Validity and Reliability of Standing Posture Measurements Using a Mobile Application

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Abstract

Objective: The purpose of this study was to evaluate the validity and reliability of standing posture assessments in asymptomatic men using the PostureScreen Mobile (PSM) iOS application.

Methods: The standing posture of 50 asymptomatic male participants (24.04 ± 1.81 years) was measured during 3 trials on the same day. The following 10 measurements using the PSM app were compared to the criterion VICON 3-dimensional analysis: from the frontal plane, shift and tilt of the head, shoulders, and hips; and from the sagittal plane, shift of the head, shoulders, hips, and knees. We used Bayesian methods to analyze the data.

Results: Compared with the VICON measurements, PSM assessments of head tilt, shoulder tilt and shift, and hip tilt and shift in the frontal plane were biased. In the sagittal plane, PSM measurements of shoulder, hip, and knee shift were biased. Only head shift in the frontal and sagittal planes were comparable between the VICON and the PSM. The VICON and PSM had similar intraclass correlations in 6 of 10 measurements. The PSM assessments of head shift and tilt and shoulder tilt in the sagittal plane were significantly less reliable than with VICON.

Conclusion: The use of the PSM app introduced significant bias in postural measurements in the frontal and sagittal plane. Until further research reports additional validity and reliability data of the PSM app, we suggest caution in the use of PSM app when highly accurate postural assessments are necessary. (J Manipulative Physiol Ther 2019;42:132-140)

Key Indexing Terms: *Posture; Standing Position; Mobile Applications*

Introduction

Posture analysis is the evaluation of the relative alignment of body parts.[1] An ideal postural alignment is thought to decrease strain on the musculoskeletal system and acute and chronic pain and discomfort.[2,3] Repetitive movements, musculoskeletal injury, pain, and muscle imbalances may lead to inefficient movement patterns, muscular compensations, and poor posture.[4-8] Postural misalignments include deviations from the ideal alignment; asymmetry between the left and right sides of the body; or segmental rotations observed in the sagittal, transverse, or frontal planes.[1,5] The assessment of posture is common in health and fitness settings because postural deviations may be associated with neck and back pain, headaches, musculoskeletal and neurological pathologies, cardiovascular-respiratory dysfunction, and physical and psychosocial well-being.[9]

Objective and reliable assessments of posture may provide information to develop an intervention to correct posture and to monitor changes in posture over time. There is no universally accepted criterion method of evaluating posture.[10] The precise measurement of the X, Y, and Z coordinate locations of reflective markers placed on anatomical landmarks allows 3-dimensional (3D) imaging technology to be used as a criterion measure for positional measurements of the human body.[11-13] Although 3D imaging is often used for motion and gait analysis, it also can be used to determine the relative position of static anatomical landmarks,[11,13,14] such as in postural assessments.[15,16] Owing to high cost of equipment, need for specialized operator training, and complex data processing, use of 3D motion analysis systems is restricted to academic and research laboratory settings. Other, more affordable methods of assessing posture are needed for health professionals to use in practice.[9]

Health care professionals could use handheld devices for the assessment of posture. Previous research[17] reported high reliability of measurements of the sacral slope and lumbar curve in 183 adults using an app[12,18] installed on a smartphone. Photographs of participants wearing reflective markers on predetermined anatomical landmarks and

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specialized computer software (ie, photogrammetry) has been used to measure various postural angles.[19-21] PostureScreen Mobile (PSM) (PostureCo, Inc., Trinity, Florida) is an affordable, user-friendly app available for iOS platforms (eg, iPad, iPhone) that is designed as a screening tool for chiropractors and physical and manual therapists who screen clients for postural deviations.[22] Using front and side-view photographs of the minimally clothed client or patient without reflective markers, the PSM app guides the user in the identification of anatomical landmarks and a rapid assessment of posture. In the frontal plane, the PSM app reports tilt and horizontal translation of the head, shoulders, and hips. In the sagittal plane, the PSM app reports forward or rearward shift measurements of the head, shoulders, hips, and knees. Although the PSM app is publicly available and widely used, to the best of our knowledge only 2 studies have investigated the reliability[23,24] and construct validity[24] of postural measurements using the PSM app in a small number of participants. A comparison of postural measurements by the PSM app and another method of assessing posture has yet to be reported in the literature. Therefore, the purpose of this study was to investigate the validity and reliability of the PSM app in assessing standing posture compared to a 3D system.

