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Original Article

Establishing Reference Values and Detectable Changes for Ankle Joint Position Sense among Healthy Young Adults: Assessment of Sensory Precision

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Abstract: [Purpose] This study aimed to establish reference values and determine detectable changes in ankle proprioceptive sense among healthy young adults, and to analyze the relationship between plantar two-point discrimination and perception of ground level, with the goal of establishing applicable standards for clinical settings. [Subjects and Methods] Thirty-one healthy young adults were enrolled in this study which developed an assessment method for ankle proprioception using a single-leg unstable platform. The plantar two-point discrimination abilities of the participants were also evaluated. [Results] High intra-rater reliability was confirmed for both the ankle joint position sense and plantar two-point discrimination tests. A Minimum Detectable Change (MDC) was established, and a significant correlation was found between the two-point discrimination of the great toe and ankle joint position sense. [Conclusion] This study provides an objective and reliable method for assessing ankle joint positioning in healthy young adults. The two-point discrimination ability of the great toe was shown to play a significant role in ankle joint position sense, suggesting that improvement in plantar sensory function is crucial, particularly in individuals with impaired ankle joint position sense.

Keywords: Ankle proprioception, Two-point discrimination, Minimum Detectable Change

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I. INTRODUCTION

Ankle proprioception is crucial for maintaining balance and ambulation, making its assessment important for facilitating the perception of bodily position and movement, which are essential for motor control and stability[1) 2)]. Deshpande [3)] et al. previously confirmed the reliability and validity of ankle proprioceptive measurements, and highlighted their importance in fall prevention and rehabilitation, particularly in older adults and individuals with motor impairments. Methods for assessing ankle proprioception include joint position sense, movement detection, and threshold sensation tests, which determine an individual's ability to accurately perceive the joint position and movement. However, Hillier[4)] et al. identified accuracy issues in many assessment methods, while Huang[5)] et al. noted that advanced technological assessments present challenges in conventional clinical settings. The practicality of using a robotic device for the objective measurement of ankle joint position sense and kinesthesia was validated through a small-scale study on healthy adults, confirming its feasibility [6)]. However, the robotic device used in this study was designed to allow for the precise measurement of ankle joint position sense and kinesthesia. This device is equipped with advanced sensors and control systems and enables precise motion control and data collection. Consequently, the challenge with robotic assessment systems used in research is that they generally require substantial financial investment. As such, there is a growing need for a simple and objective method to measure ankle joint position sense in clinical settings.

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Recent studies on use-dependent plasticity have emphasized the critical role of proprioceptive feedback in neuromotor system reorganization and recovery. This feedback is vital for detecting changes in floor surfaces, and significantly influences posture and gait, leading to a growing focus on proprioceptive acuity tests in clinical and research settings. Position-matching tasks such as ipsilateral and contralateral matching are commonly used to assess proprioceptive accuracy, each with unique challenges and implications for understanding proprioceptive function and its role in motor control [7].

The direct assessment of floor levelness is paramount in fall prevention strategies, because the perception of ground level is closely related to an individual's balance ability, and directly contributes to reducing fall risk. In a previous study, Franco[8, 9] demonstrated that a two-point discrimination assessment of the foot sole is essential for evaluating fall risk, highlighting the significance of this sensory function assessment.

The objectives of this study were twofold: first, to develop an ankle proprioception assessment method using a single-leg unstable platform, examine its clinical effectiveness through the Minimum Detectable Change (MDC), and establish applicable standards for clinical settings. Second, we analyzed the relationship between the foot sole two-point discrimination and ground level perception, enhancing the assessment of self-perceived floor levelness. This will deepen our understanding of the relationship among ankle proprioception, plantar sensory function, and neuromotor control, laying a strong foundation for more effective fall prevention strategies.

II. PARTICIPANTS AND METHODS

1. PARTICIPANTS

Thirty-one healthy young adults (17 males, mean ± standard deviation; age 20.6 ± 0.6 years; height 165.2 ± 7.6 cm; weight 57.4 ± 8.9 kg) volunteered to participate. Participants' characteristics are presented in Table 1. All the participants were informed of the experimental procedures and provided informed consent. The exclusion criteria included any self-reported neurological, vestibular, or musculoskeletal conditions that could interfere with balance. This study was approved by the Research Ethics Committee of Chubu Gakuin University (approval no. C20-0019-2).

Table. 1. Characteristics of subjects.

Characteristics	n=31
Male (%)	51.6
Age (years)	20.6 ± 0.6
Height (cm)	165.2 ± 7.6
Weight (kg)	57.4 ± 8.9
BMI (kg/m^2)	20.9 ± 1.8
Left-footed / right-footed	2 / 29

Data are mean ±SD.

