J. Phys. Ther. Sci. 34: 433–439, 2022

The Journal of Physical Therapy Science

Original Article

Clinical reliability and usability of smartphone goniometers for hip range of motion measurement

Yugo Takeda, RPT, MS[1)*], Katsuhiro Furukawa, RPT, PhD[2)]

[1)] *Iwaki Yumoto Hospital: 6 Daiyama, Joban-Yumoto-cho, Iwaki City, Fukushima 972-8321, Japan*
[2)] *Faculty of Health Sciences, Iryo Sosei University, Japan*

Abstract. [Purpose] This study aimed to utilize the objective measurements and a survey questionnaire for assessing the intra- and inter-rater reliability, measurement time, and usability of a smartphone application type of goniometer to measure the hip joint angles. [Participants and Methods] Three examiners (physiotherapists) measured the hip joint range of motion using universal and smartphone goniometers on 30 daycare center rehabilitation patients. Reliability was calculated using the intra-class correlation coefficient. The examiners completed a questionnaire survey for assessing the usability of the goniometers. [Results] The intra-rater reliability was high, but the inter-rater reliability was low. Measurement times using the two instruments showed no difference. The usability questionnaire findings suggested that the smartphone goniometer was easier to use than the universal goniometer. [Conclusion] Reliability within the raters was high, but reliability among the raters was low. However, both goniometric devices provided a satisfactory range of motion measurement data when a single evaluator used the same device for all measurements.

Key words: Goniometer, Range of motion, Smartphone-based application

(This article was submitted Dec. 30, 2021, and was accepted Mar. 6, 2022)

INTRODUCTION

Joint range of motion (ROM) is a musculoskeletal parameter frequently measured by physical therapists. Universal goniometers (UG) are commonly used for to measure joint ROM in clinical practice. They come in various sizes and shapes, but they all have the same basic design[1)]. These tools, which have existed for over 100 years [2)], have been used most commonly by physicians and physical therapists as reliable devices to measure ROM and have contributed to accurate diagnosis of patients as well as monitoring of therapeutic efficacy[3, 4)]. Recently, smartphone technologies and healthcare applications (apps) have evolved and are being utilized to measure biometrics[5–7)]. One such example is the advent of goniometry using smartphone apps (smartphone app-based goniometers; SGs). Previous studies on the use of SGs for measuring ROM have suggested good reliability and validity of this technology[8–11)].

In a previous study by the authors[12)], the reliability and usability of the University of Tokyo joint angle gage and a SG were compared in healthy adults, and intra-rater reliability (ICC=0.51–0.89) was demonstrated for the direction of knee and hip flexion with moderate to high results. The results of the questionnaire regarding the usability of the SG revealed that the SG was superior to the UG in terms of operability, visibility, and weight, although setting the measurement axis during ROM measurement was inferior. Usability was defined as the examiner's comfort level for utilizing the SG for a series of operations during ROM measurement, rather than the examiner's comfort with utilizing a smartphone or an application alone. A systematic review conducted by Keogh et al.[13)] revealed that reviewed studies focused on particular joints or specific groups of people; joints assessed were, in the descending order of the number of studies reviewed: the trunk, knees, shoulders,

*Corresponding author. Yugo Takeda (E-mail: yu.takeda021@gmail.com)

hands, elbows, feet, and hip in 12, 9, 6, 4, 3, 3, and 1 studies, respectively. Healthy adults generally served as the population assessed. The review concluded that the available data were insufficient for clinical application.

In a previous study by the current authors[12)], the direction of motion and the subjects were limited, and the results were insufficient for clinical application. Therefore, in order to apply the SG to clinical practice, it is necessary to verify the reliability and usability of the SG in various directions of motion, targeting patients who undergo physical therapy on a daily basis. In particular, the hip joint is very important for daily life activities, such as standing, squatting, climbing stairs, etc. Although the hip joint is a joint that is actively measured, there are very few studies on the usefulness of an SG for the hip in comparison with its use for other joints. We believe that this is due to the fact that the hip joint is a triaxial joint and is affected by complex motions, such as abduction and adduction in the frontal plane, and rotational motions, such as external and internal rotation, in addition to flexion and extension directions in the sagittal plane. In addition, there are no studies that have measured SG using the "Joint Range of Motion Indication and Measurement Method"[14)] published by the Japanese Orthopedic Association and the Japanese Society of Rehabilitation Medicine, so it is difficult to generalize this method of measurement. Moreover, any method proposed must be easy to use and simple to measure in order to be practical for clinical application. To the best of our knowledge, there are no studies that have examined the ease of use of a SG based on user experience. Therefore, the purpose of this study was to clarify the intra- and inter-inspector reliability of SG, the ease of usability during ROM measurement in each direction of motion, and the ROM measurement time, focusing on the hip joint, which has not been examined thus far.

