior cruciate ligament (ACL) injury is a typical non-contact sports injury[1, 2] that occurs during deceleration motions such as jump landing, stopping, and changing direction[3]. The excessive peak vertical ground reaction force (peak vGRF) during landing has been shown to increase ACL injury risk, causing a sudden change in knee valgus and an increase in the knee valgus movement.

The drop vertical jump (DVJ), a double-leg landing task with plyometric elements performed by dropping off from a platform, landing with both feet, and immediately performing a vertical jump, is widely used for ACL injury screening. Hewett et al.[4] evaluated the kinematics and kinetics of female athletes during DVJ landing and later conducted a prospective study on their correlations with ACL injuries. In that study, athletes with ACL injuries exhibited significantly higher peak vGRF, maximum knee abduction moment, knee abduction angle at initial contact (IC), and maximum knee abduction angle during double-leg landing. These findings indicate that analyzing from kinematics and kinematics of the lower limb such as the peak vGRF, knee valgus movements (knee abduction angle), and knee abduction moment during landing using DVJ in health athletes will be an evaluation screening that predicts the risk of ACL damage in the future.

We previously reported that during the first DVJ landing, shorter times from first IC to toe off (stance time) were associated with smaller hip flexion, knee flexion, and ankle dorsiflexion angles and with larger peak vGRF during landing[5]. However, the problem was that the stance time varied between participants, which means the kinematic and kinetic parameters may have been evaluated in different conditions. Stance time in the DVJ is not regulated. Participants are instructed to "jump vertically after landing from the platform" and are given no instructions on the speed of landing and jumping. Although regulating DVJ stance time could be valuable when used for ACL injury screenings, it is shorter than 1 second and thus difficult to regulate. The rebound drop jump (RDJ) is a different name task with almost the same motions as DVJ. As with the DVJ, the RDJ involves dropping from a 30-cm platform, then jumping vertically immediately after landing. The RDJ index is calculated by dividing the jump height by stance time and is used as an indicator of an individual's stretch shortening cycle (SSC) ability. SCC ability is considered to be better when RDJ stance time decreases and jump height increases. RDJ stance time is correlated with jump height, i.e., short or extremely long stance times are associated with low jump heights, whereas jump height increases when the stance time is of a preferable duration[6]. Young et al.[7] showed oral instructions about jump height and stance time during DVJ influenced jump performance. Moreover, Khuu et al.[8] showed oral instructions, such as minimize stance time, maximize jump height and synchronously extend the lower extremity joints influenced joint kinematic, and kinetic variables. The oral instruction of minimize stance time was significantly lower in jump height and shorter stance time than other conditions during DVJ. Moreover, in the oral instruction of minimize stance time, athletes maintained a more vertically oriented trunk and used less sagittal hip, knee, and ankle joint range-of-motion throughout most of the stance phase of the DVJ, and peak vGRF was significantly larger than in other conditions. Trying to jump quickly is thought to lead to short stance times, while trying to jump high increases stance time and the oral instructions influence kinematics and kinetics during DVJ. Therefore, this study attempted to modify the stance time by asking the participants to "jump high" or "jump quickly" with their best effort. By oral instructions, stance time could be made consistent. Moreover, if different instructions changed kinematics and kinetics, it could be more accurate assessment by considering the kinematic and kinetic characteristics of both conditions during DVJ.

This study aimed to examine the impact of changing the DVJ stance time on kinematic and kinetic parameters by informing the participants to "jump high" or "jump quickly" after the first landing.

PARTICIPANTS AND METHODS

The participants were 20 healthy female students at Hirosaki University (age 20 ± 1 years, height 159.8 ± 5.7 cm, weight 53.0 ± 7.1 kg). The exclusion criteria were history of orthopedic disease in the last year, having a lower limb complaint, or a history of lower limb surgery. This study was approved by the ethical review board at the Hirosaki University School of Health Sciences, Graduate School of Health Sciences (reference No. 2017-023). The objective and methods of the study were explained to the participants before obtaining their consent.

