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ORIGINAL RESEARCH

Assessing the Validity and Reliability of a New Video Goniometer App for Measuring Joint Angles in Adults and Children

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Abstract

Objective: To assess the convergent validity and reliability of joint angle measurements from a new video goniometer iPhone/iPad application separately in adults, older and young children.

Design: Cross-sectional.

Setting: Child care and university environments.

Participants: Fifty-four adults (mean ± SD=22.5±4.5y), 20 older children (mean ± SD=10.9±2.2y), 20 younger children (mean ± SD=1.6±0.8y) (N=94).

Interventions: Adults and older children performed both standardized static positions and functional activities. Younger children performed only a functional activity protocol.

Main Outcome Measures: Joint angle measurements using the app were validated against a commercially validated two-dimensional goniometric software program. In addition, validity of the app was compared to a standard mechanical goniometer for the measurement of angles drawn on a white board. Intra- and interrater reliability were assessed through independent rescoring of videos.

Results: Correlations between joint angle estimates obtained from the app and goniometer software or a mechanical goniometer were positive and very strong (r>.900; P<.0001). The intraclass correlation coefficient (ICC) for repeated scoring from the app indicated excellent intra- and interrater reliability (ICC>.900).

Conclusions: High correlations for repeated measures and comparison to gold standard angle measurement instruments suggest that the new app is a valid and reliable tool for assessing joint angles during functional activity. This tool may provide clinicians an inexpensive yet accurate method for quantification of movements and immediate feedback on range of motion during tasks in a natural environment.

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In laboratory settings, researchers often use sophisticated motion-tracking systems to estimate joint angles.[1,2] Three-dimensional (3D) motion-tracking systems, such as Vicon and Qualisys, are considered precise methods of assessing human movement.[1,3] However, they are expensive, not transportable, time consuming for data processing, and require extensive expertise of users.[4,5] Two-dimensional (2D) photo- or video-based assessment techniques are more affordable and easier to use for measurement of joint angles during dynamic movement.[4] Although 2D techniques restrict the measurement of joint angles to single planes,[6] 1 per camera view, these techniques have good to excellent validity relative to 3D systems.[7-9]

Kinovea is one example of 2D motion analysis software used in research settings. It is a free, open-source tool for measuring distance, time, and joint angles from video recordings.[5,10] Validity and reliability have been established for measuring joint angles during facial movement, vertical jumps, and hamstring flexibility

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testing.[10-12] Although Kinovea is an affordable tool that does not require formal training in video-recording or data analysis,[10,11] it does not provide an immediate assessment of joint angles. A computer platform is needed to house the software, with processing time necessary to identify joint angles. Neither 3D nor 2D motion analysis tools commonly used for research are feasible for clinicians or sports professionals to use in natural settings that require easily portable systems and immediate feedback.[5,13-15]

Health care and sports professionals need user-friendly, accurate, and clinically relevant tools for measuring joint angles. Visual estimation, inclinometers, and goniometers are commonly used.[2] A mechanical goniometer is the most widely used clinical tool to measure joint angles.[16] Previous research found good intra- and interrater reliability of goniometers when using standardized testing methods.[17] Although goniometers are valid and reliable to measure static positions, they cannot perform dynamic measurement of joint angles during activity.[18] Inclinometers have the same limitation. Visual estimation techniques are limited in that they are accompanied by a large margin of error, often 15 degrees or more.[19] There is a need for a valid, reliable, and affordable tool to measure joint angles during activity without requiring high levels of expertise, computer hardware, or long processing times.

An increase in the use of mobile smart phones and their capacity to record and measure parameters of human movement[20-22] make them a uniquely accessible tool for measuring joint angles. Several smartphone applications allow for valid and reliable measurement at individual joints and during static positioning tasks.[23-28] However, these apps are limited in accommodating measures across multiple joints or during functional activities.[29-31]

The app evaluated in this study was developed as an affordable video goniometer to measure joint angles during functional movement in natural environments. The purpose of this study was to evaluate the convergent validity and reliability of joint angle measurements from the app across multiple joints or regions of the body, during diverse tasks (static and dynamic), and across a wide range of participant ages.

