I. Introduction

Proprioceptive sense refers to the ability to perceive the spatial position or movement of a limb without visual stimulation. It provides information on all joint exercises involved in body movement to the central nervous system to enable normal motion control and to protect joints from external damage.

Deterioration of proprioceptive sense results in a loss of joint position sense and causes functional instability of joints, thus adversely affecting movement and balance ability and increasing the risk of injury. This deterioration causes secondary diseases accompanied by severe tissue damage or chronic pain.

Proprioceptive sense is more important than vision for the elderly to maintain balance, and a decrease in proprioceptive sense increases their risk of falls. In addition, proprioceptive physical activity has been shown to improve balance control in the elderly.

Proprioceptive sense is very sensitive; therefore, its measuring equipment requires sufficient validity. Although conventional specialized motion analysis equipment and electronic goniometers have been used to test joint position sense, these are expensive and have a disadvantage of requiring a separate dedicated space.

Many smartphone-based measurement tools have been developed in recent years and smartphones have greatly improved the medical system. With the advances of this technology, inexpensive gyroscope sensors that can directly measure body shake have been developed and are being used to measure balance ability. Smartphones are also useful measurement devices because they are commonly available, are not limited in time and space, and are combined with various sensor technologies. In particular, smartphones have built-in three-axis acceleration sensors and gyroscope sensors. The acceleration sensor is essentially a sensor that measures how much force the object is receiving based on the earth's gravitational...
acceleration. The sensor value output by the acceleration sensor extracts the acceleration value generated in the smartphone in the rotated state. And it shows the rotation status of the smartphone just before moving. Waddell et al. studied the accuracy of smartphone-based measurement in comparison to the goniometers that are used in clinical practice. Alawna et al. and Dos Santos studied the correlation between the application of general goniometers and those mounted on smartphones to measure knee and ankle joint ranges of motion. In the future, clinical studies will increasingly use smartphones, and measurement using smartphones is anticipated to be widely applied in physical therapy and all medical fields.

However, currently, there are insufficient position sense tests of joints using smartphones. In response, the present study was conducted using smartphones to investigate the agreement and relevancy in position-sense measurement of each leg joint in subjects of various ages.

### II. Material and Methods

#### 1. Subjects

A total of 69 subjects were selected based on the following selection criteria:

1) no history of orthopedic surgery
2) no damage to the central nervous system or vestibular system
3) understands the purpose of the present study and voluntarily agrees to participate

The exclusion criteria were having a history of fracture of the lower extremity and the pelvis, diseases affecting balance, and not understanding the evaluator’s commands. The general characteristics of the study subjects are shown in Table 1. The present study was approved by the ethics review committee of U1 University (approval number: U1IRB2019-10).

#### 2. Application and smartphones

The application used in this study was Sensor Kinetics pro (Ver.2.1.2, INNOVENTIONS Inc., US, 2015) (Figure 1). This application can simultaneously record acceleration and gyroscopic values resulting from smartphone movement. The sampling rate was set at 50 Hz and the application was run on Galaxy S8 (Galaxy S8, Samsung, Korea) smartphones (Figure 2).

A ready-made sports armband (Sports Armband 360 season3, ImCommerce Korea Co., Ltd.) was used to attach the smartphones to the sole and shin, with Velcro extensions used when the length was insufficient (Figure 3). A sleeping mask was worn during measurement to prevent the patient from seeing.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender (M/F)</td>
<td>25 / 44</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>161.81 ± 8.18</td>
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<tr>
<td>Weight (kg)</td>
<td>62.01 ± 13.37</td>
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<tr>
<td>Age (years)</td>
<td>53.72 ± 21.30</td>
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<tr>
<td>Age group</td>
<td></td>
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<tr>
<td>21-30 (%)</td>
<td>20.29</td>
</tr>
<tr>
<td>31-40 (%)</td>
<td>8.70</td>
</tr>
<tr>
<td>41-50 (%)</td>
<td>10.14</td>
</tr>
<tr>
<td>51-60 (%)</td>
<td>26.09</td>
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<tr>
<td>61-70 (%)</td>
<td>8.70</td>
</tr>
<tr>
<td>71-80 (%)</td>
<td>10.14</td>
</tr>
<tr>
<td>81-90 (%)</td>
<td>15.94</td>
</tr>
</tbody>
</table>

Table 1. Subject characteristics
3. Measurement methods
The smartphones were wrapped for skin protection and attached to the soles of the feet and posterior area of the shins on the dominant sides using an arm-band that can rotate 90°. Once attached, the smartphones were rotated to be aligned in parallel to the shin/sole axis. In addition, the subjects were asked to close their eyes for position sense measurement. Sleeping masks were worn to ensure that they were unable to see. During the ankle and knee joint measurements, the subjects sat on chairs placed at a height such that their feet did not touch the floor. The hip joints measurements were performed while the subjects were standing (Figure 4) (Figure 5) (Figure 6), with the subjects permitted to hold a support without leaning their full body weight to prevent injury. The ankle, knee, and hip joints were measured in that order. The subjects actively performed a full range of joint flexion and extension as well as hip joint abduction and adduction. The subjects were instructed to manually set an arbitrary angle and remember it, rest for 10 seconds, and to reproduce this angle. During the measurement, neither the subjects nor the examiners spoke, except for the examiner to provide verbal instructions necessary for the measurement. While the subjects reproduced the arbitrary angle they had set, the joint angles were extracted using smartphones, twice daily for two days for each joint for a total of four measurements. Previous study results confirmed that postural control improved throughout the day according to the circadian rhythm of body temperature and sleepiness/vigilance.\(^9\) In order to reduce error, it was measured once each morning and once each afternoon for two days.

