ORIGINAL ARTICLE

Knee Valgus during Jump Landing Is Related to the Inaccuracy of Knee Position Recognition in Healthy Young Women

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Objective: Knee valgus during jump landing is a cause of knee injuries during sports activities. Body recognition is important for maintaining the knees and other body parts in their proper positions. The aim of this study was to investigate whether knee valgus during jump landing in healthy young women is related to the inaccuracy of recognition of bilateral knee positions in the squatting position. **Methods:** In 39 healthy young women, the degree of knee valgus was evaluated during the drop vertical jump test using the ratio of the knee separation distance to the ankle separation distance. The accuracy of recognition of bilateral knee positions in the squatting position was evaluated by having the blindfolded subjects indicate with their index fingers the subjective positions of their bilateral patellae by placing their fingers on a horizontal bar positioned in front of them 3 cm below the navel. The difference ratio of the recognized distance to the actual distance between the bilateral patellae was measured as an inaccuracy index. **Results:** The degree of knee valgus during the drop vertical jump test was positively correlated with the degree of inaccuracy of the recognized knee position with the knees in the neutral position (r=0.358, P=0.025). **Conclusions:** In healthy young women, knee valgus during jump landing was significantly correlated with the inaccuracy in knee position recognition in the squatting posture. This finding suggests that the assessment of knee position recognition in the squatting position could be useful as a screening tool for preventing knee injuries on jump landing during sports activities.

Key Words: body recognition; drop vertical jump; landing; female adults

INTRODUCTION

Knee valgus on jump landing during sports activities is an abnormal posture that causes various knee injuries, such as anterior cruciate ligament (ACL) injuries,[1,2] patellar dislocation,[3] and medial collateral ligament injuries.[4,5] Knee valgus is a malalignment involving excessive knee abduction combined with femoral adduction and internal rotation and relative external tibial rotation.[6–8] In females in particular, the knee abduction moment increases during landing in the drop vertical jump (DVJ) task and results in knee valgus posture and potential injury.[6] Significant risk factors of knee valgus during jump landing include abnormal knee joint proprioception,[9–12] lower hip external rotation and low abduction strength,[13,14] range of motion abnormalities,[15,16] and poor trunk control.[17–20] Proprioception – the recognition of the position of one body part relative to another body part without visual information – is crucial for controlling limb

Table 1. Baseline characteristics of the study participants

Characteristic	Mean ± SD
Number of subjects (n)	39
Age (years)	21±1.9
Height (cm)	159.3 ± 5.0
Weight (kg)	50.5 ± 5.0
Body mass index (kg/m^2)	19.8 ± 1.5
No sports history (n)	6
Sports history (n)	33
Volleyball	8
Tennis	6
Basketball	4
Track and field	3
Swimming	3
Handball	2
Badminton	2
Table tennis	2
Soccer	1
Ballet	1
Dance	1

SD, standard deviation.

movements during sports activities. Therefore, it is necessary to accurately recognize the knee position in relation to the ankle position and other body parts in the landing posture, i.e., squatting, to prevent knee valgus during jump landing. However, there has been no report on the relationship between knee position recognition in the squatting position and knee valgus during jump landing. The DVJ test is widely employed to assess knee valgus during jump landing and uses the ratio of the knee separation (KS) distance, i.e., the distance between the bilateral patellae, to the ankle separation (AS) distance, i.e., the distance between the bilateral ankles.[21–23]

We hypothesized that knee valgus during jump landing in the DVJ test could be related to inaccurate knee position recognition in the squatting position, which is similar to the posture during jump landing. We investigated this hypothesis in healthy young women who had a relatively high risk of knee valgus on jump landing during sports activities.

MATERIALS AND METHODS

Subjects

A total of 39 healthy young women participated in this study (**Table 1**). Their mean age was 21 (range, 19–28) years. All participants had no previous lower limb injuries and no

orthopedic problems, e.g., ACL injuries or congenital joint deformity, and no pain, paralysis, or sensory disturbance of the upper or lower limbs. Written informed consent was obtained from all participants included in the study. The study protocol was conducted according to the principles expressed in the Declaration of Helsinki and its revisions and was approved by the Ethics Committee of Dokkyo Medical University (R-42-13 J).

Experiment

We evaluated both the knee valgus during the first jump landing in the DVJ test[24] and the degree of inaccuracy of bilateral knee position recognition with the subject in the squatting position. The DVJ test was performed first, followed by the evaluation of the knee position recognition.

