

Validation of Joint Position Sense of Dorsi-Plantar Flexion of Ankle Measurements Using a Smartphone

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Objectives: This study evaluated and validated the reliability of smartphones as measuring equipment for the dorsi-plantar flexion of ankle joint position sense (JPS) ability. **Methods:** The subjects were 20 healthy young students in their 20s. We confirmed the concurrent validity by comparison with existing electrogoniometer data. The reliability of the smartphone was confirmed using the test-retest method. **Results:** In the case of dorsiflexion, there was no significant difference between the smartphone and electrogoniometer groups ($p > 0.05$). Regarding the correlation, it was significantly high ($r = 0.65, p < 0.05$), and ICC(3,1) was good (ICC(3,1) = 0.79). For the case of plantar flexion, there was no significant difference between the smartphone and electrogoniometer groups ($p > 0.05$), the correlation was significantly high ($r = 0.69, p < 0.05$), and the ICC(3,1) was very good (ICC(3,1) = 0.82). In the case of dorsiflexion, there was no significant difference between test and retest ($p > 0.05$), the correlation was intermediate ($r = 0.59, p < 0.05$), and the ICC(3,1) value was good (ICC(3,1) = 0.74). For plantar flexion, there was no significant difference between test and retest ($p > 0.05$), the correlation was significantly high ($r = 0.63, p < 0.05$), and the ICC(3,1) was good (ICC(3,1) = 0.76). **Conclusions:** The results showed that smartphones provide high validity and reliability as measurement equipment for JPS of dorsi-plantar flexion of the ankle. Finally, the study also considers that smartphone-based JPS measuring methods may replace the traditional and expensive methods that are currently being used for the same purpose.

Keywords: Proprioception, Smartphone, Ankle, Equipment, Validation Studies

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I. Introduction

Joint position sense (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 [1,2]. From the clinical point of view, an appropriate JPS is important to maintain the dynamic stability of the joint [3]. Joint position sense is important for the prevention of musculoskeletal injuries and diseases, such as ankle sprain and osteoarthritis, and for rehabilitation from central nervous system diseases and injuries, such as stroke and spinal cord injury. In particular, ankle movements are important for a normal coordinated gait and smooth sinusoidal oscillation of the center of gravity [4].

Furthermore, the ankle is one of the most frequently injured joints of the human body [5,6]. Therefore, the measurement of ankle JPS is essential [7-9].

According to the work by Hwang et al. [10], isokinetic dynamometers are reliable for the measurement of proprioception. On the other hand, Bronner et al. [11] showed that the electrogoniometer has high reliability and validity, and it is therefore used for the movement of joints. Previous studies reported in the literature have suggested that both isokinetic dynamometers and electrogoniometers can be used as JPS measurement tools [12]. However, the penetration rate of the isokinetic dynamometer is low in clinical practice due to its cost, size, and weight. Therefore, it can be used for cases in which space is not a limitation. According to Kwon and Park [13], the weight of the lever arm of an isokinetic dynamometer may be discouraging in the assessment of proprioception. The electrogoniometer is smaller than the isokinetic dynamometer, but it also has a low penetration rate in clinical practice due to its high price. Although these types of measuring equipment are reliable and valid, they are not portable and their installation is time-consuming [14]. To overcome these issues and save time and cost, smartphones that include several sensors have been suggested as measurement and evaluation equipment [15-18]. Moreover, recent studies have reported on the reliability of smartphones for these purposes. For instance, the measurement of shoulder range of motion using a smartphone was reported by Lim et al. [19], and the measurement of heart rates using a smartphone was investigated by Matsumura and Yamakoshi [20]. In addition, the measurement of balance using a smartphone was investigated by Han et al. [21]. However, the reliability and validity of smartphones to measure JPS of dorsi-plantar flexion of the ankle have not been studied so far.

Therefore, this study was conducted to contribute to the development of smartphone-based measurement of JPS of dorsi-plantar flexion of the ankle in an easy and economical fashion. Finally, the results obtained with this new method are compared to those obtained by the electrogoniometer, whose reliability and validity have already been proved.

II. Methods

1. Subjects

The sample size was calculated a priori using the software G*Power ver. 3.1.5. We considered a statistical power of 95% and a significance level (i.e., α -value) of 5%, and we referred to the results of Kim et al. [14]. The minimum number of subjects to be considered was 17 people, while

the number of subjects in order to account for the drop-outs was 20. Ethical approval for the study was granted by the Institutional Review Board of U1 University (Bioethics 2016-15). All subjects were fully informed of the objectives and methods of the study beforehand and gave informed consent to participate in the experiments. Only subjects with no musculoskeletal or neurological disorders affecting the upper or lower extremities, lesions, or history of surgery of the spine or upper or lower extremities were considered. A total of 20 healthy subjects were randomly selected from a group of people who responded to flyers that were strategically placed throughout the university campus and also to word-of-mouth. All subjects received information about the procedures and signed an informed consent form before the testing session.