Methods

Participants

Fifty male participants with a mean age of 24.04 ± 1.81 years, height of 181.5 ± 6.7 cm, body mass of 80.9 ± 17.0 kg, and body mass index of 24.5 ± 4.0 kg/m^2 were recruited from the university student body and voluntarily participated in this study. Participants with current complaints of any type of pain were excluded from the study. This was appropriate because the purpose of the study was to determine validity and reliability of postural measurements, and pain would potentially influence posture between assessments and thereby reduce reliability. This project was approved by the Brigham Young University Institutional Review Board for Human Subjects. After being informed of all procedures of the study, each participant provided voluntary written informed consent before participating in the study.

Procedures

Standing posture of participants was evaluated using a 3D motion analysis system (VICON Motion Systems Ltd, Yarnton, Oxford, United Kingdom) as the criterion method and the PSM app. Participants wore shorts and no shirt, socks, or shoes. A mark was placed on the floor indicating where the participant was to stand during each trial. Normal standing posture was assessed during 6 trials on the same day, separated by 3 to 10 minutes. In 3 of the trials, posture was evaluated with VICON while the participant was wearing retroreflective markers placed bilaterally on the following anatomical landmarks: slightly anterior to the tragus, acromion process, anterior superior iliac spine (ASIS), greater trochanter, medial and lateral sides of the knees, and medial and lateral malleolus. Posture was evaluated in the remaining 3 trials using the PSM app. The manufacturer recommendation to assess posture without the placement of anatomical markers was followed, thereby also simulating the typical assessment of posture by practitioners. After each trial, the participant was instructed to leave the lab, walk to the end of the hallway, and return to the lab to complete the next trial. The order of the 6 trials was randomized. If a trial required the placement of retroreflective markers, the markers were removed after the trial.

PostureScreen Mobile App. Digital photographs were taken simultaneously of the frontal and right lateral view of the participant with 2 iPads mounted on tripods directly in front of and to the side of the participant. The positions of the tripods remained constant throughout the entire study to minimize variability between the 3 trials. The posture of each participant was later evaluated using the PSM app by 1 examiner. The PSM app prompts the examiner to mark specific landmarks using a zoom-in tool and a sample photo of the proper landmark placement. Using the photograph from the frontal view (Fig 1), the PSM app prompts the examiner to mark the pupils of the right and left eyes with the touchscreen of the iPad. The PSM app then prompts the marking of the upper lip, left and right acromioclavicular (AC) joints, episternal notch, left and right sides of the rib cage at approximately the eighth rib, left and right ASIS, and center of the left and right ankles. In the frontal plane, the PSM reports horizontal translation, in inches, of the head, shoulders, and hips relative to the body part below. Thus, head shift was measured relative to the episternal notch; shoulder shift was measured relative to the center of the line connecting right and left sides of the rib cage; and hip shift was measured relative to the center of the line connecting the 2 ankles. A shift to the right side of the body was recorded as a positive value, and a shift to the left side of the body was recorded as a negative value. Horizontal lines drawn between the 2 eyes, the 2 AC joints, and the left and right ASIS were used to determine tilt, in degrees, of the head, shoulders, and hips, respectively, relative to true horizontal. A tilt to the right side of the body was recorded as a positive value, and a tilt to the left side of the body was recorded as a negative value.