Methods

Study design and setting

Data collection for this cross-sectional study was completed in accordance with regulations set by the University of Delaware and Duquesne University Institutional Review Boards. Adult participants and parents of participating children provided informed consent. Children older than 6 years provided assent.

Participants

Post hoc estimates for the sample size using G*Power[32] suggested 19 participants for each of the 3 groups (adults, older children, younger children) to achieve 80% power with a confidence interval of 95% and alpha level of .05. Three groups differing in age, size, and ability to follow directions (convenience sample) were recruited from the community from March to August of 2017: (1) 54 adults (12 men; 18-42y); (2) 20 older children (13 men; 7-14y); and (3) 20 younger children (12 men; 0.7-6y). Inclusion criteria were healthy individuals with typical development and the ability to safely and independently engage in the data collection activities. Exclusion criteria were any movement restrictions, visual impairment, or motor impairments that would limit participation. Participants also needed to live within driving distance of the participating universities and be available for scheduled assessments.

List of abbreviations:

2D	**two-dimensional**
3D	**three-dimensional**
95% CI	**95% confidence interval**
ICC	**intraclass correlation coefficient**

Instruments

The Angles Video Goniometer app (Angles app) is an iPad/iPhone (iOS) app goniometric tool to measure joint angles from video. It allows the user to measure joint angles and velocity in the plane visualized (fig 1A). Each frame is 1/30th of a second (frame rate is inherent to the camera). Data are exported as an Excel spreadsheet (fig 1B). Angles are calculated by an algorithm that uses the Hypot function, a modified version of the Pythagorean Theorem, and the Law of Cosines. The code is open source under the GNU General Public License v3.0 at https://github.com/nathanjcochran/Angles.

Two instruments, Kinovea software (version 0.8.15; http://www.kinovea.org), and a mechanical goniometer were used to establish the convergent validity of the joint angle measures from the Angles app. Kinovea is used for clinical applications, and it has been shown to be valid and reliable for measuring fine movements (ie, facial) as well as gross movements (ie, lower limb movements).[5,10-12] This tool was selected as a comparative 2D, markerless tool, which could be used in natural and clinical settings during functional activity.

Procedures

Static positioning and functional activity assessments

Adults and older children were asked to wear form fitting clothing (figs 1-2). Participants were video recorded using an iPad in the laboratory or school setting during 5 minutes of static (figs 2A and B) and 10 minutes of functional activity (fig 2C). We selected activities relevant for participation and clinical assessment.[1,33-37] For all activities, the iPad was positioned perpendicularly to the side of the participant (random assignment of participants to the right or left side) to record movements in the sagittal plane. For static measures in the frontal plane, an iPad was also positioned in front of participants. The iPads remained stationary on a tripod. Video recording and measurement of joint angles can be performed in real time with the Angles app, or previously recorded videos can be imported into the app for data processing; we used this second option. Recorded videos were also imported onto a laboratory computer for measurement using Kinovea.

For the *static positioning protocol*, participants were asked to hold the following positions for 3 seconds each: (1) trunk: maximum flexion, extension; (2) shoulder: flexion, abduction at a self-selected angle between 0° and 90° and then between 90° and 180°, maximum shoulder flexion, abduction; and (3) elbow: flexion at a self-selected angle between 0° and 90°, maximum elbow flexion. Joint angles at the shoulder and elbow were measured at the onset of each static position.

For the *functional activity protocol*, participants were asked to perform the following activities 3 times each with joint angles at the hip, shoulder, elbow, and knee (fig 2C) measured at specific

Fig 1 Estimated joint angles in the Angles app as presented on the iPad screen (A) and in the Excel data output spreadsheet (B).

time points in parentheses: (1) standing to/from sitting (making/losing body-chair contact); (2) walking ≅3 meters (heel strike; toe off); (3) stepping up or down from a 20-cm bench (foot-bench contact); (4) stepping over the bench (heel-floor contact); and (5) squatting to bimanually pick up an empty box from the floor and placing it on a shelf at eye level (box off floor; box on shelf). To

