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# Reliability and Validity of Knee Joint Angles of the Elderly Measured Using Smartphones

Background: With the increasing elderly population, the need for gait analysis of these elderly individuals is also increasing. Most devices are costly and not portable; however, smartphones using built-in sensors capable of measuring motion and are easily available.
Objectives: To examine the reliability and validity of knee joint angles of the elderly using smartphone measurements during walking.
Design: Quasi-experimental research.
Methods: Sixteen elderly people, aged 65+ and living in Daejeon and Chungbuk, South Korea, participated in the study. Electrogoniometers and smartphones were attached to the thigh and the side and front of the shank of each subject, respectively, using double-sided tape, an arm band, and an elastic band. Each subject completed two sets of at least seven gait cycles (14 steps).
Results: Both the smartphones and electrogoniometers exhibited high agreement in terms of their primary and secondary measurements (ICC>.75). The agreement between the smartphones and electrogoniometers was also high in terms of both the primary and secondary measurements (ICC<.60).
Conclusion: These results indicate that smartphones can be costly equipment cannot, even though they cannot completely replace existing clinical-grade devices. Their utility is emphasized herein for measuring knee joint angles of the elderly during walking.

Keywords: *Smartphone; Gait; Elder; Knee*

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## INTRODUCTION

According to 2019 data from Statistics Korea, the proportion of population aged 65 or older in South Korea is expected to rise sharply from 14.9% in 2019 to 46.5% by 2067. Moreover, approximately half the elderly present reports on declining health. Fatigue, pain, sleep disorders, depression, and obesity, as well as chronic diseases, increase with age.[1] A factor highly related to these complex problems of aging is walking,[2-4] and the higher falling risks associated with changing walking patterns.[5,6] In particular, aging reduces range of motion (ROM) in the knee joint[7] and decreases one's ability to perform physical activities[8] due to unnecessary motions[9] and increased pain,[10] even in case of the healthy elderly. This decrease in physical activities further accelerates aging and aggravates chronic diseases, thereby forming a vicious circle that negatively affects knee motion during walking. Therefore, measuring the knee joint ROM during walking is meaningful for the elderly.[11]

If walking is objectively measured, it is possible to track the functional changes of the elderly and verify intervention techniques based on objective data.[12] In many clinical settings, however, information is collected via simple observation that requires only minimal equipment and time for evaluating the walking behavior of the elderly or other patients. This results in low reliability as well as limitations due to the subjective opinions and evaluations of the measurers.[13,14] As such, gait analysis devices that provide accurate and objective information have been developed and used[15] but are expensive and require a separate space for installation. Extraneous time must also be invested, and experts are required for installation and analysis. These make it difficult for the devices to be used in most clinical settings, and objective gait analysis is not conducted in home-based treatment at all.[16]

Since a recent rise in the development of sensor technologies, devices that can replace costly equipment have become more readily available. Acceleration sensors were used to analyze the walking behaviors of the elderly and were reported to have high validity,[17] but these devices are still difficult to introduce because they require costly software packages.[18]

Meanwhile, even inexpensive or outdated smartphones are equipped with accelerometers and various other sensors suitable for measuring the angles of segments and joints in the human body, such as gyroscope sensors and magnetic field sensors.[19] According to a recent survey report from the PEW Research Center in the U.S., the median value of smartphone ownership in 18 major countries was 76% of the population, but was as high as 95% in South Korea.[20] Furthermore, smartphone availability among the elderly is significantly increasing in South Korea. The rate increased from 51.3% in 2013 to 91.3% in 2017 for people in their 50s, from 19% to 73.6% for those in their 60s, and from 3.6% to 25.9% for people aged 70 or older.[21] In other words, if walking behavior can be measured using smartphones, equipment for these measurements can be easily acquired at little or no cost Additionally, measurers or subjects can use smartphones with ease because they are familiar with them.[16]

As such, the U.S. Food and Drug Administration Center for Device and Radiological Health has advised that it is necessary to properly examine and verify the use of smartphones for clinical evaluation on the basis of their safety and effectiveness.[22] In recent years, researchers have verified the reliability and validity of gait analysis using smartphones or have raised a need for such research. Previous studies focused on young and healthy adults; however, research is required for those without normal walking patterns, such as for the elderly and other patients.[23] In this context, this study was conducted to examine the reliability and validity of measuring the knee joint angles of elderly people using smartphones during gait cycles.