PARTICIPANTS AND METHODS

This study was comprised of two experiments. In Experiment 1, we compared the SG and UG measurements in terms of the reliability and time required for measurement. In Experiment 2, we conducted a questionnaire survey of the users (i.e., physical therapists) about the usability of the SG. The mean age of the physical therapists was 32.3 ± 4.5 years, and their mean clinical experience was 7.7 ± 3.5 years. In clinical practice, these therapists mainly provide physical therapy to elderly individuals who are over 75 years of age. All three examiners are regular users of smartphones and typically handle them throughout the day. The examiners only took measurements for the study and were not involved in analysis or additional processing of the data collected. The participants were 30 patients (10 males and 20 females) from our hospital daycare center, and their mean age was 79.7 ± 9.5 years. Some participants had cerebrovascular or orthopedic diseases, but they were not excluded from the study because of these conditions. In consideration of the fatigue and physical condition of the examinees, measurements that were unable to be completed for all examiners on the same day were conducted again on a different day. This study was conducted in accordance with the Declaration of Helsinki, with verbal and written explanations and consent obtained from the participants. Additionally, the study was conducted with the approval of the Ethics Committee of Iwaki Yumoto Hospital (202012).

The measurement devices used were a UG (Todai style goniometer with an overall length of 60 cm, and total weight of 230 g, product number TTM-KO, Sakai Medical Co. Ltd., Tokyo, Japan) and a smart device (iPod touch, 2019 model, Apple, Cupertino, CA, USA) with an overall length of 12.3 cm; and a weight of 88 g installed with an inclinometer application (PROtractor, developed by peAfe GbR, 2016). The SG was compared with the UG in advance to confirm accuracy. The Pearson's product rate correlation coefficient (r=>0.9) and measurement error (<1°) were confirmed from the measurement results of the fixed object with the true value. The usage of the SG is as follows. When starting the application, two measurement modes are displayed: one is used to measure on two distant planes (inclination angle), and the other is used to measure on the same plane (axis). For this study, we used the former method. This mode calculates angles using gyroscopic sensors independent of acceleration and gravity. The zero setting of the reference axis is completed by fixing the phone on the axis to be measured and tapping the screen. The phone is fixed to the axis to be measured again, and the user then taps the screen to display the angle on the screen.

For Experiment 1, all measurements were taken on the right hip in the flexion/extension, adduction/abduction, and medial/lateral rotation movement directions. The 30 participants were randomly assigned to one of three groups: the flexion-extension group (n=10), the adduction-abduction group (n=10), and the medial-lateral rotation group (n=10). The measured site and the devices used for measurement were also chosen in a random order. The measurement axis settings were in alignment with the ROM Representation and Measurement Methods published by the Japanese Orthopedic Association and the Japanese Association of Rehabilitation Medicine[14)]. All participants underwent hip extension measurement in the lateral decubitus position, as some participants had difficulty assuming the abdominal position.

The UG measurement was examiner passively moved the joint and determined the angle within the pain-free range.

While maintaining that position, the intersection of the basic axis and the moving axis was aligned with the center of the angle meter, and the angle was read. For the SG measurement, the participant was placed in the basic limb position, and the smartphone was placed so that the basic axis was the reference axis, and zero setting was completed.

After that, the evaluator moved the joint Passively and determined the final ROM within a range that did not result in pain. While maintaining that position, the smartphone was fixed on the moving axis, and the angle was read. SG measurements can be taken at the same site (lower leg) by setting the basic axis and the moving axis. The basic method of measuring adduction, abduction and rotation is the same with the SG as with the UG. The orientation of the smartphone was standardized to be parallel to the sagittal plane in flexion-extension and parallel to the frontal plane in other directions of motion. The time required for measurement was recorded from the beginning of measurement until the angle was written down on a sheet of paper.