2. METHODS

2.1. Proprioception test

Ankle joint position sense was measured using a rectangular swinging platform (Fumagalli Corp., Italy) (Fig. 1). The participants' lateral malleoli were placed on the red line of the board. During the trials, an experimenter ensured that the heel did not move away from the relief. To ensure that the participants remained relaxed during and after the positioning of their reference ankles, a physical therapist visually checked for the absence of muscle contractions in the reference ankle and provided feedback to the participants when they were not relaxed. If there was doubt about the muscle contraction status, the physical therapist palpated the concerned muscle for confirmation. The position of the lower extremities was standardized and maintained for all conditions with the thighs positioned horizontally and the knee joints at approximately 90° of flexion. The ankle joint position sense of the dominant foot was measured [10].

Conscious perception of the horizontal position of the ankle joint was measured by placing the dominant ankle joint on a uniaxial unstable board under closed-eye-seated conditions. The board was then passively tilted from the maximum plantar flexion at a velocity of approximately 1°/s during dorsiflexion. The operator held and manipulated the unstable board in the foremost and rearmost positions. No feedback was provided during the measurements, and all assessments were performed by the same evaluator. The participants were asked to indicate when they perceived the board as being horizontal. A similar procedure was performed with the patient in maximum dorsiflexion position.

Measurements were performed twice for each condition using a digital goniometer (EFU008; AUTOUTLET Corp., China) in four randomly selected trials. The average absolute error from the horizontal position of the board (0°) across all four measurements was used as a measure of the ankle joint position sense. An ankle joint position sense value closer to 0° indicates better accuracy, whereas larger values indicate poorer performance.

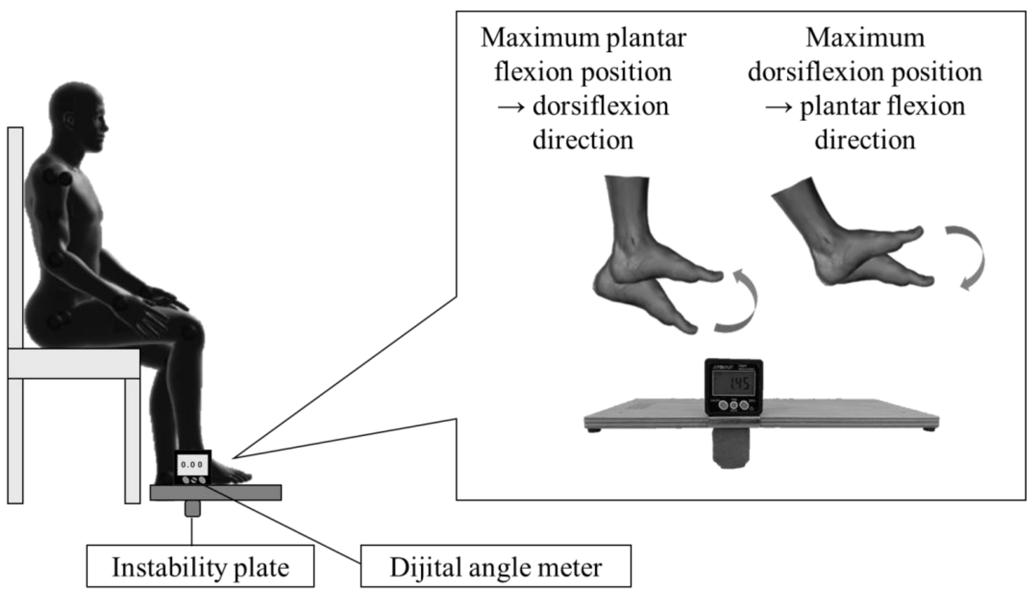

Fig. 1. Experimental setup.

2.2. Two-point discrimination for the ankle joints

To assess somatosensory function, the two-point discrimination of the plantar surface was performed using a disk-criminator (Kashima Seisakusho Co., Japan). Measurements were conducted with the participants in the supine position on the bed and bar ankle joint. The minimum distance at which the two points could be distinguished was measured at the hallux, fifth metatarsal head, and central part of the heel. To determine the two-point discrimination distance, the same distance was applied three times, and the minimum distance with two or more correct responses out of the three trials was recorded[11]. Participants were instructed to respond with "2" if they perceived two points of contact and "1" if they perceived one point. Prior to the measurements, the participants were thoroughly familiarized with the orientation of the single- and double-point contacts to ensure adequate recognition. Using the method of constant stimuli[12], ascending sequences starting from the minimum distance (defined as the point at which participants transitioned from perceiving one point to perceiving two points) and descending sequences starting from easily perceivable distances were conducted twice. The average of these four measurements was considered as the perceptual threshold.