Using the photograph from the lateral view (Fig 2), the PSM app prompts the examiner to mark the tragus, AC joint, greater trochanter, center of the lateral knee joint, and lateral malleolus. In the sagittal plane, the anterior or posterior shift of the head, shoulders, hips, and knees were measured relative to the joint below. Thus, head shift was measured relative to the AC joint, shoulder shift was measured relative to the right ASIS, hip shift was measured relative to the knee, and knee shift was measured relative to

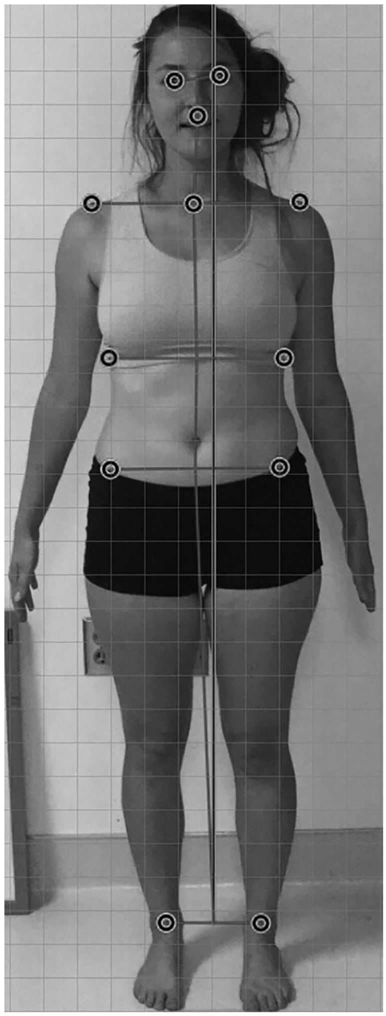

Fig 1. *Photo of a participant showing how the PostureScreen Mobile app evaluates horizontal translation and tilt of the head, shoulders, and hips from the frontal view. Also see https://www.postureanalysis.com/.*

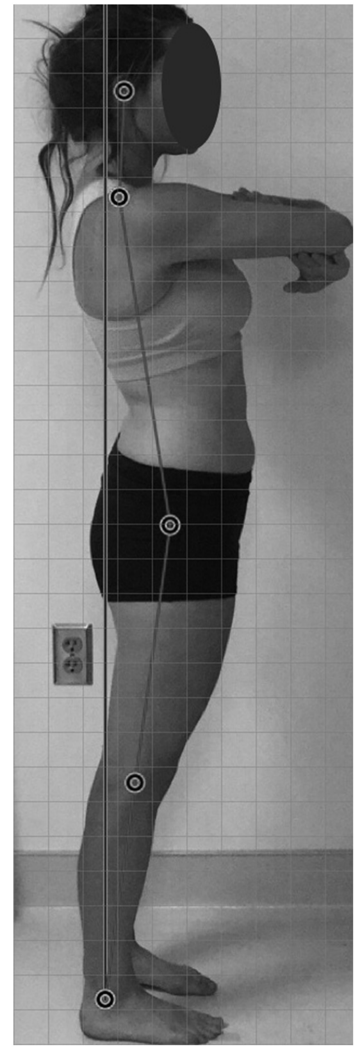

Fig 2. *Photo of a participant showing how the PostureScreen Mobile app evaluates anterior/posterior shift of the head, shoulders, hips, and knees from the lateral view. Also see https://www.postureanalysis.com/.*

the lateral malleoli of the ankle. A shift in the anterior (forward) direction was recorded as a positive value, whereas a posterior (rearward) shift was recorded as a negative value.

VICON 3D Motion Analysis System. A calibrated volume of 2 m long, 2 m wide, and 2.5 m high was created around the area where the participant was instructed to stand. The VICON captured images of the participant's standing posture with 6 MX 13+, 2 F20, and 2 T20 cameras. So shift and tilt measurements from the VICON data could follow the same pattern as measurements taken using the PSM, all possible landmarks used in the PSM app also were used during imaging with the VICON. An exception was that retroreflective markers were placed on the tragus (instead of the eyes) to allow calculation of head tilt in the frontal plane and head shift in the sagittal plane.