For statistical analysis, the intraclass correlation coefficient (ICC) was calculated to test intra-rater (1,1) and inter-rater ICC based on the first measurement taken by each assessor (2,1). To compare the mean values of the measurement time, Levene's test was used to check for equivariance, and then a two-sample t-test was used. A software program (R-2.8.1) was utilized for statistical analysis, and $p<0.05$ was considered statistically significant.

For Experiment 2, the three assessors who performed the ROM measurements took the questionnaire surveys. The surveys were conducted for all directions of motion and were completed immediately after the ROM measurement in one direction of motion for one examinee with one angle meter. The survey consisted of 10 items: shape, weight, texture, ease of holding, operability, simplicity, setting of measurement axis, visibility, versatility, and satisfaction. Responses were chosen from the following Likert scale options: extremely bad (1 point), bad (2 points), neither good nor bad (3 points), good (4 points), and extremely good (5 points). A score of 1 to 5 was assigned, and the score range was 10 to 50, with higher scores indicating better usability for ROM measurement.

Levene's test was performed for statistical analysis to compare the differences in the usability of the SG and UG for each joint, and a two-sample t-test was used after confirming the presence of equivariance. In order to compare the differences between the measuring instruments through the sub-items of the questionnaire for each joint, a two-sample t-test and Mann–Whitney U test were used after the Shapiro–Wilk test was confirmed. A software program (R-2.8.1) was used for statistical analysis, and $p<0.05$ was considered statistically significant.

RESULTS

The measurement results for each joint of SG and UG are shown in (Table 1).The intra-rater reliability of the SG and UG was ICC=0.72 or higher in all directions of hip motion (Table 2). The inter-rater reliability of the SG was ICC=0.57–0.73 in flexion-extension group, ICC=0.40–0.36 in adduction-abduction group, and ICC=0.67–0.63 in the internal rotation-External rotation group. The inter-rater reliability for the UG groups was ICC=0.60–0.86 in the UG flexion-extension group, ICC=0.43–0.47 in the adduction-abduction group, and ICC=0.65–0.51 in the internal rotation-External rotation group (Table 3). Results of the comparison of measurement time of both measurement devices only showed a significant difference for abduction (Table 4). The mean and total scores of the questionnaire items for each joint are shown in (Table 5), and there was a significant difference in total score for the SG. There was no significant difference in the operability of extension, abduction, internal rotation, and external rotation in the questionnaire items among the measuring instruments. In the measurement axis setting, the UG score was high in all joints.

DISCUSSION

In this study, the reliability, measurement time, and usefulness of the SG were examined in day care patients who were certified as requiring nursing care and support. The intra-rater reliability of both instruments was greater than ICC=0.7. According to the reliability criteria of Landis et al. 0 to 0.2 is very light agreement (mild), 0.2 to 0.4 is fair, 0.4 to 0.6 is moderate, 0.6 to 0.8 is fair agreement, and 0.8 and above is almost perfect[15)]. Therefore, it was shown that high intra-rater reliability could be obtained using either instrument. In particular, hip extension showed an ICC of 0.9 or higher for both measurement devices. In a previous study, the assessment of hip extension ROM using a UG also showed high inter-observer reliability (ICC=0.89–0.92) and intra-observer reliability (ICC=0.91–0.93) in healthy individuals[16)]. The measurement limb for extension was performed in the side-lying position, taking into account the examinee, which resulted in improved reliability because the trunk and joints could be fixed relatively easily, and the ROM was small. Intra-inspector reliability was