For the DVJ test, a 30-fps digital video camera (CASIO, Tokyo, Japan), a 31-cm high platform, and body markers were used, as described in a previous report.[24] The subjects wore athletic shoes of their choice and were instructed to perform three DVJ tests from the platform following two or three practice repetitions.[24] The subjects stood on the platform with feet shoulder-width apart, toes over the edge of the platform, eyes looking straight ahead, hands on their hips, and then jumped off the platform; they were instructed to land equally on both feet on the floor and immediately to perform a maximum vertical jump from the squatting position.[24] Before the jump, subjects were instructed to land with their knees in a neutral position such that both knee joints were directly above the feet, i.e., with KS and AS distances equal, and to keep their feet shoulder-width apart during the DVJ test. We checked the subject's performance using a video camera. If we found a failed trial, such as a loss of balance or a failure to keep the feet shoulder-width apart, we made the subject redo the DVJ test until they successfully performed it three times. The two-dimensional motion analysis software Dart Fish (Dart Fish, Fribourg, Switzerland) was used to measure the KS and AS distances at the instant of the maximal squatting position during the first landing of the DVJ test. As an index of knee valgus during landing, the difference ratio of the KS distance to the AS distance, $\{(AS - KS)/AS\} = \{1 - (KS/AS)\}$, was calculated.[22,23] Zero represents an equal separation distance between the knees and the ankles, whereas a value of >0 indicates that the centers of knees are medial to the centers of ankles.[23] The highest value of $\{1 - (KS/AS)\}$ in the three DVJ test trials was used as the representative value.

To evaluate inaccuracy of knee position recognition in the squatting position, subjects were blindfolded with an eye
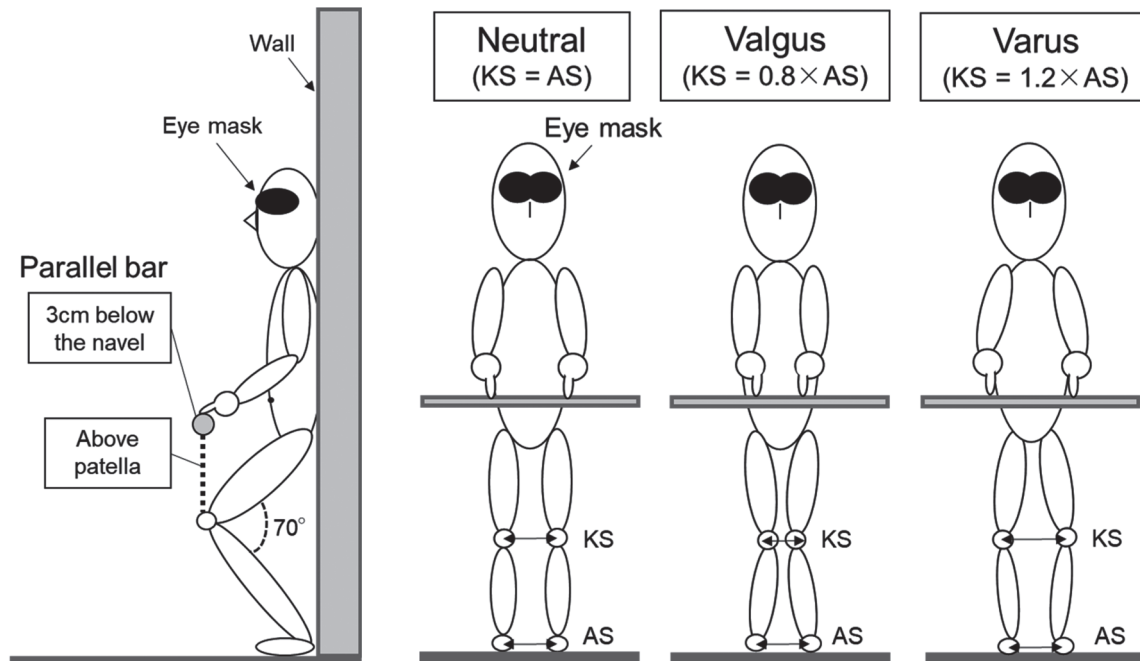
Fig. 1. Evaluation of knee position recognition with the subject in the squatting position. Squatting was performed with 70° of flexion of the knee joints; with feet shoulder-width apart; and with head, hip, and heels touching the wall. Subjects were blindfolded using an eye mask and were asked to indicate with their index fingers the center of their patellae. The tips of the fingers were located on a horizontal bar set in front of the subject 3 cm below the navel, as done in previous reports on body recognition. The assessment of knee position recognition was carried out with the knee separation (KS) distance set in three conditions: neutral (KS=ankle separation (AS) distance), valgus (KS=0.8 × AS), and varus (KS=1.2 × AS).