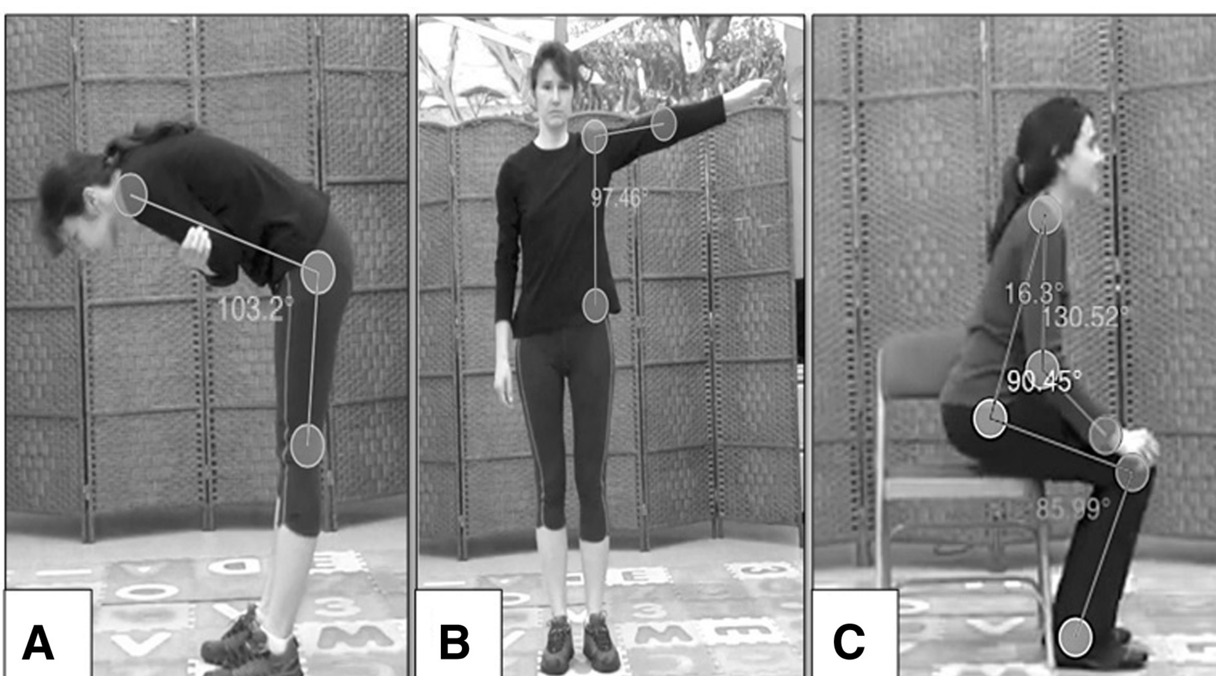

Fig 2 Examples of joint angles measured with the Angles app during static positioning activity in the sagittal (A) and frontal (B) planes and during the functional activity of transitioning between sitting and standing (C).