2.3. Statistics

Statistical analyses were conducted using R Commander software. Pearson's correlation analysis was performed to assess the linear relationships between variables. We conducted a multiple regression analysis to identify the factors influencing ankle joint position sense. The dependent variable was ankle joint position sense, while the independent variables included two-point discrimination of the great toe, two-point discrimination of the ball of the little toe, and two-point discrimination of the heel. Furthermore, a stepwise multiple regression analysis was conducted to investigate the factors influencing ankle joint position sense. The significance level was set at 5%.

The MDC for the horizontal position sense and two-point discrimination sense of the ankle joint were calculated from the respective means and standard deviations. The MDC serves as an indicator of the magnitude of measurement error based on the variability of repeated measurements. Changes within the MDC indicate a measurement error, whereas changes beyond the MDC are interpreted as changes due to the intervention. Additionally, the intra-class correlation coefficient (ICC) was calculated as an index of intra-rater reliability. A value of 0.7 or higher indicates agreement among multiple measurements conducted repeatedly [13].

III. RESULTS

Assessment of the examiners' intra-rater reliability for the horizontal position sense of the ankle joint revealed that high reliability was achieved for both measurement methods, meeting the criteria (Table 2). Intrareader reliability for two-point discrimination was achieved for all sites, including the great toe, ball of the little toe, and heel, meeting the criteria for high reliability (Table 2).

The minimum detectable change (MDC) for the horizontal position sense of the ankle joint was 1.90°, while on the two-point discrimination, the MDCs were 1.82 mm for the great toe, 2.02 mm for the ball of little toe, and 2.19 mm for the heel (Table 2).

Table. 2. Reference values for plantar two-point discrimination sensation and ankle joint position sense.

		Mean	Standard diviation	MDC	ICC (1, 2)
Two-point discrimination (mm)	Great toe	9.23	2.71	1.89	0.94
	Base of little toe	10.31	2.52	2.04	0.91
	Heel	11.31	1.99	2.55	0.82
Ankle joint position sense (°)	Total	2.99	1.73	2.04	0.71
	Dorsiflexion	2.82	1.89	1.94	0.88
	Plantarflexion	3.15	1.84	2.13	0.86

The correlations between the horizontal position sense of the ankle joint and the two-point discrimination (great toe, ball of the little toe, and heel) are shown in Table 3. Two-point discrimination of the great toe was moderately to strongly correlated with the two-point discrimination of the ball of the little toe, ankle joint position sense (total) (Fig. 2), ankle joint position sense (dorsiflexion), and ankle joint position sense (plantarflexion). The two-point discrimination for the ball of the little toe was weakly to moderately correlated with the two-point discrimination of the heel, the ankle joint position sense (total), the ankle joint position sense (dorsiflexion), the ankle joint position sense (plantarflexion). However, two-point discrimination of the heel did not correlate with the ankle joint position sensing results. The ankle joint position sense (total) was strongly correlated with the ankle joint position sense (dorsiflexion), the ankle joint position sense (plantarflexion). Ankle joint position sense (dorsiflexion) was strongly correlated with ankle joint position sense (plantar flexion). The results of the multiple regression analysis with ankle joint position sense (total) as the dependent variable are presented in Table 4. In the multiple regression analysis, the two-point discrimination threshold of the great toe significantly influenced the perception of the ankle joint position, with an R-squared value of 0.45 and an adjusted R-squared value of 0.391. This indicates that approximately 45% of the variance in the perception of ankle joint position can be explained by the model, specifically by the two-point discrimination threshold of the great toe. The adjusted R-squared value of 0.391 suggests that the model remains robust even with the accounting for the number of predictors, highlighting the significant role of the great toe's two-point discrimination in this context.

Table. 3. Correlations between plantar two-point discrimination sensation and ankle joint position sense.

	Great toe (mm)		Ball of little toe (mm)		Heel (mm)	Total (°)		Dorsiflexion (°)		Plantarflexion (°)
Great toe (mm)	-									
Ball of little toe (mm)	0.48	**	-							
Heel (mm)	0.38		0.28	*	-					
Total (°)	0.66	***	0.42	*	0.33	-				
Dorsiflexion (°)	0.52	**	0.38	*	0.31	0.92	***	-		
Plantarflexion (°)	0.70	***	0.40	*	0.29	0.92	***	0.71	***	-

