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Original article

VALIDITY AND RELIABILITY OF A DIGITAL INCLINOMETER IN ANKLE JOINT POSITION SENSE ASSESSMENT

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ABSTRACT

The ankle joint position sense is crucial for human movements. To date, several measurement tools have been used in assessing joint position sense. However, they are mostly high-costly and involve a complex system demonstrating a major limitation to be used in the field. This study employed an affordable and portable digital inclinometer to examine the angle of ankle movement in joint position sense testing. This study aimed to evaluate the criterion validity of the digital inclinometer, as well as intra- and inter-rater reliability of ankle joint position sense using a digital inclinometer. Twenty-one participants (23.86+3.98 years) without a history of lower limb injury were recruited. The ankle joint position sense was evaluated by two testers using a digital inclinometer that was attached to right dorsum of the foot to detect angle changes. The digital inclinometer's criterion validity was examined by comparing the recorded degree of movement using an isokinetic dynamometer and a digital inclinometer. Dorsiflexion and plantarflexion angles were recorded by the digital inclinometer in the right ankle and used for intra- and inter-rater reliability analysis. Intraclass correlation coefficient (ICC) models were used to determine reliability.

The Bland-Altman plots demonstrated the point distribution within the interval to validate the digital inclinometer validity. The intra-rater reliability of the joint position sense test exhibited moderate in 1st rater (ICC 0.525-0.610), and poor in 2nd rater (ICC 0.398-0.478). Inter-rater reliability was poor agreement between two raters (ICC 0.43-0.48). The digital inclinometer can be considered as a valid, accurate, and portable tool for measuring the ankle range of motion, and ankle joint position sense in an individual rater. However, the multiple-rater reliability was poor to moderate. This low inter-rater reliability may be due to inaccurate placement of the inclinometer on the foot or a different level in the testing experience.

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KEYWORDS: Digital Inclinometer/ Intra-Rater Reliability/ Inter-Rater Reliability/ Joint Posistion Sense/ Ankle

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INTRODUCTION

Balance control is important in daily life activities, sports, and exercises. The control integrates sensory inputs from vision, vestibular system, and proprioception[1]. Proprioception has been defined as the ability to integrate sensory signals from various mechanoreceptors to determine body position and movements [2] so that the continuous movements that are specific to different environments can be created. Ankle proprioception plays a crucial role in balance control and used in risk of fall and ankle injury assessment. Ankle injury is the most common sports injury[3] that is frequently associated with jumping and a sudden change of directions. This injury can lead to other negative consequences including the deficit of muscle strength, postural control, and decreased sensation of joints[4]. These impairments lead to poor balance ability which is an intrinsic factor of heightened injury risk[2]. Additionally, poor ankle proprioception altered muscle co-contraction including ankle plantar flexors and dorsiflexors, that associated with a higher risk of an ankle injury during landing[5]. Therefore, an early detection of joint position sense or proprioception deficit will help identify the performance deficiency of the somatosensory system. This information will be beneficial for injury prevention and rehabilitation and training protocol development.

Proprioception is generally evaluated by measuring joint position sense (JPS). JPS is derived from a complex array of information arriving at the brain from several different sources, including articular mechanoreceptors, cutaneous afferents, and muscle receptors[6]. JPS is required to maintain the dynamic stability of the joint. Even though it is convenient to assess the joint sensation by detecting the joint positions, the JPS assessment accuracy may be limited by the measurement tool. To date, the widely accepted tools with high reliability and validity include isokinetic dynamometers and electrogoniometers[7,8]. However, these instruments are high-cost, bulky, immobile, and require a complex and time-consuming installation procedure. These factors are a great limitation to both clinical and field test settings[9]. The previous studies have provided the inclinometer which is low-cost and convenient to use in evaluating JPS. The measurement tools were valid and reliable to assess the joint position sense of the knee[10] and shoulder joints[11]. In this regard, it may be an advantage for JPS assessment in the ankle joint which is also important in movement. Therefore, this study aimed to develop an economical and portable digital inclinometer that is field test-friendly and as valid as an isokinetic dynameter[12] for an ankle JPS assessment. Additionally, this study aimed to evaluate the intra- and inter-rater reliability of the joint position sense test using the digital inclinometer.