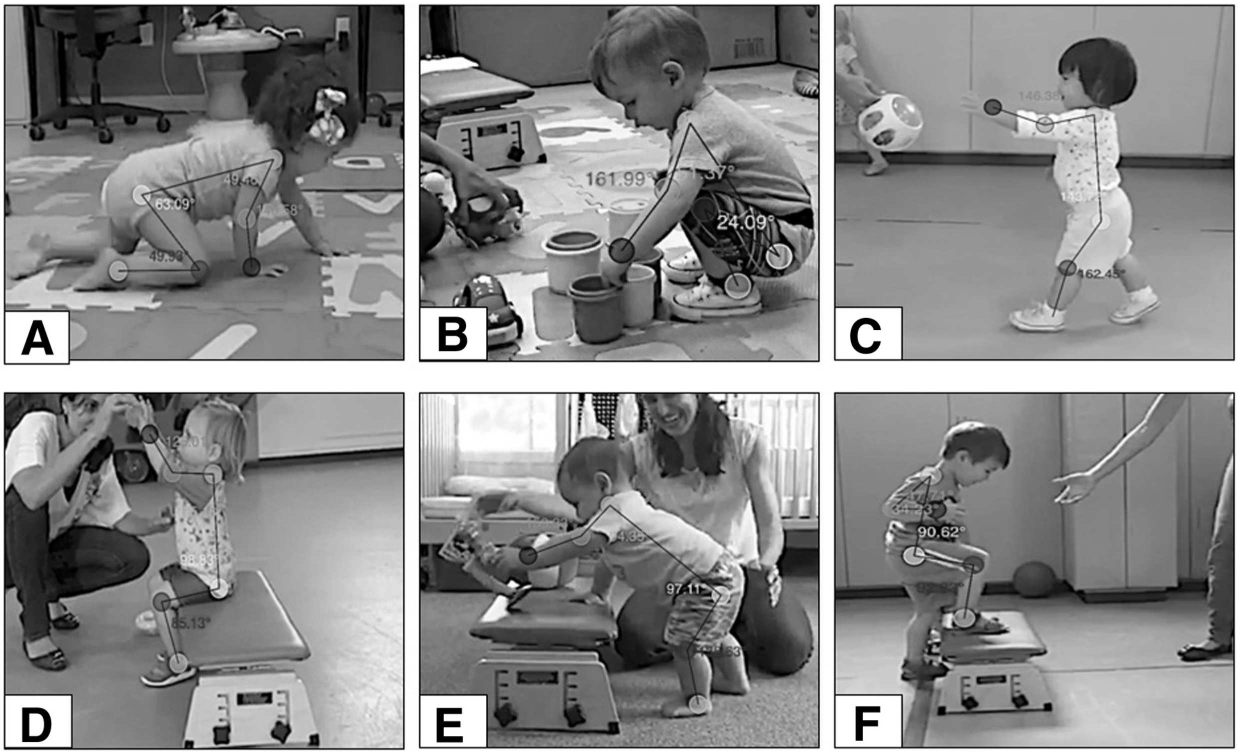

Fig 3 Examples of joint angles measured with the Angles app for some of the functional activities for younger children: crawling (A), squatting (B), walking (C), reaching for a toy while sitting (D), standing with support (E), and stepping on a bench (F).

avoid parallax error, video frames were selected for measurement when the participant was in the middle of the view perpendicular to the camera.

Because younger children could not follow instructions and remain still for the static positioning protocol, they were tested only while performing the following functional, age-appropriate activities that could typically be elicited during free play (with joint angles measured at specific frames identified by a primary coder described in parentheses): (1) play with toys while sitting on the floor or a bench (object contact); (2) reaching for a toy while sitting or standing (object contact); (3) catching and throwing a ball (ball contact or release); (4) transitioning from sitting to standing from the floor or a bench (making/losing body-support contact); (5) standing (upright position); (6) squatting (maximum knee flexion); (7) crawling (knee strike; knee off); (8) walking (heel strike; toe off); (9) running (heel strike; toe off); (10) stepping on a bench (foot-bench contact); and (11) jumping (heel down) (figs 3A-F). The iPad camera was held by an experimenter