Table 1. Measurement results for SG and UG

	A	B	C	A	B	C
Movement		SG Mean (°) ± SD			UG Mean (°) ± SD	
Flexione	127 ± 6.0	123 ± 5.3	123 ± 6.0	124 ± 7.1	120 ± 6.2	123 ± 6.3
Extension	23 ± 9.4	21 ± 7.7	17 ± 6.9	19 ± 9.1	19 ± 7.0	16 ± 6.9
Adduction	27 ± 7.9	19 ± 5.8	13 ± 4.4	11 ± 7.9	17 ± 5.9	13 ± 4.4
Abduction	43 ± 7.1	35 ± 9.3	31 ± 10.1	37 ± 7.3	32 ± 9.3	30 ± 10.4
IR	33 ± 9.0	34 ± 7.9	35 ± 7.1	36 ± 9.1	33 ± 9.1	35 ± 7.1
ER	41 ± 3.7	42 ± 4.8	43 ± 4.1	40 ± 5.2	43 ± 3.3	43 ± 4.1

SG: Smartphone goniometer; UG: Universal goniometer; IR: internal rotation; ER: external rotation; SD: Standard Deviation.

Table 2. Intra-rater reliability of SG and UG

Movement		A		B		C	
		ICC (95% CI)	SEM (°)	ICC (95% CI)	SEM (°)	ICC (95% CI)	SEM (°)
Flexion	SG	0.72 (0.41–0.91)	3.3	0.74 (0.45–0.92)	3.0	0.89 (0.74–0.97)	2.0
	UG	0.81 (0.57–0.94)	3.0	0.91 (0.77–0.97)	1.9	0.97 (0.94–0.99)	0.9
Extension	SG	0.95 (0.88–0.98)	1.8	0.95 (0.88–0.98)	1.7	0.98 (0.96–0.90)	0.8
	UG	0.96 (0.91–0.99)	1.4	0.97 (0.92–0.99)	0.7	0.99 (0.97–0.99)	0.6
Adduction	SG	0.79 (0.54–0.93)	3.5	0.93 (0.83–0.98)	1.5	0.98 (0.94–0.99)	0.5
	UG	0.77 (0.49–0.93)	2.0	0.94 (0.86–0.98)	1.1	0.96 (0.89–0.98)	0.8
Abduction	SG	0.89 (0.74–0.97)	2.1	0.95 (0.88–0.98)	2.0	0.99 (0.98–0.99)	0.7
	UG	0.88 (0.72–0.96)	2.4	0.96 (0.90–0.99)	1.7	0.99 (0.99–0.99)	0.6
IR	SG	0.87 (0.70–0.96)	3.0	0.95 (0.87–0.98)	1.7	0.98 (0.96–0.99)	0.6
	UG	0.95 (0.89–0.98)	1.7	0.97 (0.92–0.99)	1.5	0.99 (0.97–0.99)	0.5
ER	SG	0.72 (0.41–0.91)	1.8	0.71 (0.40–0.91)	2.9	0.97 (0.93–0.99)	0.5
	UG	0.84 (0.62–0.95)	1.9	0.84 (0.62–0.95)	1.3	0.98 (0.96–0.99)	0.4

SG: Smartphone goniometer; UG: Universal goniometer; IR: internal rotation; ER: external rotation; ICC: intra-class correlation coeffcient; CI: confidence interval; SEM:standard error of masurement.

Table 3. Inter-rater reliability of SG and UG

Movement	SG ICC (95% CI)	SEM (°)	UG ICC (95% CI)	SEM (°)
Flexion	0.57 (0.21–0.85)	3.7	0.60 (0.24–0.86)	4.5
Extension	0.73 (0.32–0.91)	3.5	0.86 (0.67–0.96)	2.8
Adduction	0.40 (0.02–0.77)	4	0.43 (0.05–0.78)	3.1
Abduction	0.36 (0.01–0.74)	6.2	0.47 (0.09–0.80)	6.7
Internal rotation	0.67 (0.30–0.89)	4.5	0.65 (0.30–0.88)	5.1
External rotation	0.63 (0.28–0.88)	2.7	0.51 (0.14–0.81)	2.8

SG: Smartphone goniometer; UG: Universal goniometer; ICC: intraclass correlation coeffcient; CI: confidence interval; SEM: standard error of measurement.

