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Original Article

Perception of leaning backward while standing and patellar movement

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Abstract. [Purpose] The purpose of this study was to investigate the relationship between the patellar movement and the standing backward leaning perceptibility. [Subjects and Methods] Fourteen volunteers who were confirmed presence of upward patellar movement during backward leaning from the quiet standing posture participated in this study. The quiet standing position, the standing backward leaning position at patellar movement onset and standing position perceptibility were measured. The position of the center of pressure in the anteroposterior direction in standing is represented as the percentage distance from the hindmost point of the heel in relation to the foot length (%FL). [Results] The mean value of the center of pressure on anteroposterior direction positions in quiet standing was 43.2%FL. The patellar movement onset position was 35.1%FL. The individual mean value of standard deviations for the onset position was 2.5%FL. The absolute error at the onset position is specifically and significantly small. [Conclusion] For the subjects whose patellas move during backward leaning in this study, the standing position near the onset position was perceived accurately, probably by the substantial change in sensory information associated with the onset of patellar movement while backward leaning.

Key words: Backward leaning, Perception, Patellar movement

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INTRODUCTION

The sensory information is believed to reference the internal model constructed in the higher neural centers for the positional perception of standing posture[1)]. In this reference, it is considered that standing position is perceived through the relationship between available sensory information and the body equilibrium, which has been memorized, based on experience[2)]. Positional perceptibility is considerably higher in positions where the center of pressure in the anteroposterior direction (CoPy position) is located farther from a quiet standing (QS) position[3, 4)].

Leg muscle activity[5, 6)] and foot pressure distribution[7, 8)] were reported to change substantially in standing positions far from the QS position. The large change in somatosensory information by these substantial changes may provide important cues for standing position perception in the anteroposterior direction[7, 8)]. The position of the center of pressure in the anteroposterior direction (CoPy position) in standing is represented as the percentage distance from the hindmost point of the heel in relation to the foot length (%FL). A large increase in muscle activity has been typically observed twice-at about 30–35%FL, and at about 25%FL while gradually leaning backward from the QS position[8)]. Most participants are unable to perceive the large increase in muscle activity of the rectus femoris at 30–35%FL positions[8)]. In addition, upward patellar

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movement was observed frequently while gradually leaning backwardly from the QS position. Therefore, the aspect of the patellar movement and perception of the patellar movement were investigated[9]. The rate of subjects who was confirmed the upward patellar movement was 80%, and the rate of trials which were perceived the patellar movement was 90%[9]. From this previous study, the individual onset position of the patellar movement was almost constant and perception of the patellar movement was highly accurate[9].

The patella is a sesamoid bone that has a connection to the quadriceps tendon, while the knee joint capsule surrounding the patella also adheres to the patellar tendon[10, 11]. Consequently, it is assumed that the patellar tendon tension, knee joint capsule deformity, and the cutaneous tissues surrounding the knee joint change in association with upward patellar movement. Edin has reported that sensory information from cutaneous receptors in the anterior thigh close to the knee joint play an important role in providing sensory or afferent information regarding knee joint position[12]. Rectus femoris muscle activity changes significantly in the standing position when gradually leaning backward from the QS position and that position is almost constant in each individual[8]. Therefore, large changes in somatosensory information based on patellar movement associated with rectus femoris muscle activation may contribute to the perception of a specific backward standing position. Improvement of standing stability is one of the purposes of physical therapy. Accurate perception of the standing position is required to control standing posture, especially in anticipatory postural adjustment. Hence, the investigation of function of the sensory information based on patellar movement for the perception of backward standing position in physical therapy may contribute to the understanding of the maintenance of the backward standing stability and the prevention of backward falling.

This study examined the relationship between patellar movement in the vertical direction and the standing position perceptibility. Our hypotheses was as follows: standing position perceptibility is particularly high near the patellar movement position where the large change in sensory information is perceived.

SUBJECTS AND METHODS

Fourteen participants (six females and eight males) were selected according to the following: confirmation of quadriceps femoris muscle relaxation and free movement of the patella by palpation in the quiet standing position, presence of upward patellar movement during backward leaning detected by palpation and inspection. Participant mean (± standard deviation [SD]) age, height, weight, and foot length were 21.7 ± 1.7 years, 165.2 ± 7.3 cm, 58.3 ± 8.6 kg, and 24.3 ± 1.0 cm, respectively.

Participants were free from neurological and orthopedic impairments. All participants gave informed consent to the experimental protocol, which was approved by the institutional ethics committee of Kanazawa University in accordance with the Declaration of Helsinki (No. 229).

A force platform (WAMI WA1001, Tokyo, Japan) composed of three load cells was used to measure CoPy positions while participants were standing with eyes closed and bare feet. Patellar movement onset timing was recorded using a miniature unidirectional accelerometer (KYOWA, AS-2G, Tokyo, Japan), which was taped to the upper edge of the patella. The output from the accelerometer was amplified using an amplifier (KYOWA, DPM-611A, Tokyo, Japan). These electrical signals were recorded on a computer (Dell Japan, Inspiron 1300, Kawasaki, Japan) via an A/D converter (Contec, ADA16-32/2(CB)F, Osaka, Japan) with a 1,000-Hz sampling rate and 16-bit resolution.