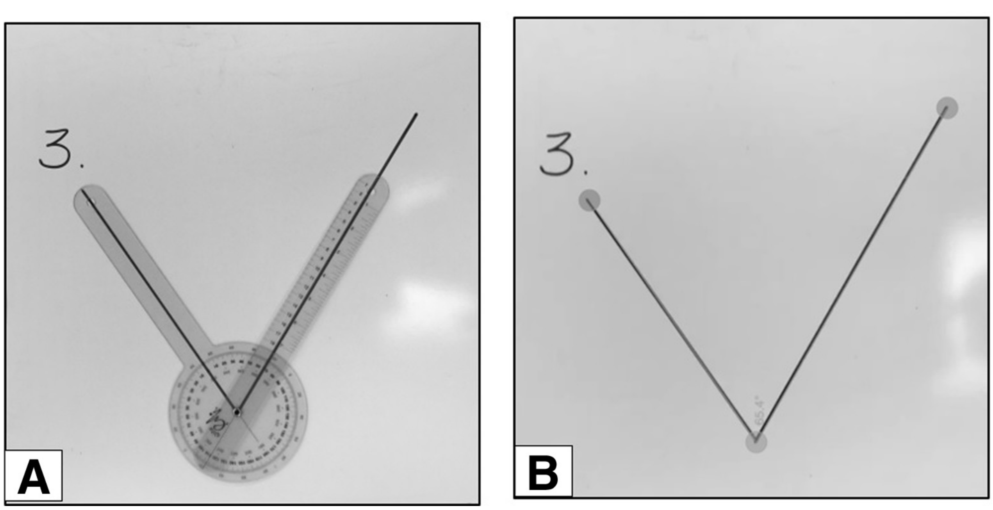

Fig 4 An example of the angles drawn on a whiteboard for measurement with a goniometer (A) and with the Angles app (B).

Table 1 Demographic characteristics for the study participants

Parameters	Adults	Older Children	Younger Children
Sample size	54	20	20
Mean age ± SD (y)	22.5±4.5	10.9±2.2	1.6±0.8
Men	22.2%	65.0%	60.0%
White	77.8%	75.0%	65.0%
African American or Black	3.8%	0.0%	20.0%
Asian	12.9%	10%	10.0%
Multiracial	3.7%	15.0%	5.0%
Other race	1.8%	0.0%	0.0%

to maintain a sagittal relation to the child to allow for the measurement of movements in the sagittal plane.

Joint angle measurement procedures

Joint angles were measured from videos by independent coders using the Angles app and Kinovea software. The same 4 coders, 2 certified physical therapists, and 2 senior undergraduate exercise science majors were used across all of the assessments. Coders were trained to reach ≥90% intra- and interreliability. For the adults and older children, coders were each trained to identify the frames described above. Because multiple instances of each behavior occurred for younger children, a primary coder identified the frames to be coded. All data were coded twice by each coder using Angles to assess intrarater reliability. Anatomical landmarks were identified from the videos and were always marked in the Angles app and Kinovea using the same order. For the static positioning assessment, the anatomical landmarks marked in the sagittal plane, in order of marking, were the acromion process, the greater trochanter, and the lateral condyle of the tibia for the trunk and hip angle; the lateral epicondyle of the humerus, the acromion process, and the greater trochanter for the shoulder angle; the acromion process, the lateral epicondyle of the humerus, and the styloid process of the ulna for the elbow angle. In the frontal plane, 3 anatomical landmarks were marked in order: the midpoint between the lateral and medial epicondyles of humerus, the acromion process, and the anterior superior iliac spine for the shoulder angle. For the functional activity assessment, 6 anatomical landmarks were marked in the sagittal plane in order: the styloid process of ulna, the lateral epicondyle of the humerus, the acromion process, the greater trochanter, the lateral condyle of the tibia, and the lateral malleolus. If an anatomical point was not visible in a trial, it was considered missing data in the analysis.

In addition, 20 angles ranging from 0° to 180° were drawn on a whiteboard, measured with a mechanical goniometer (fig 4A) or from video using the Angles app by 2 independent coders, blinded to the measurement values obtained by the other mode of measurement (fig 4B). We included this comparison because our participants could not be expected to accurately hold identical static positions for sequential goniometric measurement and Angles app video measurement.

Outcome measures

For the static positioning assessment in adults and older children, the following joint angles were measured in the sagittal plane: (1) trunk flexion; (2) trunk extension; (3) shoulder extension; (4) shoulder flexion between 0° and 90°; (5) shoulder flexion between 90° and 180°; (6) elbow flexion between 0° and 90°; and (7) maximum elbow extension. The angles measured in the frontal plane were (8) shoulder abduction between 0° and 90° and (9) shoulder abduction between 90° and 180°. Joint angle was evaluated for 1 frame in each static position.

For the functional activity assessment, the following joint angles were measured in order in the sagittal plane: (1) elbow flexion or extension; (2) shoulder flexion or extension; (3) hip flexion or extension; and (4) knee flexion or extension. Therefore, 4 joint angles were evaluated at each of the aforementioned points of focus for each activity.

One angular measurement was evaluated for each of the 20 angles drawn on a whiteboard.