mask and were asked to point with their index fingers to the centers of their patellae; for standardization, the tips of their index fingers were touching a parallel bar set in front of them 3 cm below the navel, as described in previous reports[25,26] (**Fig. 1**). The squatting posture was performed with 70° flexion of the knee joints; the feet shoulder-width apart; and the head, hips, and heels touching the wall. The subjects indicated the positions of the centers of their patellae with KS set at three distances, i.e., neutral (KS=AS), valgus (KS=0.8 × AS), and varus (KS=1.2 × AS) (**Fig. 1**).[22,23] The order of the three KS distances during recognition measurements was randomized. The finger-indicated KS value was defined as the recognized knee position (i.e., the recognized KS). The degree of inaccuracy of knee position recognition relative to the actual knee positions was an absolute value calculated using the following equation: $|\{(\text{the actual KS}) - (\text{the recognized KS})\}/(\text{the actual KS})| = |1 - \{(\text{the recognized KS})/(\text{the actual KS})\}|$. The original value of the degree of inaccuracy of the knee position recognition (i.e., including both negative and positive inaccuracy values) was calculated using the following equation: $(\text{the actual KS}) - (\text{the recognized}$

$\text{KS})\}/(\text{the actual KS}) = 1 - \{(\text{the recognized KS})/(\text{the actual KS})\}$. Furthermore, the relationships between knee valgus during jump landing and hip abduction muscle strength and between knee valgus and the ROMs of internal rotation and external rotation of hip joints[15] were investigated in 29 of the 39 participants. We measured the subjects' isometric muscle strength[27,28] using the Power Track II Commander (NIHON MEDIX, Chiba, Japan) and normalized the results using individual body weights. ROMs were measured using a goniometer (SAKAImed, Tokyo, Japan)[29] and recorded in increments of 5°. The recorded values of the muscle strength and the ROMs were averaged for the left and right sides.

Data Analyses and Statistical Tests

Pearson correlation coefficients were calculated between the degree of knee valgus during jump landing and the degree of inaccuracy of knee position recognition (in the neutral, valgus, and varus conditions); the hip abduction muscle strength; and the ROMs of adduction and internal rotation of hip joints. Univariate analysis was carried out between the recognition inaccuracies in the neutral, valgus, and varus

Table 2. Average values of the measurements

Measurement	Mean ± SD	
Degree of knee valgus	0.39±0.13	
Degree of inaccurate recognition of the knee position	Absolute value	Original value
Neutral	0.11±0.09	0.03±0.15
Valgus	0.14±0.13	−0.10±0.17
Varus	0.15±0.12	0.08±0.18
Hip abductor strength (N/kg)	2.96±0.50	
ROM of internal rotation (°)	55.5±9.65	
ROM of external rotation (°)	59.8±6.00	

conditions. SPSS version 21 (IBM, Armonk, New York) was used for statistical analysis. The significance level was set at 0.05. Values are expressed as means ± standard deviations.

RESULTS

The average (±SD) values of the degree of knee valgus; the degree of inaccurate recognition of the knee position in the neutral, valgus, and varus conditions; the muscle strengths; and the ROMs are shown in **Table 2**. The number of times the DVJ test was repeated ranged from 0 to 3 in the 39 subjects.

A positive correlation was shown between the degree of knee valgus during jump landing and the degree of inaccuracy of knee position recognition in the neutral condition (r=0.358, P=0.025) (**Fig. 2**). However, no significant correlation was observed for position recognition inaccuracy in the valgus and varus conditions (r=0.026, P=0.876; r=0.051, P=0.757, respectively). Analysis using the original value of the degree of inaccuracy of knee position recognition indicated no significant correlation in the neutral, valgus, or varus condition (r=0.029, P=0.863, r=0.041, P=0.803, r=−0.009, P=0.957, respectively).