Data taken from the VICON were in the form of X, Y, and Z coordinates; X signifying left to right, Y signifying forward to backward, and Z signifying up and down. For each trial, 10 seconds of data or 600 frames were collected. The averages of the X, Y, and Z coordinates of the middle 3 seconds (180 frames) of each trial were used for the analysis of data. In the frontal plane, head, shoulder, and hip shift refers to left or right horizontal translation along the x-axis, and head, shoulder, and hip tilt refers to rotation about the y-axis. In the sagittal plane, head, shoulder, hip, and knee shift refers to forward or rearward translation along the y-axis.

From the frontal view, head shift was calculated as the difference between the center of the right and left AC joint X coordinates and the center of the right and left tragus X coordinates. Shoulder shift was calculated as the difference between the center of the right and left ASIS X coordinates and the center of the right and left AC joint X coordinates. Hip shift was calculated as the difference between the center of the right and left ankles and the center of the right and left ASIS X coordinates. The center of each ankle was calculated as the center of the medial and lateral malleoli. Head, shoulder, and hip tilt angles in degrees were determined with triangulation based on Z coordinates.

From the sagittal view, head shift was calculated as the difference between the right tragus Y coordinate and the right AC joint Y coordinate. Shoulder shift was computed as the difference between the right AC joint Y coordinate and the right greater trochanter Y coordinate. Hip shift was calculated as the difference between the right greater trochanter Y coordinate and the right knee joint Y coordinate. Knee shift was calculated as the difference between the right knee joint Y coordinate and the right lateral malleolus Y coordinate.

Statistical Analysis

Ten postural measurements were recorded for each trial of each participant using each method (ie, PSM and VICON): from the frontal plane—head shift and tilt, shoulder shift and tilt, and hip shift and tilt; and from the sagittal plane—head shift, shoulder shift, hip shift, and knee shift. To evaluate the bias or validity of PSM assessments of posture, postural deviations as measured with the PSM app were compared with the postural deviations as measured with the VICON. Reliability was established from the multiple trials of each method. We used Bayesian methods to analyze the data, where the evidence about the validity and reliability of PSM is expressed in terms of probability. The data are hierarchal in nature with the following structure:

$$Y_{VICONij} – N\left(\mu_{VICONi}, \sigma^2{}_{VICON}\right)$$

where the j^{th} measurement on the i^{th} individual using the VICON is normally distributed with a mean (μ_{VICONi}) and variance ($\sigma^2{}_{VICON}$). For the PSM data, we further assumed the following structure:

$$Y_{PSMij} – N\left(\mu_{VICONi} + \delta, \sigma^2{}_{VICON}/\gamma\right)$$

where the j^{th} measurement on the i^{th} individual using PSM is normally distributed with the mean equal to $\mu_{VICONi} + \delta$, and variance equal to $\sigma^2{}_{VICON}/\gamma$. Delta ($\delta$; $\mu_{PSM} - \mu_{VICON}$) is a measure of the bias of PSM relative to VICON, and gamma (γ) is the ratio of the variance of VICON measurements to the variance of PSM measurements. We used delta as a measure of validity. A Delta of zero indicates that there is no bias between the means. A positive delta value indicates that PSM overestimated the VICON measurement, whereas a negative delta value indicates that PSM underestimated the VICON measurement.

To evaluate reliability, the intraclass correlation coefficients (ICCs) were calculated for the VICON and PSM as:

$$ICC_{VICON} = \sigma^2{}_{ind}/\left(\sigma^2{}_{ind} + \sigma^2{}_{VICON}\right)$$

$$ICC_{PSM} = \sigma^2{}_{ind}/\left(\sigma^2{}_{ind} + \sigma^2{}_{VICON}/\gamma\right)$$

where $\sigma^2{}_{ind}$ is the individual variability. Thus, the ICC is the ratio of the individual variability to the individual variability plus the variability in the replicate measures. A large ICC (ie, replicate variability is low relative to the individual variability) indicates a highly reliable measure. Considering the VICON to be the criterion measure, ICC values for each of the 10 measurements by each method were of less import than the ratio of the ICC_{VICON} to the ICC_{PSM}. A ratio near 1.0 indicates that the 2 methods are equally reliable.