Table 4. Comparison of SG and UG measurement times

Hip joint	SG	UG
	Mean ± SD (sec)	Mean ± SD (sec)
Flexion	68.8 ± 10.5	71.5 ± 9.7
Extension	61.4 ± 8.7	63.8 ± 9.1
Adduction	72.4 ± 9.4	76.1 ± 11.7
Abduction	63.0 ± 8.4	68.0 ± 5.0*
Internal rotation	60.7 ± 11.7	64.9 ± 12.3
External rotation	60.7 ± 9.3	64.7 ± 12.2

SG: Smartphone goniometer; UG: Universal goniometer; S: Second; SD: Standard Deviation.
Mean ± SD, *: vs. SG, $p<0.05$.

also confirmed for measurements at joints such as adduction/abduction and internal/external rotation in the frontal plane. A study that measured cervical spine rotation motion using the SG reported moderate validity but low reliability[18]. During gyration motion on the horizontal plane, the use of a magnetic sensor compass app, which does not depend on gravity, makes it susceptible to the tilt of the iPhone. In addition, there is a possibility that the measurement may be adversely affected by the surrounding magnetic field or that the axis may have shifted because the measurement was performed during axial rotation motion[17, 18].

In this study, the smartphone was set so that it was parallel to the measurement surface in all directions of motion, and the tilt angle (consisting of the basic axis and the moving axis) was measured to unify the axes so that they would not be set ambiguously. In addition, to ensure reliability, we used an application that was independent of the magnetic sensor, which

Table 5. Comparison of SG and UG. Questionnaire sub-items and total score

	Flexion		Extension		Adduction		Abduction		IR		ER	
	SG	UG	SG	UG	SG	UG	SG	UG	SG	UG	SG	UG
Shape	4.1 ± 0.2	3.6 ± 0.3*	4.0 ± 0.2	3.5 ± 0.5*	4.1 ± 0.3	3.2 ± 0.4*	4.0 ± 0.2	3.3 ± 0.3*	4.0 ± 0.2	3.4 ± 0.4*	4.1 ± 0.1	3.4 ± 0.4*
Weight	4.1 ± 0.2	3.3 ± 0.4*	4.0 ± 0.2	2.9 ± 0.4*	4.1 ± 0.2	3.1 ± 0.4*	4.1 ± 0.1	3.2 ± 0.3*	4.1 ± 0.2	3.1 ± 0.4*	4.1 ± 0.2	2.9 ± 0.4*
Texture	4.0 ± 0.2	3.4 ± 0.4*	4.0 ± 0.2	3.2 ± 0.4*	4.1 ± 0.2	3.2 ± 0.3*	4.1 ± 0.1	3.3 ± 0.3*	4.1 ± 0.2	3.2 ± 0.4*	4.1 ± 0.2	3.1 ± 0.4*
Easy to hold	4.1 ± 0.1	3.4 ± 0.4*	4.0 ± 0.3	3.0 ± 0.5*	4.1 ± 0.2	3.2 ± 0.4*	4.0 ± 0.2	3.3 ± 0.2*	4.0 ± 0.2	3.5 ± 0.4*	4.0 ± 0.3	3.4 ± 0.5*
Operability	3.4 ± 0.5	3.8 ± 0.4*	3.2 ± 0.6	3.2 ± 0.4 n.s.	2.9 ± 0.5	3.5 ± 0.3*	3.4 ± 0.4	3.6 ± 0.3 n.s.	3.4 ± 0.3	3.7 ± 0.5 n.s.	3.6 ± 0.6	3.7 ± 0.5 n.s.
Convenience	4.0 ± 0.2	3.3 ± 0.5*	3.9 ± 0.3	3.0 ± 0.4*	3.5 ± 0.4	3.0 ± 0.2*	3.8 ± 0.3	3.1 ± 0.2*	3.9 ± 0.3	3.4 ± 0.5*	3.9 ± 0.4	3.2 ± 0.4*
axis setting	2.9 ± 0.3	4.1 ± 0.2*	2.7 ± 0.4	3.8 ± 0.2*	2.2 ± 0.2	3.8 ± 0.3*	2.5 ± 0.2	3.9 ± 0.2*	2.9 ± 0.4	3.8 ± 0.3*	2.8 ± 0.4	3.7 ± 0.4*
Visibility	4.4 ± 0.2	2.6 ± 0.4*	4.4 ± 0.2	2.9 ± 0.2*	4.4 ± 0.1	2.6 ± 0.2*	4.3 ± 0	2.6 ± 0.1*	4.3 ± 0.2	2.8 ± 0.3*	4.3 ± 0.2	2.9 ± 0.2*
Versatility	3.9 ± 0.4	2.9 ± 0.3*	3.8 ± 0.3	2.8 ± 0.3*	3.8 ± 0.4	2.8 ± 0.4*	3.8 ± 0.3	2.9 ± 0.2*	4.0 ± 0.3	2.9 ± 0.4*	4.0 ± 0.3	2.8 ± 0.5*
Satisfaction	3.8 ± 0.4	3.3 ± 0.5*	3.7 ± 0.3	3.0 ± 0.2*	3.4 ± 0.5	2.9 ± 0.3*	3.5 ± 0.3	3.0 ± 0.2*	3.9 ± 0.4	3.1 ± 0.3*	3.9 ± 0.3	3.0 ± 0.3*
Total	38.7 ± 4.0	34.0 ± 3.8*	37.7 ± 4.8	31.4 ± 3.8*	36.6 ± 6.8	31.5 ± 3.5*	37.6 ± 5.3	32.3 ± 3.5*	32.3 ± 3.5	33.1 ± 2.6*	38.8 ± 4.3	32.3 ± 3.1*