There was no significant correlation between the degree of knee valgus during jump landing and the hip abduction muscle strength (r=0.145, P=0.463) (**Fig. 3a**) or the ROMs of internal rotation (r=−0.233, P=0.233) or external rotation (r=−0.190, P=0.331) of the hip joints (**Figs. 3b, c**). There was no significant difference in inaccurate recognition for the neutral, valgus, and varus conditions (F=1.207, P=0.305).

DISCUSSION

We found a significant positive correlation between the degree of knee valgus during jump landing and the degree of inaccuracy of the knee position in the neutral squatting position. This finding suggests that knee valgus during jump landing might be caused by inaccurate recognition of the knee positions in the landing posture.

In general, movements are predictably controlled based on body recognition. The recognition of body posture, the positional relationship of body parts, and the prediction of movements of each body part from one place to another enable us to perform appropriate actions rapidly and smoothly, particularly in sports activities. However, inaccurate body recognition can cause prediction errors during movement and result in inappropriate postures.[30] Our findings suggest that inaccurate knee position recognition leads to knee valgus during jump landing, probably as a result of error in prediction of the knee position.

In the current study, the degree of recognition inaccuracy was correlated with knee valgus only for the neutral condition (KS=AS). No relationship was observed for the valgus or varus condition. In the DVJ test, we asked the subjects to land in the neutral condition. Therefore, because the subjects attempted to assume a neutral knee position during the DVJ test, we consider it reasonable that a significant correlation was shown only for the neutral condition. Sports players are often trained to land in the neutral condition; consequently, assessment of knee position recognition in the neutral condition could be a useful screening tool to evaluate the risk of ACL injuries caused by jump landing. If knee position recognition in the neutral condition is inaccurate, it may be better to conduct training to correct the inaccurate recognition before the performance of jump landing in the neutral condition.

Subjects showed a tendency to perceive the knee distance to be less than the actual distance in the valgus condition, and to perceive it to be more than the actual knee distance in the varus condition. We considered that subjects may have overperceived the knee distance according to their knee postures. When a certain sensory input is transmitted to the brain, sensitivity enhancement can occur.[31,32] The sensory
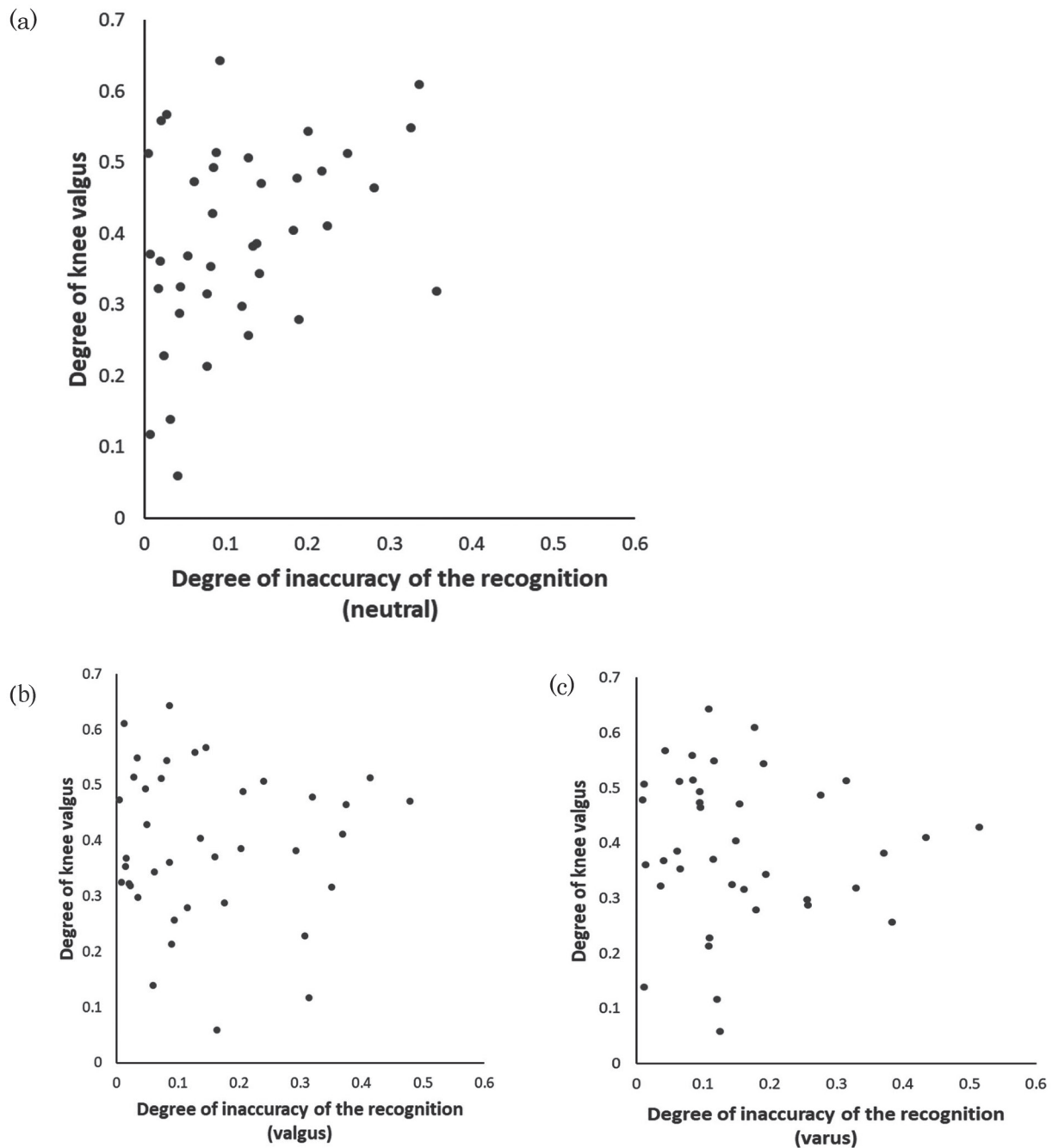
(a)