## SUBJECTS AND METHODS

### Research Subjects

The subjects of this study were elderly volunteers, aged 65 or older, living in Daejeon and Chungbuk, South Korea. Sixteen subjects having no experience of falling in daily life due to diseases of vision or vestibular nerve systems and no musculoskeletal and neurological diseases were recruited from the population. This study was conducted after receiving signed, informed consent from each participant, who voluntarily agreed to participate the study.

This study was approved by the Institutional Review Board of the U1 University (U1-2018-1). Table 1 shows the general characteristics of the subjects.

**Table 1.** General characteristics of subjects (N=16)

| | Mean ± SD |
|---|---|
| Sex (M/F) | 9 / 7 |
| Age (year) | 74.81 ± 4.00 |
| Height (cm) | 159.50 ± 5.19 |
| Weight (kg) | 63.19 ± 5.12 |

### Research Facilities and Equipment

This study was conducted in a rehabilitation hospital in Daejeon, South Korea and in an elderly nursing home in Yeongdong, Chungbuk, South Korea.

The smartphone model Galaxy S8 (Samsung, KR) was used in this study to measure the angles of segments and to take videos while attached to the participant's leg. The tablet MediaPad M3 Lite (Huawei, CN) was used to record the international standard time while taking videos.

The 360 season 3 arm band (Imcommerce, CN) was used to attach the smartphone to the participant's leg. After attaching the smartphone, the arm band allowed for a rotation 180° to the left and right (total 360°).

The application Sensor Kinetics pro (Ver.2.1.2, INNOVENTIONS Inc, US) was installed in the smartphone to extract the values of the built-in sensors. Sensor Kinetics pro can simultaneously extract kinematic values such as acceleration and gyroscope values from the built-in sensors in the smartphone. It converts the values into rotation values and records the international standard time at the time of extraction. The data recorded and stored in the smartphone is converted into the ".csv" format and transferred via e-mails, cloud storage, and SNS for computer analysis.

The sampling rate was set to 50 Hz, and the international standard time was used to synchronize the values extracted from each smartphone.

To measure the changes in knee joint ROM (in degrees), the BN-GON-150-XDCR (BIOPAC Systems, Inc., USA) was utilized. The collected data were processed with the Acknowledge 4.1 (Biopac System, USA) software.

### Measurement Method

Electrogoniometers were attached to the side of the left thigh and shank using double-sided tape and covered with the arm band that was used to attach the smartphones.

The smartphones were attached to the front of the left thigh and shank of each subject using the arm band. The smartphones were attached in a landscape mode and aligned with the coronal plane so that the pitch value was -90°.

While each subject maintained a standing posture, the knee angle was measured using a goniometer and the result was used as a reference value for the values measured using the electrogoniometer and the smartphone.

The subjects were instructed to perform seven gait cycles (14 steps) and the measurement scenario was also captured using the tablet that displays the international standard time. While the subjects walked, the segment angles of the thigh and shank were extracted using the smartphones. The values were converted into ".csv" format and transferred to cloud storage. The knee joint ROM measured using the electrogoniometer was also stored and transferred to cloud storage immediately after measurement. The primary and secondary measurements were performed on a daily basis.

### Analysis Method

The values collected through the electrogoniometers and those measured and calculated with the smartphones were synchronized based on the larger changes in motion which occurred at the start of a gait cycle in comparison to the very tiny changes in motion while standing.

After examining the recorded video and international standard time, the moment at which the left heel touched the floor was set as the start point of the gait cycle and the next moment at which the left heel touched the floor again was set as the last point of the cycle. The reference values measured from the standing pose before walking were subtracted from the values measured at each point in time to calculate segment angles. After assuming the time interval for each gait cycle was 100%, data were extracted at 5% intervals of the cycle, and 21 data sets were extracted for each cycle. At each 5% interval, the knee joint angle was calculated by subtracting the shank segment angle from the thigh segment angle. The difference between the maximum and minimum values of each of the thigh segment angles, shank segment angles, and knee joint angles extracted or calculated during walking was obtained to determine the ROM for each item.