2. Measuring Equipment

The electrogoniometer used in this study was operated with a MP150 (BIOPAC System Inc., Santa Barbara, CA, USA) data acquisition system. This equipment is a basic device that digitizes the signal of the joint angle, and the extracted data is processed using a digital signal analysis program (AcqKnowledge 4.1, BIOPAC System Inc.) that ran on a personal computer.

The smartphone used in this study was a Galaxy S4 (SHV-E330S; Samsung, Suwon, Korea), and the application was Sensor Kinetics Pro 2.1.2 by INNOVENTIONS Inc. (Houston, TX, USA). We also used Mobizen (Rsupport, Seoul, Korea) to display the output information from the smartphone and to synchronize and record it on the laptop.

3. Measurement Method

The test-retest method was used for sample 2, and all the measurements were performed at the same rate. The subjects in sample 2 were analyzed in two sessions separated by an interval of 7 days. We used an average value of 3 times the measurements in the test-retest analysis. The person who conducted the experiment was the same during the entire process, and he or she was experienced in the use of electrogoniometers and smartphones [22].

The JPS assessment was performed on the subjects positioned in a sitting posture, and their maximum dorsiflexion and plantar flexion ranges of motion of the dominant side ankle were determined. The electrogoniometer was attached to sensors located at the front and back of the lateral malleolus of the ankle joint. The smartphone was attached to the facies plantares with Velcro (ankle support; Bioplus, Seoul, Korea) (Figure 1). During the JPS measurement, the subjects

wore shorts and used eye patches and ear plugs to minimize sensible compensation. The subjects were only allowed to move the ankle following given instructions, while the rest of the body remained at rest. Before the measurement process started, the subjects were given an explanation of the entire process. Then, a demonstration of the measurement process was shown, followed by a smooth start of the process itself. The subjects were asked to maintain a position at a random target degree within the range of motion of their own ankle dorsiflexion, and they were asked to remain in that position for 10 seconds. After this, they were asked to return to the initial position and progressively move towards the target degree. JPS of dorsiflexion and plantar flexion of ankle joint retests were also processed, thus following the test-retest method.

4. Statistical Analysis

The software SPSS ver. 12.0 (SPSS Inc., Chicago, IL, USA) was used for the statistical analysis. A significance level of 5% ($p < 0.05$) was set. Each smartphone and electrogoniometer used an average value for the middle 4 seconds within the total of 10 seconds of the manual setup and active reproduction. Subsequently, we calculated the absolute difference between the values of the manual setup and active reproduction. Finally, we analyzed the absolute value. The data exhibited a normal distribution ($p > 0.05$), as verified by the Kolmogorov-Smirnov test, and it was presented in terms of its mean and standard deviation values. In this study, a matched-pairs t -test was carried out to determine the statistical differences between the electrogoniometer and smartphone data, namely, between each measurement of the



Figure 1. Attached smartphone and electrogoniometer.

test-retest. In addition, the matching Pearson correlation was used to determine the correlation between the electrogoniometer and smartphone data, between each measurement of the test-retest. The reliability and validity was determined with the intraclass correlation coefficient (ICC(3,1)) for intra-raters [23,24]. ICC values were considered poor when below 0.20, fair from 0.21 to 0.40, moderate from 0.41 to 0.60, good from 0.61 to 0.80, and very good from 0.81 to 1.00 [23].

III. Results

1. General Characteristics of the Subjects

The general characteristics of the subjects are presented in Table 1.

2. Validity of JPS of Dorsi-Plantar Flexion of Ankle Obtained Using a Smartphone

In the case of dorsiflexion, there was no significant difference between the smartphone and electrogoniometer groups ($p > 0.05$). Regarding the correlation, it was significantly high ($r = 0.65$, $p < 0.05$) and ICC(3,1) was good (ICC(3,1) = 0.79).

For the case of plantar flexion, there was no significant difference between the smartphone and electrogoniometer groups ($p > 0.05$). The correlation was significantly high ($r = 0.69$, $p < 0.05$), and the ICC(3,1) was very good (ICC(3,1) = 0.82) (Table 2).

Table 1. General characteristics of the subjects

	Value
Gender (male:female)	10:10
Age (yr)	22.95 ± 4.05
Height (cm)	170.65 ± 8.29
Weight (kg)	72.50 ± 16.62

Table 2. Validity of smartphones for measuring JPS of dorsi-plantar flexion of the ankle

	Dorsiflexion	Plantar flexion
Electrogoniometer (°)	3.71 ± 1.63	4.37 ± 1.97
Smartphone (°)	3.58 ± 1.72	3.87 ± 2.04
Paired t -test (p -value)	-0.39 (0.70)	-1.41 (0.17)
Pearson rho r (p -value)	0.65 (<0.01**)	0.69 (<0.01**)
ICC(3,1) (95% CI)	0.79 (0.47-0.92)	0.82 (0.54-0.93)

Values are presented as mean ± SD.

JPS: joint position sense, ICC: intraclass correlation coefficient, CI: confidence interval.