A Bayesian approach to the analysis of the data produces posterior distributions of the parameters of interest, namely delta (δ), gamma (γ), ICC_{VICON}, and the ICC_{PSM}. The posterior distributions were used to determine 99.75% credible intervals (CIs) for delta and the ICC_{VICON}-to-ICC_{PSM} ratio. A conservative 99.75% CI was chosen to use a Bonferroni correction owing to the number of CI being computed. The 99.75% CI for delta defines the range within which there is a 99.75% probability that the true value of delta lies. Because a delta of zero (0) indicates no bias, if zero (0) fell within the 99.75% CI of delta, we concluded that the PSM mean was an unbiased estimate of the value measured by the VICON. If 1.0 fell within the CI for the ICC_{VICON}-to-ICC_{PSM} ratio, we concluded that the PSM measurement has comparable reliability compared with VICON measurements.

In the Bayesian framework, the model consists of the scaled product of the likelihood of the data given the parameters and prior probability densities for each of the parameters.[25,26] Current practice to analyze such a model is to implement a Markov Chain Monte Carlo procedure to produce samples from the posterior distributions of interest.[27,28] The program JAGS[29] was used to generate the samples from the posterior distributions using Markov Chain Monte Carlo. The sampling chains were then analyzed using the program R.[30]

Results

All 50 male participants completed all trials. Table 1 shows the means of each of the 10 postural measurements using the VICON and the PSM and the 99.75% CI of the bias between the 2 methods.

Compared with VICON measurements, 8 of 10 PSM measurements were biased. Table 2 shows the point estimates of the ICC values of VICON and PSM postural measurements, the ICC_{VICON}-to-ICC_{PSM} ratio, and the 99.75% CI of the ratio. The VICON and PSM were equally

Table 1. *Validity of Postural Assessments Using PostureScreen Mobile App*

	VICON 3D	PostureScreen Mobile	
Postural Measurement	Mean	Mean	Bias (99.75% CI)
Frontal plane			
Head shift	0.13 ± 0.04	0.23 ± 0.04	0.09 ± 0.03 (-0.0003 to 0.18)
Head tilt	0.70 ± 0.37	1.48 ± 0.42	0.79 ± 0.24 (0.04-1.53) [a]
Shoulder shift	-0.20 ± 0.04	0.19 ± 0.04	0.39 ± 0.04 (0.27-0.51) [a,b]
Shoulder tilt	0.68 ± 0.20	1.59 ± 0.22	0.91 ± 0.13 (0.50-1.33) [a]
Hip shift	-0.17 ± 0.06	0.25 ± 0.07	0.41 ± 0.07 (0.21-0.61) [a,b]
Hip tilt	0.11 ± 0.21	0.74 ± 0.21	0.63 ± 0.16 (0.13-1.12) [a]
Sagittal plane			
Head shift	1.68 ± 0.11	1.55 ± 0.11	-0.14 ± 0.06 (-0.32; 0.04)
Shoulder shift	-0.23 ± 0.11	-0.57 ± 0.10	-0.34 ± 0.06 (-0.53; -0.15) [a,b]
Hip shift	0.24 ± 0.11	0.90 ± 0.10	0.66 ± 0.06 (0.47; 0.85) [a,b]
Knee shift	2.16 ± 0.12	1.08 ± 0.12	-1.08 ± 0.05 (-1.24; -0.92) [a,b]

CI, credible interval; *SD*, standard deviation.
Bias = mean difference (99.75% CI) between PostureScreen Mobile and the VICON 3D motion analysis system.
Values are mean ± SD. Shifts are measured in inches. Tilts are measured in degrees.
[a] Statistical bias between PostureScreen Mobile and the VICON 3D motion analysis system.
[b] Bias is greater than clinically acceptable (>5 mm or 5°).

reliable in measuring 6 of 10 postural measurements. The VICON was more reliable than the PSM in measuring 3 of 10 postures, and the PSM was more reliable than the VICON in 1 of the measurements of posture (Table 2).