For the statistical analysis in this study, data were processed and analyzed using Excel (Microsoft Office 365 ProPlus, v.1707) and R (3.5.2). The significance level was set to .05. To examine the agreement between the primary and secondary measurements as well as the agreement between the electrogoniometers and smartphones, the intraclass correlation coefficient (ICC (2,1)) of the ROM of each item was examined.

## RESULTS

### Leg Segment ROM Agreement

Both the thigh segment ROM and the shank segment ROM exhibited an extremely high agreement between the primary and secondary measurements performed using the smartphones (ICC>.75), as seen in Table 2.

**Table 2.** Segment angle agreement

| | Mean ± SD (°) | | |
|---|---|---|---|
| | Primary | Secondary | ICC |
| Thigh | 20.736 ± 5.594 | 20.964 ± 5.404 | .983* |
| Shank | 35.066 ± 6.771 | 35.839 ± 7.031 | .987* |

*ICC>0.75

### Knee Joint ROM Agreement

For the knee joint ROM, both the electrogoniometers and smartphones exhibited a very high agreement in terms of the primary and secondary measurements (ICC〉.75), as seen in the third row of Table 3, and the agreement between the electrogoniometers and smartphones was also high for both the primary and secondary measurements (ICC〉.60) (rightmost column in Table 3).

**Table 3.** Joint angle agreement

| | Mean ± SD (°) | | |
|---|---|---|---|
| | Primary | Secondary | ICC |
| Electrogoniometer | 34.326 ± 11.155 | 35.121 ± 11.512 | .997** |
| Smartphone | 34.542 ± 6.513 | 33.846 ± 7.431 | .976** |
| ICC | .687* | .646* | |

*ICC〉0.60, **ICC〉0.75

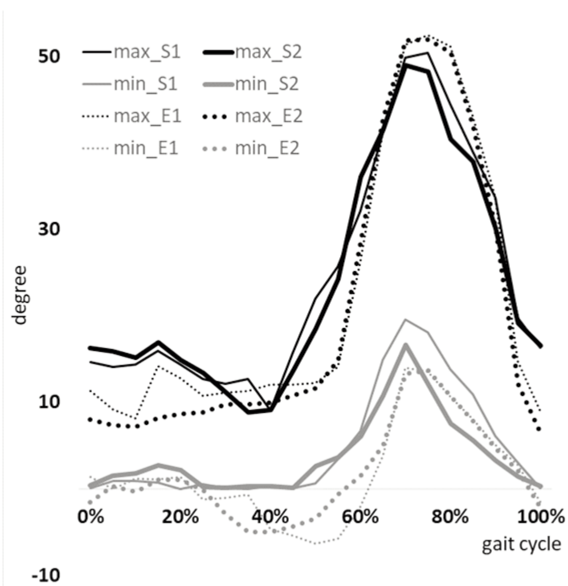


**Figure 1.** Joint angle agreement

## DISCUSSION

This study tested the reliability and validity of using smartphones to measure the knee joint angles of the elderly while walking. For the electrogoniometers used in this study, the degree of agreement between the primary and secondary measurements was .99 or higher. In addition, the degree of agreement between the smartphones and electrogoniometers was .60 or higher. Domenic[24] claims that a degree of agreement is .60 or higher is 'excellent'. These results indicate that smartphones can be useful for home-based (or remote) healthcare services where costly equipment cannot be used or when portability is essential, even though they cannot completely replace highly reliable electrogoniometers.

To prevent the rotation values extracted from the smartphones from being reversed when the thigh or shank moved to the back of the human body, the recorded axis of the smartphone (parallel to the vertical axis of the leg segment) was set to be perpendicular to the long axis of the human body. This is because when the segments in the human body were measured with the recorded axis of the smartphone aligned with the long axis of the human body, either the hip joint was subjected to hyperextension in the standing posture or the rotation values extracted from the smartphone sensors were incorrectly reversed to positive numbers when the knee joint was bent and the segments moved backwards forming angles.[25]

In this study, the most difficult task was attaching the smartphone to the thigh of each subject when installing the measuring devices. This is because the thigh is thicker towards the top of the leg and thinner towards the bottom, and its cross section is not circular but rectangular.[26] The arm band worn on the thigh in the same way as on the shank can easily slide down to the knee. As such, a wider medical band, which has higher elasticity and friction than the existing arm band, was used for reinforcement. Besides, the thigh band was connected to a waist-band, but it appeared to have affected the walking patterns of the subjects. The application of highly adhesive tape or non-slip tape was tested, but was found not suitable for tests on the human body due to the risk of damaging the skin of the subjects. Considering the purpose of this study, only research devices, including the arm band and elastic band, that could be easily acquired were used, except for the electrogoniometers. If research is conducted in the future on measuring dynamic motion with a smartphone attached to the thigh, it is expected that a customized elastic tool that covers the entire thigh will be developed or applied.