SG: Smartphone goniometer; UG: Universal goniometer; Mean ± SD, *: vs. SG, p<0.05; n.s.: vs. SG, p>0.05.

we believe was a factor in obtaining reliability. Charlton et al.[19] measured hip ROM in healthy adults using the SG and found an intra-rater reliability of ICC=0.68–0.94, which was similar to the results of our study. However, the abduction and adduction measurements were more reliable for us. In the present study, most measurements were performed in the supine position. Charlton et al.[19] measured abduction and adduction in the lateral supine position, and the phone was set to zero in the horizontal plane and then strapped to the center of the lateral thigh for measurement. We believe that measuring abduction and adduction in the lateral supine position resulted in increased difficulty with controlling compensatory movements of the trunk and pelvis, and errors occurred because the phone was not fixed to the basic axis, which reduced reliability. Therefore, we believe that it is important to select a unified measurement limb position, measurement axis, and an app with an accelerometer or gravity-dependent gyro sensor for ROM measurement using a SG.

Inter-rater reliability ranged from mild to high agreement for the SG (ICC=0.36–0.73) and UG (ICC=0.43–0.86) devices, with the SG showing slightly higher reliability than the UG for internal and external rotation. Inter-inspector reliability for adduction and abduction was lower for both instruments. Kato et al.[20] stated that the measurement method of hip abduction and adduction is problematic because of the need for pelvic immobilization and rotation of the pelvis on the frontal plane. Adduction is difficult because it requires raising the opposite lower limb in flexion, passing it under the limb, and turning it inward to fix the joint and manipulate the angle gage simultaneously. Moreover, causes of ROM restriction are classified into the following eight groups: pain; skin adhesion or limited stretching; adhesion or shortening of the joint capsule; adhesion or shortening of musculotendinous tissue; increased muscle tone; impaired intracapsular movement; swelling or edema; and bone collision[21]. The assessor must give appropriate consideration to these restrictive factors and must minimize compensatory movements in order to achieve accurate measurements[22]. Therefore, the results may have depended on technical errors among examiners. The most important factor that reduced inter-rater reliability was the fact that the participants of this study were not healthy adults, but patients of a daycare center who required support or care. In some cases, it was difficult for the three examiners to measure the ROM of the participant on the same day. Considering the fatigue and physical condition of the examinees, if the measurement was unable to be completed on the same day, the patient was measured again at a later date, which is presumed to be the cause of the decreased reliability. Although intra-rater reliability can be ensured by having the same examiner consistently use the same measurement device to measure the participant, measurement using the SG among different examiners is not recommended at this stage. Miyamae et al.[23] reported that the inter-rater reliability could be improved by using the same well-defined measurement method across all examiners. Therefore, it is necessary to establish a standardized method for understanding the characteristics of the smart phone, applying the axis, and measuring the ROM of the SG among examiners.

In terms of the ROM measurement time between the two measurement devices, measurement was completed slightly faster for all joints with the SG, and it was clear that the use of the SG did not negatively affect work time.