METHODS

Participants

The participants were screened for eligibility based on the following inclusion criteria: males and females aged between 18 and 35 years old, willingness to participate in the testing and had normal joint position sense (JPS). To test position sense, the participant is placed in the supine position and is asked to close their eyes. The big toe is grasped at the sides between the thumb and index finger and extended and flexed. The patient is asked, "Is the toe pointing up or down?", on completion of each movement.[13] Participants were excluded if they had any acute lower extremity injury, ankle deformity, or a history of neurological or neuromuscular disease. The test protocol of the current study was approved by the Institutional Review Board of the Mahidol University (MU-CIRB 2021/417.2809) and all participants provided written informed consent prior to participation.

Instrumentation

A digital inclinometer (DI) was used to measure ankle joint position sense. DI consists of two main parts: a display screen and a control circuit. The control circuit consists of a microcontroller (Arduino UNO) and an Accelerometer/Gyro sensor that measures the angular velocity (GY-521 Accelerometer/Gyro module; MPU6050).

Procedures

Criterion validity of the Digital inclinometer

To explore the validity of the digital inclinometer, we used criterion validity using an isokinetic dynamometer (Biodex multi-joint system 4™) as the gold standard. The DI was attached to the arm of the isokinetic dynamometer before both DI and the isokinetic dynamometer were set to zero (shown in Figure 1). The dynamometer arm was moved in 6 different angle positions (repeated 10 times at each angle 10, 15, 20, 30, 45, 60 degrees), and then the angle obtained from DI was recorded. After determining that DI was a valid tool, the DI was used to assess ankle JPS.

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Figure 1. The digital inclinometer's validity testing

Ankle joint position sense test reliability using digital inclinometer

The intra-rater and inter-rater reliability of the ankle JPS test using DI were evaluated in dorsiflexion and plantarflexion positions. The two raters were trained to measure the degree of ankle movement using a goniometer and a digital inclinometer in dorsiflexion and plantar flexion with a physical therapy teacher for 5 hours (1-hour practice per day for 5 days) until they are proficient in measuring. Additionally, they practised instructing participants to move their feet. The DI was attached to the dorsum of the foot at the 2nd metatarsal bone as shown in figure 2. Then, the participants lay in the supine position and closed their eyes with a blindfold. Testers placed the participant's foot to a target angle (dorsiflexion 15^{o} and plantar flexion 30^{o}) and maintained the position for 10 seconds. During these 10 seconds, participants were instructed to concentrate on the position of the foot. Next, the ankle was moved back to the starting position (neutral position). After that, the participants were instructed to reproduce the tested ankle placement to the target position[14]. The reproduced angle was recorded by DI.

The ankle JPS were tested for 2 directions in random order. Two trials at each of the two directions to the target angle were tested. All direction tests were performed in the same manner. The testing directions were randomly chosen. The amount of degrees was recorded for analysis. There were 2 testers who investigated ankle JPS using DI (the first and second tester). The minimum 10-15 resting period was assigned between the first and second tester's assessment. Both testers were blinded, which means they were unaware of the testing protocol and were not presented in the room at the same time during the measurement.

Figure 2. Ankle joint position sense test using digital inclinometer (DI)

STATISTICAL ANALYSIS

The criterion validity of the DI compared to the isokinetic dynamometer was determined by Bland-Altman analysis, along with 95% limits of agreement. The intraclass correlation coefficient (ICC) test with 95 % confidence interval was applied to examine intra-rater reliability (ICC 3,1) of each tester and inter-rater reliability (ICC 2,2) of both testers in measuring ankle JPS using DI. The ICC interpretation was categorized as follows: poor (<0.5), moderate (0.5–0.75), good (0.76–0.90), or excellent (>0.90) reliability[15]. All statistical analyses were performed using JAMOVI software[16], and significance was determined at $p < 0.05$.