The DVJ was started by instructing the participants to stand on a 30-cm platform with both legs stationary. The participant dropped from the platform, landed 30 cm in front of it, and immediately jumped vertically. Two different tasks were performed, a high jump (HJ) and a quick jump (QJ), in which the participants were instructed to "jump high" or "jump quickly" upon landing from the platform. The participants were not given any instruction regarding the upper limbs or trunk. If a participant was unable to maintain her posture after landing, the attempt was considered a failure. Each participant performed three successful attempts for both conditions. Two of the three attempts with similar peak vGRF waveforms were selected, with the later attempt used in the analysis.

Motion analysis was performed with 3-dimensional (3D) motion analysis equipment (Vicon Nexus; Vicon Motion Systems, Oxford, UK) composed of eight infrared cameras and a force platform (400×600 mm; AMTI, Watertown, MA, USA) with sampling frequencies of 200 Hz and 2,000 Hz, respectively. Processing was performed using a Butterworth filter with a cut-off frequency of 12 Hz.

The participants wore sports undergarments. Following the Plug-in Gait Full Body model configured for 3D motion analysis equipment, 35 infrared reflective markers of 14 mm in diameter were attached to the participants' bodies (head, spinous process of the 7th cervical vertebra, spinous process of the 10th thoracic vertebra, episternum, xiphoid process of the sternum, right scapula, acromion, elbow, radial styloid process, ulnar styloid process, 2nd metacarpophalangeal joint, anterior superior iliac spine, posterior superior iliac spine, lateral thigh, knee joint axis, lateral lower leg, external malleolus, 2nd metatarsophalangeal joint, and heel). The leg usually used by the participants to kick a ball was defined as the dominant leg. The non-dominant leg was analyzed and was determined as the left leg for all participants.

The analysis interval was from the platform to landing, which was considered the first landing phase. During this phase, IC was determined when vGRF exceeded 10 N and toe off (TO) when it decreased below 10 N. The time from IC to TO was identified as the stance time.

Jump height (mm) were center of mass difference from static standing position to reaching highest center of mass. The kinematic parameters were hip, knee, and ankle angles (°) on the sagittal and frontal planes at IC, peak vGRF, and the lowest center of mass point. The kinetic parameters were stance time (msec), peak vGRF (N/kg), time from IC to peak vGRF (msec), and external knee abduction moment at IC (Nmm/kg).

For the statistical analysis, a paired t-test was used to compare stance time; the hip, knee, and ankle angles on the sagittal

and frontal planes at IC, peak vGRF, and the lowest center of mass point; peak vGRF; time from IC to peak vGRF; and external knee abduction moment at IC between the HJ and QJ conditions. IBM SPSS Statistics 24.0 (Chicago, IL, USA) was used for the statistical analysis. The significance level was set to 5%.

RESULTS

Table 1 shows stance time and jump height in HJ and QJ conditions. The results show that the stance time was significantly shorter with QJ and that Jump height was significantly lower with QJ. Table 2 shows lower limbs angles in HJ and QJ conditions. QJ showed significantly higher knee abduction angles at IC and peak vGRF, and significantly lower hip flexion, knee flexion, and ankle dorsiflexion angles at the center of the mass lowest point. Further, it shows that kinetic parameters in Table 3. Peak vGRF was significantly higher with QJ. But time to peak vGRF and knee abduction moment at IC was not significantly different between HJ and QJ.

Table 1. Stance time and jump height in 2 drop vertical jump (DVJ) conditions

	HJ		QJ		p value
	Mean	SD	Mean	SD	
Stance time (msec)	490.1	110.8	335.7	72.1	<0.05*
Jump height (mm)	333.3	56.2	293.2	60.4	<0.05*

HJ: high jump condition; QJ: quick jump condition; SD: standard deviation.
*p value: obtained with a paired t-test.