In an earlier study that analyzed the walking behavior of young and healthy people using smartphones,[25] it was reported that the reliability of measuring the knee joint was .626. Although that study, which presented the average joint angle of the gait cycle, cannot be directly compared with this study, which presented the range of motion during the gait cycle, a degree of agreement as high as .976 was observed in this study. This could be because the elderly participants reduced their walking speed to offset their low motor control capabilities and to improve the accuracy of their motion.[27-29] In addition, it appears that the ground reaction force also decreased as their walking speed decreased. In other words, it is believed that a higher degree of agreement was achieved as participants may have slowed their walking speed to reduce shock caused by the unnecessary shaking of the smartphones. For this, it is necessary to conduct further research on young and healthy people by performing measurements while walking speed is varied.

A drawback of this study is that it focused only on the knee joint. Although it was necessary to attach a smartphone to the foot to measure the ankle joint, this could not be performed because the attachment of a hard smartphone to the foot could restrict the motion of the foot. Moreover, as rotations occur in various directions, these could not be analyzed using only the values extracted from a smartphone. The analysis of the ankle joint is expected to be possible when small wearable sensors that can be attached to the foot are developed in the future. Furthermore, this study has limitations because it focused only on elderly people from certain areas and did not include people with diseases. It is necessary to conduct further research on people from various areas and those with diseases.

## CONCLUSION

This study was conducted to examine the reliability and validity of the knee joint angles of elderly people measured using smartphones during walking. The subjects of this study were 16 elderly people aged 65 or older living in Daejeon and Chungbuk, South Korea.

It was found that the smartphone exhibited extremely high reliability (ICC〉.75) and high validity (ICC〈.60).

These results indicate that smartphones can be used in the field where costly equipment cannot be available. Further, the portability of these devices is emphasized for measuring the knee joint angles of the elderly during walking even though they cannot completely replace the existing costly devices.

## CONFLICT OF INTERESTS

The author declares that there are no conflicts of interest.

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## REFERENCES

1. Moon S. Gender Differences in the Impact of Socioeconomic, Health-Related, And Health Behavioral Factors on the Health-Related Quality of Life of the Korean Elderly. *The Korea Society of Digital Policy and Management*. 2017;15(6):259-271.
2. Lord S, Galna B, Verghese J, Coleman S, Burn D, Rochester L. Independent domains of gait in older adults and associated motor and nonmotor attributes: validation of a factor analysis approach. *J Gerontol A Biol Sci Med Sci*. 2013;68(7):820-827.
3. Verghese J, Wang C, Lipton RB, Holtzer R, Xue X. Quantitative gait dysfunction and risk of cognitive decline and dementia. *J Neurol Neurosurg Psychiatry*. 2007;78(9):929-935.
4. Hirvensalo M, Rantanen T, Heikkinen E. Mobility difficulties and physical activity as predictors of mortality and loss of independence in the community-living older population. *J Am Geriatr Soc*. 2000;48(5):493-498.