Based on the total score of the questionnaire on usability, the SG was found to have good usability for all targeted joints. In the author's previous study[12], the usability of the SG was only in one direction, flexion in the sagittal plane, but in this study, it was found that the usability of the SG was also good for adduction, abduction, and rotation in the frontal plane. The results of the sub-items of the questionnaire showed that the UG had a longer arm and was superior for axis alignment, but it was inferior for holding and reading data. Although the SG itself does not have shape characteristics as an angle meter, the examiner is accustomed to using it, since he or she uses a smartphone on a daily basis. Additionally, the burden on the examiner was reduced due to its ability to be read on a digital display, which resulted in the examiner feeling of use was high. The SG users commented that the measurement method was easy, but they also noted that there was some confusion regarding the axis setting. I assume that the SG users were confused because they did not align the axis of the angle gauge with the center of the basic and moving axes after fixing the joint at the final range of motion as in the UG. Robson[24] stated that a long-armed angle finder reduces errors in applying the axis of the angle finder, and, in general, a larger arm is more advantageous for larger joints. For the current study, no difference in scores was found for operability among the four joints. This is thought to be because the operation of holding the angle meter to measure ROM is the same for both measurements; the issue for the SG is the lack of a standard axis (arm). A previous study[25] that used an inclinometer reported that the reliability was improved by attaching a handle to improve ease of interpretations of the axis, and it is expected that the user's opinions of ease of use and reliability of the tool could be improved with innovations such as incorporation of an elastic attachment for the smartphone. Furthermore, the UG weighs about 230 g, while the SG weighs only about 88 g. The smartphone device is small enough to fit in a trouser pocket. It is lightweight and portable, so it can be carried anywhere at any time, which is a great advantage.

Limitations of the study is for day care users who have been certified as requiring support or nursing care it was difficult to completely control the ROM measurements. In addition, the standardized ROM measurement method of the SG is not uniform, which may have affected the reliability of this study. There is a need for the creation of a protocol with more validity and reliability. Users who are familiar with smartphones may not be apprehensive of the clinical application of smartphone devices, but therapists and patients who are not comfortable with these devices should also be considered. Since the questionnaire survey was conducted on a limited number of people, future research should include a larger pool of examinees and patients to accumulate additional data. Research should also consider ways of introducing the device into clinical practice.

In conclusion, we conducted a questionnaire survey on the reliability and measurement time of a SG and a UG in Experiment 1. We examined the usability of the SG and UG in Experiment 2. The participants of this study were day care patients who were certified as requiring support and care. It was confirmed from the results of Experiment 1 that the SG could measure ROM with similar intra-inspector reliability and measurement time as the UG, but the inter-inspector reliability was low. The SG was able to measure ROM in a manner that was comparable to the UG, but more standardized measurement protocols need to be developed for the SG to be used for clinical application. In Experiment 2, examiners clearly indicated that the SG was more user-friendly than the UG, but future work on the axis setting is needed. This study suggests that good results could be obtained by using either of the angle meters assessed in this paper, as long as the same examiner uses the same measurement device.

Conflict of interest

There are no conflicts of interest to declare.