Table 2. Lower limbs angle at initial contact (IC), appearance of peak vGRF and the center of the mass lowest point in 2 drop vertical jump (DVJ) conditions

		HJ		QJ		p value
		Mean	SD	Mean	SD	
IC	Hip flexion/extension (°)	22.8	7.1	12.3	10.6	0.88
	Hip abduction/adduction (°)	5.6	4.0	4.5	4.2	0.12
	Knee flexion/extension (°)	12.8	6.9	8.1	8.0	0.37
	Knee abduction/adduction (°)	−0.5	4.3	−0.1	3.4	<0.05*
	Ankle dorsiflexion/plantarflexion (°)	−24.2	5.9	−26.3	8.3	0.09
Peak vGRF	Hip flexion/extension (°)	42.5	9.1	39.7	9.6	0.05
	Hip abduction/adduction (°)	5.9	4.8	6.3	4.4	0.61
	Knee flexion/extension (°)	52.9	8.1	50.7	8.6	0.14
	Knee abduction/adduction (°)	−3.2	10.1	0.8	8.6	<0.05*
	Ankle dorsiflexion/plantarflexion (°)	23.0	7.8	24.8	5.8	0.18
Lowest point center of mass	Hip flexion/extension (°)	65.0	16.4	38.3	20.9	<0.05*
	Hip abduction/adduction (°)	3.3	5.2	3.2	4.5	0.32
	Knee flexion/extension (°)	84.7	12.7	62.4	18.6	<0.05*
	Knee abduction/adduction (°)	4.2	12.8	4.3	9.4	0.07
	Ankle dorsiflexion/plantarflexion (°)	34.9	5.6	30.9	10.8	<0.05*

HJ: high jump condition; QJ: quick jump condition; SD: standard deviation.
Positive value: hip flexion, hip abduction, knee flexion, knee abduction and ankle dorsiflexion.
Negative value: hip extension, hip adduction, knee extension, knee adduction and ankle planter flexion.
*p value: obtained with a paired t-test.

Table 3. Peak vGRF, time to peak vGRF and knee abduction moment during landing phase in 2 drop vertical jump (DVJ) conditions

	HJ		QJ		p value
	Mean	SD	Mean	SD	
Peak vGRF (N/kg)	14.7	2.6	18.2	3.4	<0.05*
Time to peak vGRF (msec)	83.4	11.1	84.9	16.5	0.63
IC Knee abduction moment (Nmm/kg)	86.8	54.4	80.0	52.3	0.54

HJ: high jump condition; QJ: quick jump condition; SD: standard deviation.
*p value: obtained with a paired t-test.

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DISCUSSION

The study participants performing the DVJ were instructed to "jump high" or "jump quickly" to modify the stance time during the landing motion. Its effects on kinematic and kinetic parameters were investigated. Compared to HJ, the stance time was significantly shorter with QJ. Kajitani et al.[6] showed that the relationship between stance time and jump height exhibits a reverse U-shape, with short and long stance times associated with lower jump heights, which increases when stance time is of a preferable length. In this study, the stance time was 490.1 ± 110.8 msec with HJ and 335.7 ± 72.1 msec with QJ, showing that attempting to jump high prolonged the stance time, while attempting to jump quickly shortened it, which is similar to previous results[5]. This indicates that oral instructions can shorten or lengthen the stance time in the same participant. ACL injuries are reported to occur during rapid deceleration such as landing, cutting, and other motions involving a change of direction[3]. These motions involve comparatively shorter stance times. In competitive sports, athletes must move fast to apply their optimal performance, meaning that landing and cutting motions must be performed quickly. The DVJ with QJ is thought to appropriately reflect the motions of competitive sports rather than DVJ with HJ.