Data analysis

Data were exported to Excel sheets and analyzed using SPSS[a] statistics version 25 with an alpha level of .05 as the criterion for significance. Descriptive analyses characterized sample demographics and missing data. Data were analyzed separately for each group (adults, older children, younger children).

Convergent validity of the Angles app was evaluated by comparing measures from the app and Kinovea.[38] For angles drawn on the whiteboard, correlations between the measures from the mechanical goniometer and the Angles app were evaluated. Measures were correlated using bivariate Pearson 2-tailed

Table 2 Bivariate (2-tailed) Pearson product-moment correlation correlations between the joint angle measurements from Angles app and Kinovea for the static positioning and functional activity protocols in adults and children

Joints	Adults	Older Children	Younger Children
Static Positioning			
Elbow	r (96) = .970; P<.0001	r (42) = .997; P<.0001	-
Shoulder	r (242) = .993; P<.0001	r (105) = .997; P<.0001	-
Trunk	r (97) = .990; P<.0001	r (42) = .986; P<.0001	-
Functional Activity			
Elbow	r (2137) = .924; P<.0001	R (619) = .903; P<.0001	r (412) = .995; P<.0001
Shoulder	r (2152) = .924; P<.0001	r (620) = .945; P<.0001	r (412) = .996; P<.0001
Hip	r (2151) = .981; P<.0001	R (620) = .976; P<.0001	r (412) = .995; P<.0001
Knee	r (2145) = .982; P<.0001	R (616) = .984; P<.0001	r (412) = .997; P<.0001

Table 3 Interclass correlation coefficients between independent coders for the static positioning and functional activity protocols in adults and children

Joints	Adults	Older Children	Younger Children
Static Positioning			
Elbow	ICC=.963 (95% CI, .937-.978)	ICC=.995 (95% CI, .991-.997)	-
Shoulder	ICC=.975 (95% CI, .962-.984)	ICC=.996 (95% CI, .994-.997)	-
Trunk	ICC=.960 (95% CI, .932-.977)	ICC=.984 (95% CI, .970-.991)	-
Functional Activity			
Elbow	ICC=.962 (95% CI, .958-.966)	ICC=.957 (95% CI, .950-.963)	ICC=.991 (95% CI, .989-.992)
Shoulder	ICC=.962 (95% CI, .958-.966)	ICC=.985 (95% CI, .982-.987)	ICC=.992 (95% CI, .991-.994)
Hip	ICC=.971 (95% CI, .967-.974)	ICC=.990 (95% CI, .989-.992)	ICC=.993 (95% CI, .992-.995)
Knee	ICC=.990 (95% CI, .989-.991)	ICC=.990 (95% CI, .988-.991)	ICC=.995 (95% CI, .994-.996)

correlation in SPSS,[a] with r=.40-.59 considered as *moderate*, r=.60-.79 as *strong*, and r=.80-1.0 as *very strong*.[39]

Inter- and intrarater reliabilities of the app were evaluated across repeated measurements.[38] *Interrater reliability* was assessed by having independent coders; each scores 100% of the videos. *Intrarater reliability* was assessed by having individual coders repeat scoring on 20% of the videos. For inter- and intrarater reliability, the intraclass correlation coefficient (ICC) was estimated and 95% confident intervals (95% CIs) were calculated using SPSS based on a mean rating (k=4), consistency agreement, 2-way mixed-effects model. Values >.80 were considered *good*, and those >.90 were considered *excellent*.[38]

Results

Table 1 provides detailed demographic information for the participants.

There were 624 data points analyzed for the static positioning and 6968 data points for the functional activity assessment. No data were missing for the static positioning assessment. For the functional activity assessment, there were instances where anatomical markers were not visible. This occurred for 0.5% of the data in adults, 0.1% of the data in older children, and 0.1% of the data in young children. Not all of the younger children performed all 11 functional activities because the activities were too advanced for them or lack of motivation: 6 did not catch or throw a ball, 2 did not crawl, 1 did not walk, 11 did not run, 9 did not step on or over the bench, and 14 did not jump. These were included as missing data in the analyses.

Validity

Angles app versus Kinovea

There were very strong positive correlations between joint angle measurements from the Angles app and Kinovea for both the static positioning and functional activity assessments for each group (table 2).