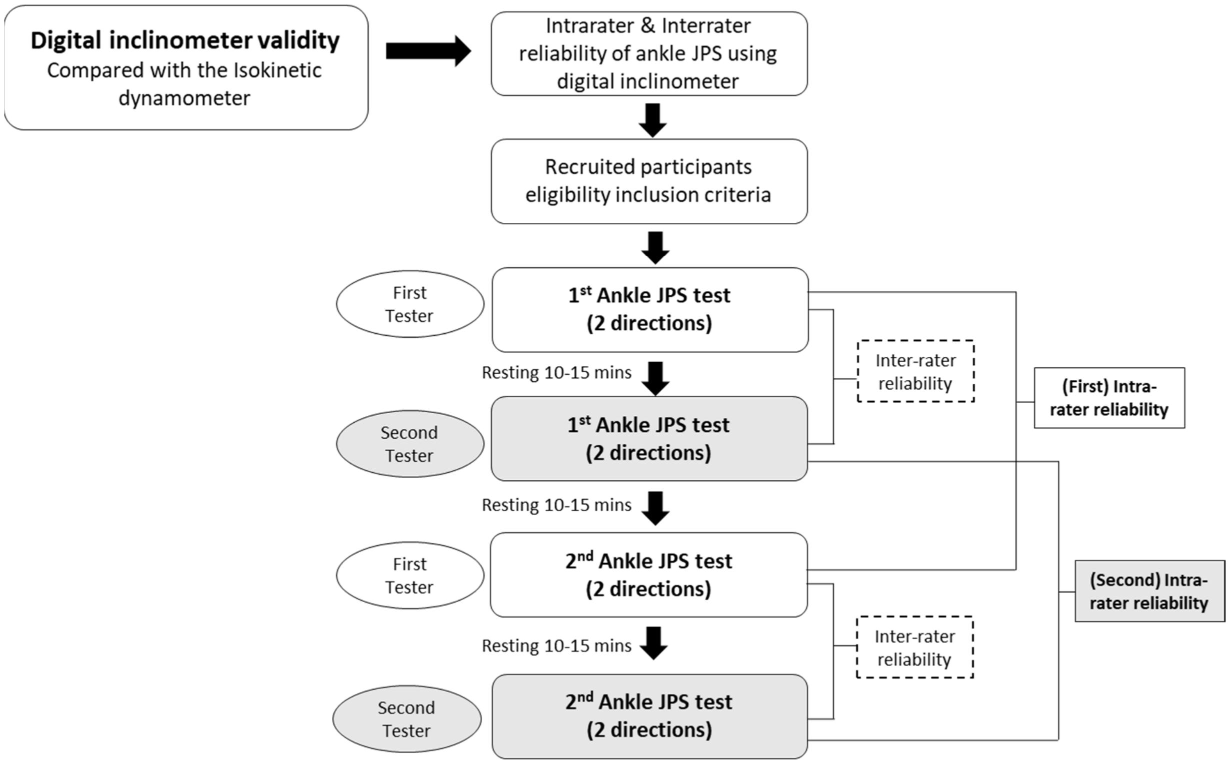

Figure 3. Flow diagram

RESULTS

Demographic data of the participants

Twenty-one healthy adults from different university campuses in the local and metropolitan areas voluntarily participated in this study (9 males and 12 females; age 23.86 ± 3.98 years, weight 68.38 ± 9.63 kg, and height 171.43 ± 8.03 cm).

Criterion Validity

Based on the Bland-Altman plot, the scatterplot graph showed the points were distributed within the interval. There were a few points detected on the bias line, however, the majority of the points lay within the limits of agreement. Furthermore, there were points on the line of equality between isokinetic dynamometer and digital inclinometer (DI). The p-value reported from the Bland-Altman analysis revealed no significant difference between the recorded degrees from the isokinetic dynamometer and DI (p = 1.00).