In addition, the electrical CoPy signal was sent to two computers (NEC, PC-9801RX2, Tokyo, Japan) via an A/D converter (I/O DATA, PIO-9045, Kanazawa, Japan) with 12-bit resolution. One computer was used to analyze the mean standing position for an arbitrary time with a 20-Hz sampling rate. In measuring the perceptibility of standing position, another computer (NEC, PC-9801RX2, Tokyo, Japan) was used with a 1,000-Hz sampling rate to sound a cue and inform the participants each reference position as the position to keep for 3 sec and memorize. When the participant had adjusted the CoPy position within a range of 1.0 cm from the reference position, a buzzer sound was generated as a cue.

The CoPy position was represented as the percentage distance (%FL) from the hindmost point (0%FL) of the heel in relation to the foot length. Participants were instructed to move the body with the ankle as the pivotal axis and to maintain the geometrical interrelationship among the body segments that was presented during QS position.

The CoPy position was measured first for three seconds during quiet standing posture in ten trials. Next, ten additional trials were conducted to investigate the patellar movement while leaning backward from the QS position. In these trials, the participants were instructed to actively and slowly lean the body from their QS posture to the most backward standing position in about ten seconds.

Next, perceptibility of five reference positions was evaluated from the reproducibility of these positions. The reference positions were set as follows: the CoPy position at the patellar movement onset position (the onset position), +5%FL from the onset position, +10%FL from the onset position, −5%FL from the onset position, and −10%FL from the onset position. There were seven experimental blocks. The five reference positions were randomly carried out in each experimental block. Each reference position was reproduced according to the following procedure with reference to previous study[3] (Fig. 1). 1) Participants maintained the QS posture for three seconds (Fig. 1-a). 2) They voluntarily and slowly (within ten seconds) moved their standing position by leaning backward until the buzzer sounded (the reference position) with the ankles as the pivotal axes, and then maintained and perceived the position for three seconds (Fig. 1-b). 3) They sat on a chair behind the force platform for three seconds without returning to the QS position (Fig. 1-c). 4) They then stood up, maintained the QS

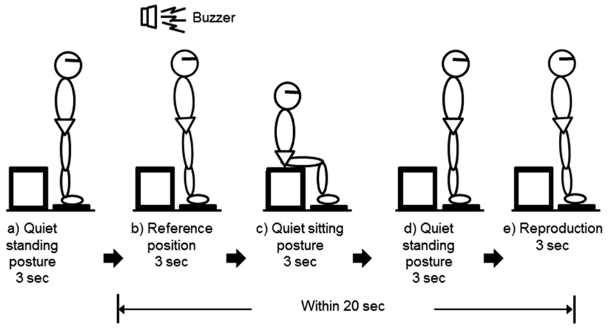

Fig. 1. Experimental protocol for reproducing reference positions (Modified from Fujiwara et al.[3])
a) Participants maintained the QS posture. b) They voluntarily and slowly moved their standing position by leaning backward until the buzzer sounded (the reference position), and then maintained and perceived the position for 3 sec. c) They sat on a chair behind the force platform. d) They then stood up, maintained the QS posture. e) They reproduced the reference position and maintained this position.

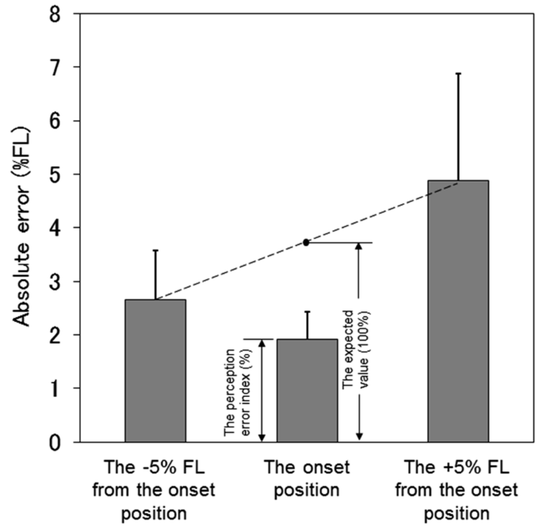

Fig. 2. The calculation method for the perception error index

posture for three seconds (Fig. 1-d). 5) They reproduced the reference position and pressed the switch when they judged themselves to be standing in the reference position and maintained this position for three seconds (Fig. 1-e).

All analyses were performed using BIMUTAS-II software (Kissei Comtec, Japan).

The mean value for ten trials was calculated and adopted as the representative CoPy position during quiet standing. Next, the onset position was defined as the position where the acceleration waveform beyond the mean amplitude of the baseline. The mean values and standard deviation (SD) of the onset position for ten trials were calculated for each participant.