(b)

(c)

Fig. 2. Correlations of the degree of knee valgus with the degree of inaccuracy of recognition of knee position in the (a) neutral, (b) valgus, and (c) varus conditions. A significant positive correlation was observed for the neutral condition (r=0.358, P=0.025), whereas no significant correlation was noted for the valgus (r=0.026, P=0.876) or varus (r=0.051, P=0.757) conditions.

input is enhanced in the relevant sensory cortex according to the directed attention and concurrently blocks other neural activity from irrelevant brain areas.[32] The sensation of knee position may have been enhanced according to the direction of knee joints in the various postures. Further studies would be necessary to investigate such overperception. There was no significant difference between the three conditions in terms of inaccurate recognition, which suggests that the inaccuracy of recognition in a subject may have been present not only in the neutral condition but also the valgus and the
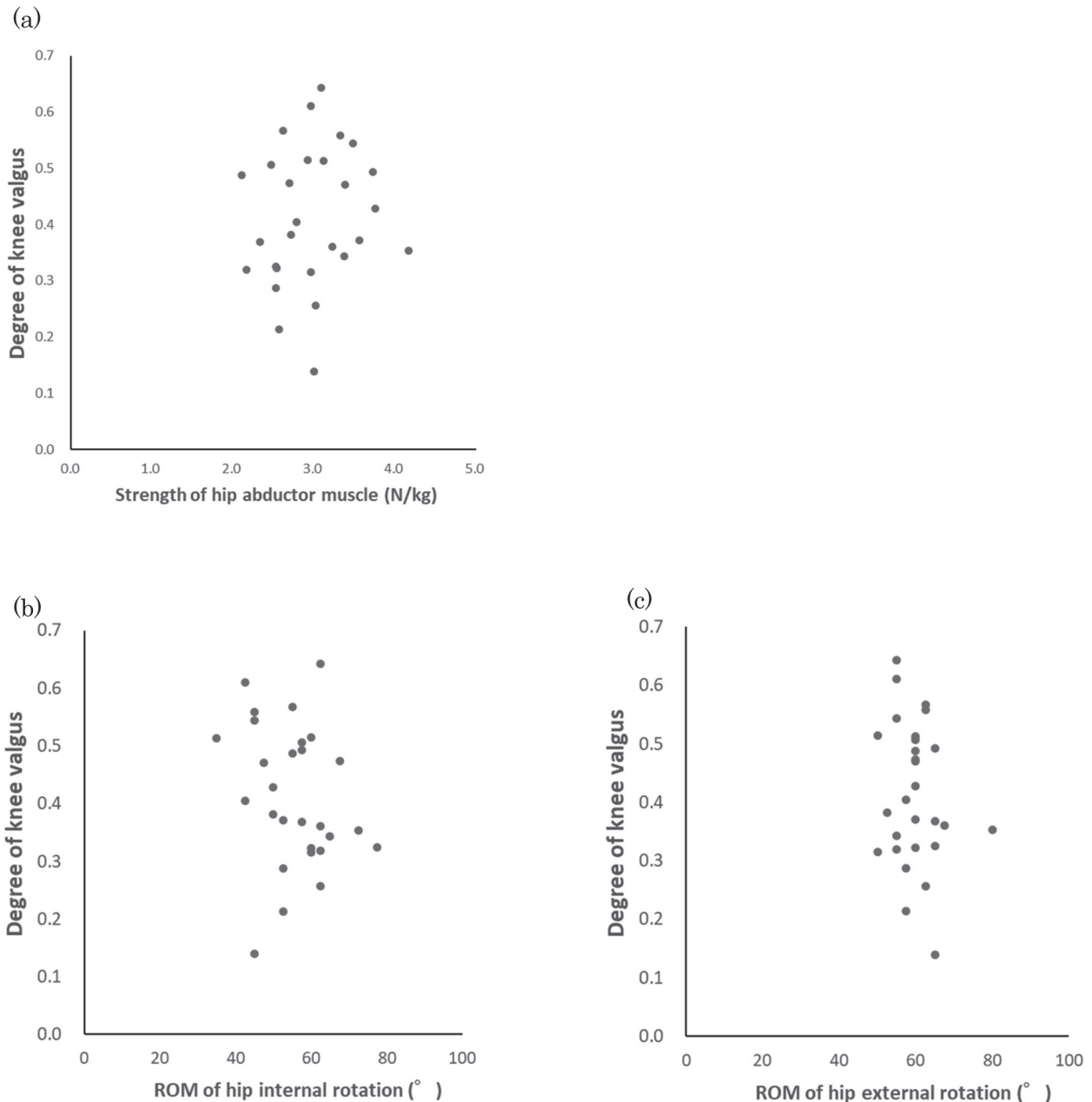
(a)