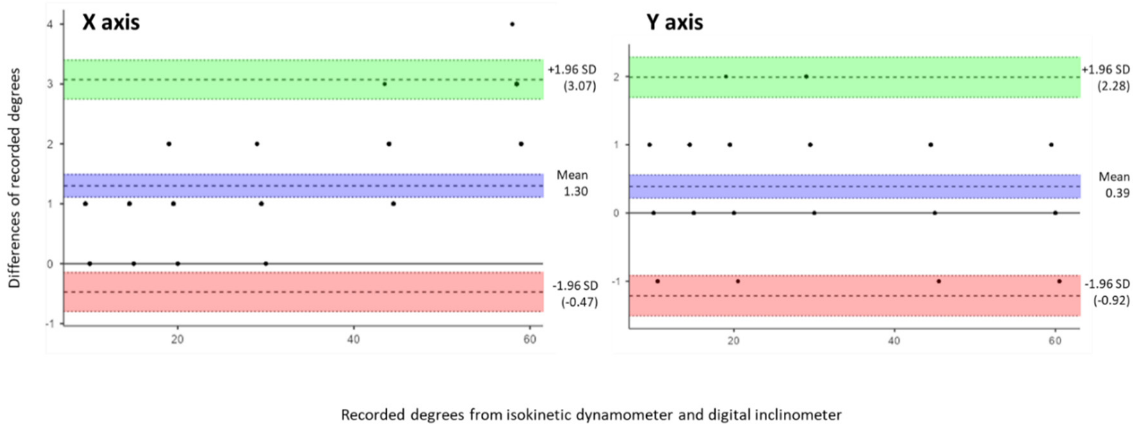

Figure 4. Bland-Altman plot for isokinetic dynamometer and digital inclinometer

Reliability

The mean values and standard deviations of reproducing ankle movements (degree) for each tester, ICC, and 95% CI are presented in Table 1. The intra-rater reliability of the first tester in the ankle JPS test using DI showed moderate reliability in both directions (ICC: DF = 0.610, PF = 0.525). However, the second tester exhibited poor intra-rater reliability (ICC: DF = 0.398, PF = 0.478). Also, poor inter-rater reliability (ICC: DF = 0.435, PF = 0.480) was observed.

Table 1. Intra-rater and Inter-rater reliability results

Ankle JPS test direction	Mean of reproducing ankle movement (degree)	Intra-rater ICC (3,1)	95% CI	
			Lower	Upper
Dorsiflexion 15°				
A	19.98 ± 5.48	0.610	0.473	0.699
B	18.33 ± 5.34	0.398	0.175	0.602
Inter-rater A – B		0.435	0.304	0.555
Plantar flexion 30°				
A	33.38 ± 7.26	0.525	0.312	0.686
B	31.26 ± 7.76	0.478	0.205	0.694
Inter-rater A – B		0.480	0.306	0.612

Statistical analysis: Intraclass correlation coefficient (ICC) test with 95 % confidence interval

DISCUSSION

This study investigated the validity of the digital inclinometer (DI) for measuring ankle movement in the sagittal plane. The intra- and inter-rater reliability in the ankle joint position sense (JPS) test using DI was investigated. The findings of this study showed that the digital inclinometer is a valid tool for assessing ankle range of motion during sagittal plane movement in comparison with the reference standard (isokinetic dynamometer). However, the results of intra- and inter-rater reliability showed poor to moderate reliability in JPS test using DI.

As ankle proprioception gives sensory information for joint position adjustment to maintain balance, especially during recovery from injury[17], the proprioception deficit reduces the ability to continuously monitor motor sequences that interferes with motor coordination and balance ability. This leads to postural instability and poor sports performance. To date, few portable tools have been validated to measure the ankle range of motion including an inertial device (WIMU™)[18], iPhone applications[19,20], and electronics goniometers[7,21,22]. The results of these studies in terms of equipment's validity were similar to our study. It means that these developed devices can accurately measure the angle of movement. However, collecting accurate JPS information has been a challenge, especially in clinical and field settings due to several limitations of the measurement tools including their cost, portability, and installation protocol. To overcome the limitations in assessment and investigate the validity and reliability of JPS using DI, therefore, this study developed the digital inclinometer.