The knee abduction angle at IC and peak vGRF and the peak vGRF were higher with QJ than with HJ in this study. Koga et al.[10] found that an abrupt change in knee valgus occurred within 40 msec of IC in this study. Krosshaug et al.[9] reported that ACL injuries occurred in 17–50 msec. Ogasawara et al.[11] analyzed ACL injury videos, describing how the injuries occurred from a sudden increase in the knee valgus moment immediately after IC. Many other video analyses[2, 12] have indicated that ACL injuries are caused by an abrupt change in knee valgus and increase in the knee valgus moment immediately after IC. Regarding the ACL injury mechanism, Koga et al.[10] reported that the generation of a knee valgus moment during contact puts lateral pressure on the femorotibial joint, causing relative anterior migration and internal rotation of the tibia, which resulted in the ACL injury. Meyer et al.[13] reported that paired compression and torsion experiments conducted on femorotibial joints of cadaver knees led to posterior inclination of the tibial plateau, causing anterior displacement and interior rotation of the tibia with respect to the femur. Therefore, pressure on the lateral femorotibial joint is thought to be an important factor causing ACL injuries. In addition, Shimokochi et al.[14] reported that the amount and timing of pressure on the long axis in the tibia during landing correlated with the amount and timing of peak GRF. Cerulii et al.[15] reported that the timing of peak GRF and peak ACL strain synchronized during anterior hops. Based on these findings, increased peak GRF elevated the femorotibial joint pressure, which increases stress on the ACL, indicating that peak GRF, particularly peak vGRF, is a risk factor for ACL injury. Hewett et al.[4] reported that when female athletes performed the DVJ, increases in the knee abduction moment, knee abduction angle, and peak vGRF during landing were all risk factors for ACL injury. This indicates that the knee abduction (valgus) moment, knee valgus position (knee abduction angle), and peak vGRF during DVJ landing should be evaluated when screening for ACL injury risk. The knee valgus angle at IC and peak vGRF were higher with QJ than with HJ in this study, indicating that ACL injury risk increases in tasks with shorter stance times such as with QJ. Furthermore, adding oral QJ instructions to the DVJ could be suitable for ACL injury screening.

In this study, the knee abduction angles at IC and peak vGRF were higher with QJ than with HJ, whereas the hip flexion, knee flexion, and ankle dorsiflexion angles were lower at the lowest center of mass point with QJ than with HJ. Previous research showed that in the RDJ, which involves jumping quickly after landing, the amount of work performed by the ankle is relatively large during the counter movement drop jump; thus, the participant sinks down after landing and then jumps[16]. Movement during the RDJ has been shown to be centered around the ankle[6], therefore movement is thought to be centered around the ankle when QJ is added to the DVJ to intentionally make stance time shorter. In other words, as QJ with its short stance time involves an ankle-centered landing motion, landing with HJ is thought to have a larger range of movement involving the lower leg joints, primarily the hip and knee. Therefore, hip flexion at the lowest center of mass point were particularly higher with HJ than QJ, Hewett et al.[17] reported an increased lateral trunk inclination and knee abduction angle during ACL injuries in females. Olsen et al.[12] found that ACL injuries occur in handball during cutting motions with plantar contact and one-leg landings after jump shots and that knee flexion was 5–25° and knee valgus was 5–20° when injuries occurred. Boden et al.[1] reported that most injuries occur with the knee in complete extension and during abrupt decelerations, direction changes, and jump landings. Previous research has also shown that the knee flexion angle increases during landing[18–20] and that increasing the knee flexion angle with landing training reduces peak vGRF[21]. These findings indicate that a large knee abduction (valgus) and small knee flexion angle during landing are risk factors for ACL injury. In this study, the knee abduction angles and peak vGRF were higher with QJ than with HJ, whereas the hip flexion, knee flexion, and ankle dorsiflexion angles were lower at the lowest center mass point with QJ than with HJ, which suggests a higher risk for ACL injury. Therefore, QJ is thought to be suitable for screening ACL injury risk. Moreover, the standard deviation of stance time was smaller with QJ, indicating QJ is better than HJ for making stance time consistent.

However, a clear cut-off value for peak vGRF and knee abduction moment values related to ACL injury risk have not been reported. In this study, the mean knee abduction angles with QJ were 0.4° at IC, 0.8° at peak vGRF, and 4.3° at the lowest center of mass point. Koga et al.[10] reported that knee valgus in ACL injuries changes by a mean of 12° within 40 msec after landing. In this study, the mean knee abduction angle with QJ was lower than that reported during ACL injury. Therefore, the QJ task is still as safe as the HJ for screening of ACL injury. Assessments should be performed while considering the kinematic and kinetic characteristics of both conditions.

In this study, instructing participants to "jump quickly" in the QJ condition of the DVJ led to significantly shorter stance times than instructing them to "jump high" in the HJ condition. Moreover, QJ had significantly lower hip flexion, knee flexion, and ankle dorsiflexion angles at the lowest center of mass lowest and significantly greater knee abduction angles at IC and appearance of the peak vGRF as well as the peak vGRF compared to HJ. These results indicate that the difference in kinematic and kinetic characteristics due to jumping should be considered when using the DVJ for ACL injury risk screening.

Conflict of interest
None.

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