The relationship between the reference position and perceptibility was investigated based on the reproduction absolute error. The measured reproduction absolute error (absolute error) was calculated using the following formula for each trial individually.

Absolute error = K(reproduced position) − (reference position)|

In addition, the mean absolute error at both the +5%FL and the −5%FL from the onset position was defined as the expected value. Then, the ratio of the absolute error in the onset position to the expected value was calculated as the perception error index (Fig. 2). Smaller absolute error and smaller perception error index mean higher perceptibility.

The one-way repeated-measures analysis of variance (ANOVA) was used to study the effect of reference position on the absolute errors. Post-hoc multiple comparison analysis using Newman-Keuls procedure was used to assess significant differences found with the ANOVA. The t-test was used to determine whether the perception error index differed from the expected value. The alpha level was set at $p<0.05$. All statistical analyses were performed using SPSS 14.0 J (SPSS Japan, Tokyo, Japan).

RESULTS

The mean value of the CoPy positions in QS was 43.2 ± 4.6%FL.

One hundred twenty-seven trials among all 140 trials (10 trials per subject) were confirmed the patellar movement by the acceleration waveform (the patellar movement confirmed in ten trials: 10 subjects; in 8 trials: 1 subject; in 7 trials: 2 subjects; in 5 trials: 1 subject). The onset position was 35.1 ± 4.5%FL. The individual mean value of standard deviations for the onset position was very small, 2.5 ± 1.3%FL.

A significant effect of reference position on absolute error was found ($F(4,13)=17.9$, $p<0.001$) (Table 1). Absolute errors at the onset position, the −5%FL from the onset position, and the −10%FL from the onset position were significantly smaller than those at the +5%FL from the onset position, and the +10%FL from the onset position.

The perception error index was 54.1 ± 18.5%, and this value was significantly smaller than the expected value ($t(13)=8.94$, $p<0.001$) (Table 1).

DISCUSSION

It was reported that patellar movement was perceived accurately while moving the patella as previous study[9]. The mean standard deviation values for individual the onset position was 2.5 ± 1.3%FL. This value shows that the onset position is

Table 1. Absolute error in five reference positions and the perception error index in the onset position

	Reference positions				
	The −10%FL from the onset position	The −5%FL from the onset position	The onset position	The +5%FL from the onset position	The +10%FL from the onset position
Absolute error (%FL)	1.9 ± 0.60*	2.7 ± 0.90*	1.9 ± 0.51*	4.9 ± 2.00	4.4 ± 1.52
The perception error index (%)			54.1 ± 18.51**		

*Statistically smaller than the +5%FL from the onset position, and the +10%FL from the onset position.
**Statistically smaller than the expected value (100%).

distributed ranging from 6 to 7 mm in case that foot length is 25 cm. Therefore, since these positions locate to an almost constant position in each individual, the change pattern of sensory information in relation to a standing position is also constant[7].

Thus, the sensory information that changes largely for each individual in an almost constant position should play an important role in postural stability at that position. In other words, it is conceivable that the standing position is perceived by building up the sensory reference frame based on that information, and by referring the incoming sensory information to this frame. In this experiment, the onset position was about 35%FL, and this position is located near the posterior end of the stability range for the standing position. Standing posture stability decreases posterior to this range end[13]. The large increase in sensory information associated with patellar movement during backward leaning may represent warning information meaning there is a deviation from the standing position stability range. Therefore, the perceptibility of the standing position would increase specifically at the standing position near the onset position.

Five reference positions were set to measure the perceptibility of the standing position. As a result, the absolute error in the onset position was significantly smaller than that in the +5%FL from the onset position. In a previous study, the perceptibility of different standing positions in the anteroposterior direction for 36 participants whose QS position was located from 31 to 58%FL was investigated[4]. The absolute errors in every 5%FL reference position backward from 40%FL changed linearly, and no significant differences were found between each adjacent absolute error[4]. The perception error index was calculated based on the relationship of the standing position and the absolute error. The perception error index at the onset position was significantly smaller than the expected value which was the mean absolute error at both the +5%FL from the onset position and the −5%FL from the onset position. In addition, the absolute error in the −10%FL from the onset position was same as that in the onset position. In this experiment, the −10%FL from the onset position was about 25%FL from the hindmost point of the heel. The heel pressure distribution was reported to change substantially approximately near 25%FL position from the hindmost point of the heel and the perceptibility of this change was highly accurate[5]. Hence, the perceptibility in the −10%FL from the onset position was high as same as that in the onset position.

Finally, it is clear that the absolute error at the onset position is specifically small. Therefore, the standing position near the onset position should be perceived accurately by the large change in sensory information associated with patellar movement while backward leaning. Two types of participants were confirmed in our previous study: those whose patellas move during backward leaning and those whose patellas do not move during backward leaning[9]. In this study, fourteen participants whose patellas move during backward leaning were selected. However, there are healthy individuals whose patellas do not move during backward leaning. It is considered that they also have no deficiency to perform backward leaning in daily living. Therefore, the individuals whose patellas do not move may use other sensory modalities to perceive backward leaning posture.

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