(b)

(c)

Fig. 3. Correlations of the degree of knee valgus with the hip abductor muscle strength and the ranges of motion of hip internal rotation and external rotation. No significant correlation was found for hip abductor muscle strength (r=0.145, P=0.463) or the ROMs of hip internal rotation (r=−0.233, P=0.233) or external rotation (r=−0.190, P=0.331).

varus conditions.

No correlation was noted between the knee valgus during jump landing and the hip muscle strength or the ROMs of internal rotation or external rotation of the hip joints. Low hip abductor muscle strength is significantly correlated with knee valgus,[33] whereas normal muscle strength is not.[34] The subjects in the present study all had normal hip abductor muscle strength. Therefore, no significant correlation was

evident in this study, which is consistent with the findings of a previous study.[34] Another study has shown that limitations in the ROM of hip internal rotation is likely to cause non-contact ACL injuries.[15] However, the subjects in the current study did not have any limitation of the hip ROMs.

Knee valgus is a three-dimensional alignment involving hip flexion, internal rotation and adduction, and knee flexion. However, the two-dimensional assessment of knee valgus

using the ratio of KS to AS is widely used and has been validated compared with three-dimensional assessments.[21–23] Therefore, we used this standard two-dimensional assessment and evaluation for knee position recognition. However, it is difficult to evaluate the degree of joint rotation.[23] It is a limitation of the current study that we could not evaluate the degree of rotation of the femur and the tibia. Future studies using three-dimensional assessments will be necessary.

In conclusion, knee valgus during jump landing was significantly correlated with the level of inaccurate knee position recognition in the neutral squatting position in healthy young women. This is the first report of the relationship between knee valgus during jump landing and the inaccuracy of subjective knee position recognition in the squatting position. The evaluation of knee position recognition in the squatting position may be useful as a screening test for the risk of knee valgus during jump landing in sports activities in healthy young women. Our findings indicate that the inaccuracy of knee position recognition is related to the knee valgus during jump landing, but it is still unclear whether it is further related to sports injuries. Future studies are necessary to investigate the relationship between the prevalence of knee injuries and the degree of inaccuracy of knee position recognition and to develop exercise programs to correct knee position recognition and to prevent knee valgus during jump landing.

ACKNOWLEDGMENTS

CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest.

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