Angles app versus mechanical goniometer

There was a very strong positive correlation between the joint angle measurements obtained from the Angles app and those measured using the mechanical goniometer (r [20]=.999; P<.0001, SEM=6.3).

Reliability

Interrater reliability

Excellent interrater agreement was found among independent coders for the static positioning and functional activity assessments for each group (table 3).

Intrarater reliability

Excellent intrarater agreement was found within each coder. The ICC for the static positioning assessment was .963 (95% CI, .937-.978; SEM=1.2) for elbow, .975 (95% CI, .962-.984; SEM=1.5) for shoulder, and .985 (95% CI, .978-.990; SEM=1.5) for trunk angles. For the functional activity assessment, the ICC was .946 (95% CI, .932-.957; SEM=0.9) for elbow, .901 (95% CI, .877-.921; SEM=1.5) for shoulder, .902 (95% CI, .878-.922; SEM=1.7) for hip, and .978 (95% CI, .973-.982; SEM=1.6) for knee angles.

Discussion

The purpose of this study was to assess the convergent validity and reliability of joint angle measurements from the Angles app. The app was shown to be a valid, reliable tool for assessing joint angles during static and functional tasks in natural environments for adults and children.

A very strong, positive correlation between the measures from the app and Kinovea was found, showing that the app is a valid tool that can be used to measure joint angles during the performance of both static positioning as well as meaningful, functional tasks. Kinovea has been shown to be accurate and consistent for measuring joint angles[10,11] but does not provide immediate feedback. The Angles app could serve as an alternative to allow for real-time feedback during functional tasks in research, clinical, or natural settings.

Moreover, there was a very strong, positive correlation between measures from the app and the goniometer. Although accurate measurement of static joint angles can be accomplished using a goniometer,[40] the Angles app allows clinicians to measure joint angles during dynamic activity as well.

Intra- and interrater reliability of the app were excellent in all of the tasks. In contrast, the reliability of measurement using a goniometer can occasionally be poor, due to movement of adjacent joints.[17] The Angles app can allow a clinician to use both hands to accurately position a client for static assessment, whereas the mounted iPad records the position. The app can also allow users to reliably measure several joint angles simultaneously during ongoing functional activities. In addition, the app requires no cost for equipment like computers or movement-tracking markers and cameras and no extensive training.

Recent studies have shown that other smartphone apps can provide valid, reliable measurement of motion at a specific joint or region, such as the ankle, knee, wrist, or spine.[21,25-27,31,41,42] These apps can provide valid and reliable measurement of lower extremity motion during a specific exercise (ie, squats or lunges).[15,23,24,29,31,37,43] The current study is the first to evaluate an app designed to more broadly measure motion across joints, ages, and activities. All existing goniometer apps, including the Angles app, are limited in that they have a fixed frame rate that may not capture fast changes in motion. They also require that the camera be positioned perpendicular to the plane of movement and correct and consistent marking of anatomical landmarks by the user. Overall, this study showed that an app designed to measure motion across joints during static and functional activity can be valid and reliable when used in natural settings for children and adults.

Study limitations

It was not possible to perform the static positioning assessment for younger children. Moreover, younger children were encouraged to perform as many functional activities as possible; however, it was not possible to obtain the complete repertoire of movements from every child because the activities were not age appropriate for some of the youngest children. For example, running and jumping are not typical for children younger than 18 months. Future research should investigate the use of the Angles app across a wider range of users, joints, settings, and activities.

Conclusions

The current results suggest that the Angles app is a valid, reliable tool for assessing joint angles during static positioning as well as functional activity for adults and children. The app is a tool with minimal requirements yet can obtain accurate, consistent measurements. Requirements include perpendicular placement of the mobile recording device and an understanding of anatomical landmarks to identify to retrieve desired joint angles.

The Angles app is potentially affordable ($0.99), feasible to use in natural environments, and allows immediate feedback. This tool can allow therapists and athletic trainers to get a better sense of how clients use their available range of motion during meaningful activities across time and settings.

Keywords

Range of motion; Rehabilitation

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Supplier

a. SPSS; IBM Corporation.

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