Discussion

To the best of our knowledge, this is the first study to report measures of validity of the PSM app, a publicly available postural screening tool designed for use by health professionals. Use of the PSM app to assess posture resulted in statistically significant bias in 8 of 10 postural measurements (Table 1). Measurements of head shift in the frontal and sagittal planes were the only 2 measurements that were not statistically different between VICON and the PSM app. Harrison et al hypothesized that horizontal and vertical translation measurements with an error (bias) of less than 5 mm and rotations with a bias of less than 5° are acceptable for clinical use.[31] When posture was assessed using the PSM app, 5 of 10 postural measurements exceeded this definition of clinically acceptable bias (Table 1). Clinically significant bias was apparent only when measuring horizontal translation in the x-axis and forward or rearward translation in the y-axis (ie, shift). All the measurements of rotational translation in the y-axis (ie, tilt) had acceptable levels (<5°) of bias (Table 1). The criteria of an acceptable bias of less than 5 mm in horizontal and vertical displacement is appropriate when comparing a measured body position to a known position of a mannequin,[31] but the range of acceptable values may be greater when studying humans who normally have some degree of sway in the standing position.

The ICC values of postural measurements using the PSM app with 50 participants in this study (Table 2) tend to be lower than those recently reported in 10 participants.[23] The differences in the ICC values may be attributed to differences in sample size or sex. The wide range of ICCs in this study (Table 2) concurs with previously reported ICCs between 0.1 and 0.95 when using the PSM app[23] and 0.13 and 0.69 when using photographs to measure posture.[32] High trial-to-trial variability in posture rather than operator error has previously been reported,[11,23,33] thus low ICC values may be a result of postural sway in the standing position.[34] Two important observations can be made from the reliability data (Table 2). The lowest ICC values for both methods were observed in measuring shoulder and hip shift in the frontal plane. Second, both methods had lower ICC values for measurements of shift in the frontal plane

Table 2. *Reliability Estimates of VICON 3D and PostureScreen Mobile App Assessments of Posture*

Postural Measurement	VICON 3D ICC	PostureScreen Mobile ICC	ICC Ratio (99.75% CI)
Frontal plane			
Head shift	0.81 ± 0.04	0.40 ± 0.06	2.07 ± 0.27 (1.43-3.13) [a]
Head tilt	0.82 ± 0.04	0.44 ± 0.06	1.88 ± 0.23 (1.37-2.79) [a]
Shoulder shift	0.36 ± 0.09	0.34 ± 0.07	1.08 ± 0.21 (0.58-1.88)
Shoulder tilt	0.75 ± 0.05	0.45 ± 0.06	1.69 ± 0.20 (1.20-2.50) [a]
Hip shift	0.30 ± 0.07	0.23 ± 0.08	1.35 ± 0.33 (0.56-2.52)
Hip tilt	0.45 ± 0.07	0.46 ± 0.07	0.99 ± 0.14 (0.65-1.48)
Sagittal plane			
Head shift	0.66 ± 0.07	0.66 ± 0.06	1.00 ± 0.09 (0.73-1.30)
Shoulder shift	0.55 ± 0.07	0.66 ± 0.07	0.83 ± 0.10 (0.58-1.17)
Hip shift	0.53 ± 0.07	0.74 ± 0.05	0.72 ± 0.07 (0.51-0.96) [b]
Knee shift	0.79 ± 0.05	0.74 ± 0.05	1.08 ± 0.09 (0.82-1.40)

CI, credible interval; *ICC*, intraclass correlation coefficient.
Values are point estimates for ICC. ICC ratio = the ratio (99.75% CI) of the ICC for VICON divided by the ICC for the PostureScreen Mobile.
[a] VICON 3D significantly more reliable than PostureScreen Mobile.
[b] PostureScreen Mobile significantly more reliable than VICON 3D.

compared with measurements of tilt in the same body part. Shift measurements in the frontal plane appear to present challenges even when using the criterion measure.