4. Analysis methods
Excel (Microsoft Office 365 ProPlus, v.1907) was used to process the data for statistical analysis with a significance level of 0.01. In the case of the soles, the joint position-sense data of the ankle joints were calculated. In the case of the shin, each data obtained by calculating the joint position-sense data of the knee and hip joints were converted to csv file format and were sent to a computer drive or email. The converted csv files were then downloaded and statistically analyzed. To determine the degree of agreement between the first and second measurements, intraclass correlation coefficients (ICCs) were calculated in R-3.6.0 (v.19.4.26). The effect sized were calculated using G-Power 3.1.

III. Results

1) The ankle joint dorsiflexion and plantarflexion showed a high correlation between the first and second measurements ($r>0.70$, $p<0.01$) and a very high degree of agreement (ICC $>0.75$) (Table 2).

2) The knee joint flexion and extension showed a moderate correlation between the first and second measurements ($r>0.05$, $p<0.01$) and a very high degree of agreement (ICC $>0.75$) (Table 3).

3) The hip joint flexion and extension showed no correlation between the first and second measurements ($r<0.30$, $p>0.05$) and a low degree of agree-
Reliability Test of Smartphone-based Leg-Joint Position-Sense Measurement in People of All Ages

Table 2. Reliability of ankle joint position sense

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean±SD</th>
<th>Difference</th>
<th>Pearson correlation</th>
<th>ICC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dorsiflexion-Plantarflexion</td>
<td>2.29±3.214</td>
<td>1.43±1.529</td>
<td>0.758** &lt; 0.01</td>
<td>0.849***</td>
</tr>
</tbody>
</table>

Table 3. Reliability of knee joint position sense

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean±SD</th>
<th>Difference</th>
<th>Pearson correlation</th>
<th>ICC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexion-Extension</td>
<td>1.85±1.929</td>
<td>1.09±1.069</td>
<td>0.692** &lt; 0.01</td>
<td>0.818***</td>
</tr>
</tbody>
</table>

Table 4. Reliability of hip joint position sense

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean±SD</th>
<th>Difference</th>
<th>Pearson correlation</th>
<th>ICC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexion-Extension</td>
<td>1.63±1.471</td>
<td>1.29±1.538</td>
<td>0.208 &gt; 0.05</td>
<td>0.341</td>
</tr>
<tr>
<td>Adduction-Abduction</td>
<td>2.72±2.877</td>
<td>1.68±2.076</td>
<td>0.488* &lt; 0.01</td>
<td>0.646***</td>
</tr>
</tbody>
</table>

The present study was conducted using smartphones to assess the reliability of the position-sense measurement of each leg joint in people of various ages. Smartphones are convenient to carry, can be purchased at a low price, and can quickly and easily perform measurements. Previous research has shown that the results of the study confirmed high reliability, of measurement of the position senses of the ankle and knee joints using a smartphone. A recent study found that smartphone application was appropriate to measure pelvic tilt and thoracic kyphosis angle.

Position sense was measured in the ankle, knee, and hip joints using three-axis acceleration and gyroscope sensors built into smartphones. Manual setting-active reproduction was performed to check the test-retest reliability. Perlau et al. suggested that a method that examines the passive range of motion during an open-chain exercise was the most accurate method to test proprioceptive sense, thus providing the basis for the test method used in the present study.

In the results of the present study, ankle joint dorsiflexion and plantarflexion showed a high correlation between the first and the second measurements (r>0.70, p<0.01) and a very high degree of agreement (ICC>0.75). The knee joint flexion and extension showed a moderate correlation between the first and second measurements (r>0.50, p<0.01) and a very high degree of agreement (ICC>0.75). However, the hip joint flexion and extension showed no correlation between the first and second measurements (r<0.30, p>0.01) and showed a low degree of agreement (ICC<0.40). Finally, there was a low correlation in hip joint abduction and adduction between the first and second measurements (r>0.30, p<0.01) and a high degree of agreement (ICC>0.60).

Unlike the ankle and knee joint measurements, the
hip joint measurement showed a low degree of agreement, most likely because the measurement was taken in a standing position, thus requiring an increased subject sense of balance. Ferreira et al.\(^{23}\) reported that the hip joint is an important structure for weight bearing as well as static and dynamic balance; moreover, the hip joint exhibits minute movements in a standing position and is important for postural control.\(^{24}\) The present study measured hip joint motion while the subjects were standing and did not adjust for their sense of balance. Future studies should perform these measurements in a more stable posture and adjust for factors that may affect the results to allow for more accurate measurements. In the results of the present study, hip flexion-extension was not significant due to the posture requiring balance, but abduction-adduction was significantly. The frontal plane movement is lateral leg raises, which are comprised of adduction and abduction of the hip. When hip joint measuring, the support was next to the hip joint (not ahead). Therefore, we would guess that abduction-adduction is in a more advantageous position than flexion-extension.

In the present study, measurements were made using gyroscope sensors, which require more time for data extraction because no dedicated application was available for proprioceptive sense measurement. Therefore, the results of this study provide basic data for developing an application that provides both convenient use and easy data extraction. There has been no previous study on the reliability and validity of measuring joint position sense of lower limbs using smartphones in all ages. This study was aimed at healthy people. Subsequent studies based on these results will test the joint position sense of subjects with various diseases.

In summary, the present study investigated the reliability of measuring the position sense of each leg joint in people of various ages using smartphones. The results of the study confirmed high reliability, of measurement of the position senses of the ankle and knee joints but not the hip joint. These findings confirmed that smartphones can be used as a measuring device for leg-joint position sense.

References