**P* <0.05, ***P* <0.01, ****P* <0.001

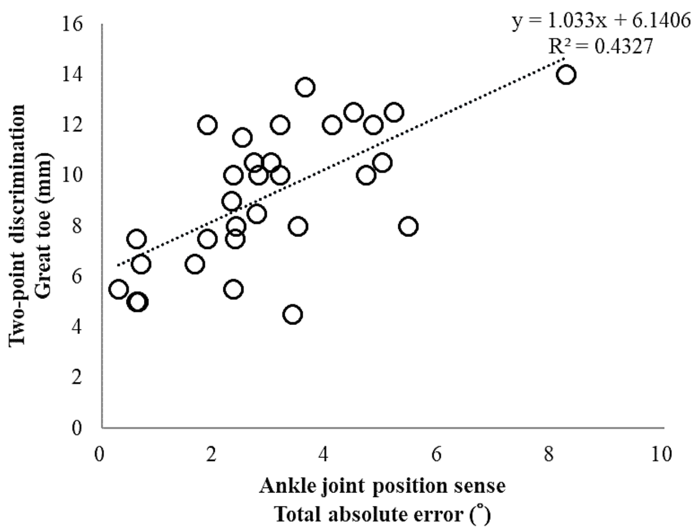

Fig. 2. Correlation between two-point discrimination of the great toe and total ankle joint position sense.

Table. 4. Stepwise multiple linear regression analysis of ankle joint position sense (total).

	Explanatory variable	Standardize regression coefficient (β)	Standard error	*P-value*	95% CI	VIF
	Great toe	0.36	0.11	<0.01	[0.139, 0.584]	1.43
Two-point discrimination	Base of little toe	0.09	0.11	0.45	[-0.144, 0.317]	1.32
	Heel	0.07	0.13	0.63	[-0.210, 0.342]	1.20
	R-squared = 0.45, Adjusted R-squared = 0.39					

IV. DISCUSSION

The results of this study identified the MDC and baseline values for subjective foot-level position sense in young healthy individuals. Our experiments revealed that two-point discrimination of the great toe plays a significant role in ankle joint position sense. Given that the great toe is the most sensitive site for two-point discrimination, this suggests that this limb is utilized to perceive the level of the board, indicating its potential for recognizing the ground level. Regarding the validity of the current measurements, high inter-rater reliability was observed for both ankle joint position sense and all two-point discriminations of the plantar foot. This indicates that the current measurement method is reliable. Furthermore, the established MDC values for these tests enhance their clinical applicability, allowing the identification of meaningful changes in somatic sensation over the course of treatment and in response to interventions. Previous research has not presented the MDC for passive ankle joint position sense; however, it has been demonstrated that the average measurement error in healthy individuals is 3 degrees [14]. This indicates that the measurement error in this study is like the previously reported results.

Furthermore, the significant correlations observed between the two-point discrimination of the great toe and other parts of the foot, as well as various aspects of ankle joint position sense, emphasize that the inputs from plantar tactile pressure sensitivity and proprioception act in concert to maintain the somatosensory function of the ankle joint. These correlations suggest that improvements in one area of sensory discrimination or proprioception may influence other inter-linked sensory functions.

Multivariate regression analysis further revealed that the two-point discrimination of the great toe played a significant role in ankle joint position sensing. Therefore, interventions aimed at improving the sensory function of the plantar great toe are of primary importance in individuals with impaired ankle joint position sense.

Tactile pressure sensitivity is particularly acute in the plantar region, particularly in the great toe. The great toe is believed to have a high sensory acuity, largely because it plays a crucial role in maintaining balance during standing and walking[15]. Additionally, the tactile pressure sensitivity of the plantar foot, which comes into contact with the ground or floor, plays a vital role in detecting the level and hardness of the ground during walking or while standing[16]. Pressure sensors in the plantar foot can sense various ground characteristics. This suggests that the great toe of the plantar foot may be involved in perceiving the levelness of an unstable board upon which it is grounded.

The measurement method for ankle joint position sense used in this study did not require expensive equipment or a PC, making it clinically feasible to perform these simple measurements. Furthermore, the range of errors in young healthy individuals in perceiving the levelness of a board (or floor surface) using ankle joint position sense were clarified. One limitation of this study is that the measurements of ankle joint position sense were conducted by the same person and the board was manipulated passively, which might not precisely reflect its control. However, this method is significant for evaluating ankle joint position sense because it enables reliable and easy measurements in a clinical setting. Future research should be extended to multiple populations, including community-dwelling elderly, frail elderly, orthopedic patients, and individuals with stroke-induced hemiplegia. Another limitation of this study includes its sole focus on young and healthy individuals; thus, it excluded individuals with floating toes. We assessed intra-rater reliability but not inter-rater reliability. Future studies should address these limitations by considering these aspects.

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The authors declare no conflicts of interest regarding the publication of this article.

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