5. Muir BC, Rietdyk S, Haddad JM. Gait Initiation: The First Four Step in Adults Aged 20–25 years, 60–79 years, and 81–91 years. *Gait Posture*. 2014;39(1):490–494.
6. Lee JY, Kim TH. Effects of Changes in the Indoor and Outdoor Environmental on the Walking Speed and Lower Extremity Muscle Activities in People Aged Forty and Older than Seventy Years. *J Korean Soc Phys Med*. 2018;13(4):139–148.
7. Vandervoort AA, Chesworth BM, Cunningham DA, Rechnitzer PA, Paterson DH, Koval JJ. An outcome measure to quantify passive stiffness of the ankle. *Can J Public Health*. 1992;83 Suppl 2:S19–23.
8. Abate M, Schiavone C, Pelotti P, Salini V. Limited joint mobility (LJM) in elderly subjects with type II diabetes mellitus. *Arch Gerontol Geriatr*. 2011;53(2):135–140.
9. Horak FB. Clinical measurement of postural control in adults. *Phys Ther*. 1987;67(12):1881–1885.
10. Powers CM. The influence of altered lower-extremity kinematics on patellofemoral joint dysfunction: a theoretical perspective. *J Orthop Sports Phys Ther*. 2003;33(11):639–646.
11. Brunnekreef JJ, van Uden CJ, van Moorsel S, Kooloos JG. Reliability of videotaped observational gait analysis in patients with orthopedic impairments. *BMC Musculoskelet Disord*. 2005;6(1):17.
12. Jette DU, Halbert J, Iverson C, Miceli E, Shah P. Use of standardized outcome measures in physical therapist practice: perceptions and applications. *Phys Ther*. 2009;89(2):125–135.
13. Stuberg WA, Colerick VL, Blanke DJ, Bruce W. Comparison of a clinical gait analysis method using videography and temporal-distance measures with 16-mm cinematography. *Phys Ther*. 1988;68(8):1221–1225.
14. Norris BS and Olson SI. Concurrent validity and reliability of two-dimensional video analysis of hip and knee joint motion during mechanical lifting. *Physiother Theor Pr*. 2011;27(7):521–530.
15. Webster KE. Validity of the GAITRite walkway system for the measurement of averaged and individual step parameters of gait. *Gait Posture*. 2005;22(4):317–321.
16. Silsupadol P. Reliability and validity of a smartphone-based assessment of gait parameters across walking speed and smartphone locations: Body, bag, belt, hand, and pocket. *Gait Posture*. 2017;58:516–522.
17. Hartmann A, Luzi S, Murer K, de Bie RA, de Bruin ED. Concurrent validity of a trunk tri-axial accelerometer system for gait analysis in older adults. *Gait Posture*. 2009;29(3):444–448.
18. Murphy SL. Review of physical activity measurement using accelerometers in older adults: considerations for research design and conduct. *Prev Med*. 2009;48(2):108–114.
19. Polechoński J, Nawrocka A, Wodarski P, Tomik R. Applicability of Smartphone for Dynamic Postural Stability Evaluation. *Biomed Res Int*. 2019;1–6.
20. Taylor K, Silver L. *Smartphone ownership is growing rapidly around the world, but not always equally*. Pew Research Center. 2019.
21. Jeong YC. Smartphones, catalysts for active media use. *Korea Information Society Development Institute*. 2018;18(14):30.
22. U.S. Food and Drug Administration, Center for Device and Radiological Health. *Policy for Device Software Functions and Mobile Medical Applications Guidance for Industry and Food and Drug Administration Staff*. http://www.fda.gov/downloads/MedicalDevices/DeviceRegulationandGuidance/GuidanceDocuments/UCM263366.pdf. Accessed on September 2019.
23. Longoni L, Brunati R, Sale P, Casale R, Ronconi G, Ferriero G. Smartphone applications validated for joint angle measurement: a systematic review. *Int J Rehabil Res*. 2019;42(1):11–19.
24. Domenic V. Guidelines, Criteria, and Rules of Thumb for Evaluating Normed and Standardized Assessment Instruments in Psychology. *Psychological Assessment*. 1994;6(4):284–290.
25. Lee DH, Han SK. Study on the Reliability of Smartphone-Based Measurements of Leg Segment and Joint Angles During Gait. *J Korean Soc Precis Eng*. 2019;36(3):293–300.
26. Jeong JW. *Orthosis and prosthetics*. Seoul: Daihakseorim; 2018 (ISBN 9788969401717).
27. Kim SJ, Choi BK. The Effect of Age and Speed Tendency on the Anticipation Timing. *Korean J Sport Psychol*. 2000;11(1):19.
28. Jeong TG, Park JS, Choi JD, Lee JY. The effects of sensorimotor training on balance and muscle activation during gait in older adults. *KSPT*. 2011;23(4):29–36.
29. Walker N, Philbin DA, Fisk AD. Age-related differences in movement control: Adjusting submovement structure to optimize performance. *J Gerontol B Psychol Sci Soc Sci*. 1997;52(1):40–52.