In the development of DI, we employed the microcontroller consisting of Arduino (UNO) and GY-521 Accelerometer/Gyro module (MPU6050). The DI would calculate the changed angle from raw data obtained from the accelerometer base on the triple-axis tilt calculation theory[23]. Accordingly, these approaches could be applied in the development of a measurement tool, which is valid as same as the standard and could modify into an appropriate size. The DI's size was made smaller using 3D printing. Therefore, these approaches would be reliable, appropriate size, and low-cost equipment. Consequently, our results exhibited high concurrent validity suggesting that DI can be considered as a valid instrument for field evaluation, allowing to obtain immediate feedback for adjustable in the planning of training or rehabilitation program. In addition, the size of DI in this study was smaller than other products and can be attached to the dorsum foot during the assessment. Furthermore, the device was synchronized with an application, which real-time records the changing ankle angle, so the accurate JPS data can be accurately collected throughout the testing. Regarding these advantages, we suggest that health professionals should consider incorporating DI for a rapid ankle JPS test.

For the intra-rater and interrater reliability of the ankle joint position sense test using a digital inclinometer, there was investigated across between two examiners. The results showed that inter-rater reliability was poor in both dorsiflexion and plantar flexion. While the intra-rater reliability was moderate in the first tester and poor in the second tester. Though the results of validity of the digital inclinometer were comparable with the reference standard, the reliability of JPS test using a digital inclinometer was not as expected. Possible reasons for this low inter-rater reliability may be either due to the different placement of an inclinometer on the foot or the testing experience of raters. The variability of touching areas on the foot could result in testing inaccuracies, due to the pressure affecting the sensation perception. Therefore, training hours in this study may not be sufficient for the joint position sense test. Consequently, the lack of experience could result in excitement and nervousness, which could alter their performance during testing. Additionally, the JPS test in this study was assessed in the open chain, which may result in an error occurring between testing.

This study has some limitations. Firstly, the validity of DI during JPS as compared to an isokinetic dynamometer was not evaluated. Secondly, when the DI was attached to the dorsum of the foot, the inaccuracy of recording may occur due to the uneven surface. This could affect intra- and inter-rater reliability in JPS test using DI. Finally, only one placement of DI was investigated in this study. Future studies may explore other placements which may provide higher accuracy of the measurement such as setting the location of the DI to be 2 cm from the 2^{nd} metatarsophalangeal bone.

The future development of this device includes an application of the device to measure ankle inversion and eversion angle as well as other JPS evaluations such as the knee, elbow and scapular. Developing DI into a convenient wireless device will be needed so the JPS can be assessed during a wider range of movements. The potential practical application of DI is accurately recording the angle of ankle movement, which may also be applied in various tasks. Furthermore, extending the ranges of variables such as velocity and acceleration to be recorded by the device is also beneficial. The use of wearable sensors is necessary for human activity monitoring when it comes to maximizing athletic performance, injury prevention, as well as monitoring physical activity in clinical, pathological, and ageing populations[24].

CONCLUSION

The digital inclinometer (DI) can be considered as a valid tool that can be used as an accurate and portable instrument to measure the ankle range of motion and joint position sense for an individual rater. The measurement of ankle joint position sense using DI by each rater was considered reliable in both dorsiflexion and plantar flexion. However, the multiple raters reliability was poor to moderate in both directions. Possible explanations for the low inter-rater reliability include the varied placement of an inclinometer on the foot and the different testing experiences between raters. Future studies should provide an inclinometer placement practice to the examiners prior to the JPS evaluation to improve the inter-reliability.

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