** $p < 0.01$.

Table 3. Reliability of smartphones for measuring JPS of dorsi-plantar flexion of the ankle

	Dorsiflexion	Plantar flexion
Test (°)	3.58 ± 1.72	3.87 ± 2.04
Retest (°)	3.52 ± 1.46	3.97 ± 2.28
Paired <i>t</i> -test <i>t</i> (<i>p</i> -value)	0.21 (0.84)	-0.53 (0.60)
Pearson rho <i>r</i> (<i>p</i> -value)	0.59 (<0.01**)	0.63 (<0.01**)
ICC(3,1) (95% CI)	0.74 (0.34–0.90)	0.76 (0.40–0.91)

Values are presented as mean ± SD.

JPS: joint position sense, ICC: intraclass correlation coefficient, CI: confidence interval.

***p* < 0.01.

3. Reliability JPS of Dorsi-Plantar Flexion of Ankle Obtained Using a Smartphone

In the case of dorsiflexion, there was no significant difference between test and retest ($p > 0.05$). The correlation was intermediate ($r = 0.59$, $p < 0.05$), and the ICC(3,1) value was good (ICC(3,1) = 0.74).

For plantar flexion, there was no significant difference between test and retest ($p > 0.05$). The correlation was significantly high ($r = 0.63$, $p < 0.05$), and the ICC(3,1) was good (ICC(3,1) = 0.76) (Table 3).

IV. Discussion

Losses in the proprioceptive system reduce the ability to continuously monitor motor sequences and interfere with coordination and balance. In particular, JPS of dorsi-plantar flexion of the ankle is important for maintaining balance during recovery [25,26].

The goal of this study was to evaluate the reliability and validity of smartphones as measuring equipment for JPS of dorsi-plantar flexion of ankle. The results of this study indicate that smartphones provide high validity and reliability as measurement equipment for JPS of dorsi-plantar flexion of the ankle.

Since home-based physical therapy is necessary [27], measurement equipment must also be easily portable. Thus, in the healthcare sector, including physical therapy, smartphones can be broadly applied.

Some difficulties were faced in obtaining the data because there are no applications for the measurement of JPS. Therefore, efforts were directed towards the verification and consolidation of a huge amount of data. If an exclusive application to test JPS is to be developed, a thorough manual test should be made both in audio and video formats. Moreover,

the computed test results should be automatically linked to the cloud to enable users to compare them with previous results. An intuitive interface should be provided so that users can easily use it in clinical tests. Moreover, the user interface should allow for the representation of graphs through which test results can be easily explained to patients.

In this study, the smartphones were attached to the facies plantares because it was more difficult to attach them to the instep or both sides of the feet. In contrast, smartphones attached to the facies plantares cannot be manipulated through their touch screens. For this reason, smartphones were remotely controlled with a laptop. The development of an exclusive JPS test application will therefore depend on the difficulty of touch screen operations. When the JPS of dorsi-plantar flexion of the ankle is measured using a smartphone, the method must be accurate. An electrogoniometer only measures the movement of the ankle to which the device is attached. However, when a smartphone is used, any joint except the ankle can be connected to the device since the movement is the same, in principle. On the other hand, the registered data was slightly influenced by the bending or straightening of the knee.

In this study, test-retest was performed in two sessions separated by an interval of 7 days. This interval was selected to represent the timeframe over which the measurement is likely to be used by clinicians to assess changes in JPS [28].

We confirmed the concurrent validity by comparing the results with those obtained by an electrogoniometer, whose validity has already been proved. According to Relph and Herrington [29], there were no significant correlations for the validity of knee JPS with image captures in the case of flexion; however, there were significant correlations in the case of extension. Hence, it can replace high-end equipment to a certain extent. In the present study, the electrogoniometer and smartphone concurrent validity was satisfactory. In addition, Vuillerme et al. [30] reported that the knee JPS method showed a reliability of 0.75 points. In the present study, the reliability of measurements of JPS of dorsi-plantar flexion of the ankle obtained using smartphones was more than 0.74. Therefore, when applied to fixed joints, except for the ankle, a smartphone can be used to measure the JPS of dorsi-plantar flexion of the ankle. In this regard, this study is valuable because a protocol to process the measurement and an automatic data extraction scheme have been presented. Moreover, it highlights the demand for the development of applications for JPS with save features and the main factors to be developed in this regard.

As the present study was conducted on young subjects only,

our results cannot be generalized to older individuals or to those with shoulder conditions. There has been no previous study on the reliability and validity of measuring JPS of dorsi-plantar flexion of the ankle using smartphones. Therefore, the study was aimed at healthy young people. Based on the results obtained in this study, a further study will be planned with patients as subjects.

In conclusion, the evaluation of the reliability and validity of smartphones as measuring equipment for JPS of dorsi-plantar flexion of the ankle was the main goal of this study. The results showed that smartphones provide high validity and reliability for this purpose. Finally, the results of this study also suggest that smartphone-based JPS measuring methods may replace the traditional and expensive methods that are currently being used for this purpose.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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