REFERENCES

1) Nancy BR, William D: Joint range of motion and muscle length testing. Tokyo: Ishiyaku Publications, 2005, pp 12–13.
2) Fox RF: Demonstration of the mensuration apparatus in use at the Red Cross Clinic for the physical treatment of officers. Proc R Soc Med, 1917, 10: 63–68. [Medline]
3) Gajdosik RL, Bohannon RW: Clinical measurement of range of motion. Review of goniometry emphasizing reliability and validity. Phys Ther, 1987, 67: 1867–1872. [Medline] [CrossRef]
4) Bruton A, Ellis B, Goddard J: Comparison of visual estimation and goniometry for assessment of metacarpophalangeal joint angle. Physiotherapy, 1999, 85: 201–208. [CrossRef]
5) Tomlinson S, Behrmann S, Cranford J, et al.: Accuracy of smartphone-based pulse oximetry compared with hospital-grade pulse oximetry in healthy children. Telemed J E Health, 2018, 24: 527–535. [Medline] [CrossRef]
6) Pipitprapat W, Harnchoowong S, Suchonwanit P, et al.: The validation of smartphone applications for heart rate measurement. Ann Med, 2018, 50: 721–727. [Medline] [CrossRef]
7) Chan C, Inskip JA, Kirkham AR, et al.: A smartphone oximeter with a fingertip probe for use during exercise training: usability, validity and reliability in individuals with chronic lung disease and healthy controls. Physiotherapy, 2019, 105: 297–306. [Medline] [CrossRef]
8) Onoda K, Huo M: Reliability and validity of a smartphone application for position sense measurement. Rigakuryoho Kagaku, 2016, 31: 701–704. [CrossRef]
9) Pourahmadi MR, Ebrahimi Takamjani I, Sarrafzadeh J, et al.: Reliability and concurrent validity of a new iPhone® goniometric application for measuring active wrist range of motion: a cross-sectional study in asymptomatic subjects. J Anat, 2017, 230: 484–495. [Medline] [CrossRef]
10) Furness J, Schram B, Cox AJ, et al.: Reliability and concurrent validity of the iPhone® Compass application to measure thoracic rotation range of motion (ROM) in healthy participants. PeerJ, 2018, 6: e4431. [Medline] [CrossRef]
11) Melián-Ortiz A, Varillas-Delgado D, Laguarta-Val S, et al.: [Reliability and concurrent validity of the app Goniometer Pro vs Universal Goniometer in the determination of passive knee flexion]. Acta Ortop Mex, 2019, 33: 18–23 (in Spanish). [Medline]
12) Takeda Y, Takeda H, Watanabe N, et al.: Usability and reliability of smartphone applications in range of motion measurement. Trans Jpn Soc Kansei Eng, 2020, 19: 369–373. [CrossRef]
13) Keogh JW, Cox A, Anderson S, et al.: Reliability and validity of clinically accessible smartphone applications to measure joint range of motion: a systematic review. PLoS One, 2019, 14: e0215806. [Medline] [CrossRef]
14) Yonemoto K, Ishigami S, Kondo T: Range of motion display and measurement method. Rehabil Med, 1995, 32: 207–217.
15) Landis JR, Koch GG: The measurement of observer agreement for categorical data. Biometrics, 1977, 33: 159–174. [Medline] [CrossRef]
16) Clapis PA, Davis SM, Davis RO: Reliability of inclinometer and goniometric measurements of hip extension flexibility using the modified Thomas test. Physiother Theory Pract, 2008, 24: 135–141. [Medline] [CrossRef]
17) Quek J, Brauer SG, Treleaven J, et al.: Validity and intra-rater reliability of an android phone application to measure cervical range-of-motion. J Neuroeng Rehabil, 2014, 11: 65. [Medline] [CrossRef]
18) Tousignant-Laflamme Y, Boutin N, Dion AM, et al.: Reliability and criterion validity of two applications of the iPhone™ to measure cervical range of motion in healthy participants. J Neuroeng Rehabil, 2013, 10: 69. [Medline] [CrossRef]
19) Charlton PC, Mentiplay BF, Pua YH, et al.: Reliability and concurrent validity of a Smartphone, bubble inclinometer and motion analysis system for measurement of hip joint range of motion. J Sci Med Sport, 2015, 18: 262–267. [Medline] [CrossRef]
20) Katoh M, Takahashi K, Yamamoto Y, et al.: Measuring joint range of motion in clinical practice. J Tokyo Phys Ther Chapter JPTA, 1999, 14: 9–13.
21) Ichihashi N: Exercise therapy-theory and practice of disability-specific approaches, 2nd ed. Tokyo: Bunkodo, 2014, p 186.
22) Kumagai T, Asano A, Ida S: The ABC of hip range of motion assessment. Pt J, 2021, 55: 157–163.
23) Miyamae T, Ogawa K: Reliability of range of motion test. Phys Ther Occup Ther, 1978, 12: 139–144.
24) Robson P: A method to reduce the variable error in joint range measurement. Ann Phys Med, 1966, 8: 262–265. [Medline]
25) Shigeshima K, Sakanoue N: Simultaneous validity and reproducibility of tiltmeters in range of motion measurement. Bull Kochi Rehabil Acad, 2005, 7: 39–46.