The similar reliability of PSM measurements compared with VICON measurements in 6 of 10 postural measurements is promising, especially considering that the patterns in the ICC noted above are similar in both PSM and VICON measurements. The PSM app measurement of hip shift in the sagittal plane (Table 2) had an ICC that was greater than the VICON, which we speculate is due to chance. The reliability of VICON postural assessments reflects both the naturally occurring trial-to-trial variability in posture as well as the trial-to-trial variability in marker placement. The data presented in this study likely represent the variability between sequential postural measurements in a clinical setting. Dunk et al previously suggested that posture must be consistent enough to detect changes that occur as a result of an intervention.[35] Based on the variability of posture observed in this study, the effectiveness of tracking postural changes resulting from interventions is questionable. If the analysis of posture is used to detect changes resulting from an intervention, then the measured changes must be larger than the normal variation in posture (day-to-day, or repositioning).

One advantage of using the PSM app is that posture can be assessed without palpation and placement of anatomical markers, which preserves patient or client privacy, saves time, and reduces cost. Nevertheless, the bias in postural measurements in 8 of 10 measurements (Table 1) and lower ICC values in 3 of 10 measurements (Table 2) when using the PSM app suggest that use of photographs and touchscreen technology may have some inherent sources of error. One possible source of error may be an inherent difficulty in identifying anatomical landmarks using the PSM app. Although the zoom feature of the app is intended to help identify anatomical landmarks on the photos, improved resolution to reduce pixilation of the enlarged area of the photograph would improve this feature. Some error may simply be due to the size of the fingerprint in using a touchscreen. The use of a stylus may reduce bias and variability. Errors may also occur if the camera is positioned incorrectly relative to the participant. The PSM app includes features to ensure that the iPad camera is positioned correctly; specifically, when taking photographs, a set of crosshairs appears on the screen, which turns green when the camera is level. Problems arise when the camera is positioned obliquely to the participant—in which case the camera can be leveled correctly, but the photos may result in erroneous postural measurements.[36] For the most accurate data, the camera must be positioned square to the participant. In this study, photos were taken with participants standing on the same marked area of the floor with the iPad camera directly in front of them or directly perpendicular to them. We recommend that postural assessments be made in clothing that permits easy visual identification of anatomical landmarks, specifically those of the shoulders, hips, and knees. In this study, participants wore only spandex shorts and the chest, shoulders, legs, and feet were bare. Only men were recruited in this preliminary study to allow wearing of minimal attire. However, because bias was observed in this study despite the fact that participants were wearing minimal clothing, we expect that assessing posture in patients or clients who are wearing loose shorts, t-shirts, leg length pants, blouses, and so on could potentially introduce greater bias and variability in postural measurements.

Clinical Implications

We found the PSM app to be user friendly and able to assess posture in a timely manner. The use of photographs and lines drawn on the photographs indicating deviations in posture are meaningful for screening and educating individuals about posture. The ability to store photographs and compare one set of photographs to another is useful in monitoring the effects of corrective exercises on posture over time. These features may be of importance to clinicians as postural deviations are often present with a variety of symptoms. Owing to the suspected trial-to-trial variation in posture, single postural assessments and serial measurements intended to detect improvement in posture over the course of an intervention should be interpreted with caution.

Limitations

Only male participants were included in this study. It is possible that the inclusion of female participants may have resulted in different findings, although it may be reasonable to assume that if landmarks can be accurately identified on the female body, similar results could be expected. Although 2 recent studies evaluated posture in men and women, they had a small sample of participants,[23,24] had unequal numbers of men and women,[24] and did not report sex differences.[23,24] Thus, additional studies are warranted in women and in mixed samples of participants to determine whether sex differences exist. In addition, we anticipate that bias and variation in postural measurements would be greater in populations who have difficulty maintaining a standing position, for example, the elderly and frail or individuals with complaints of pain. We only included asymptomatic participants in this study. Thus, we are not able to make conclusions about validity or reliability of the PSM app in evaluating posture in people who have pain or other symptoms.

Another limitation is that VICON measurements represented an average of 3 seconds of X, Y, and Z coordinate data. Averaging 3 seconds of data would tend to reduce variances in posture that may normally occur in the standing position, thereby improving trial-to-trial variability and ICCs. Photos used in PSM represent only a single moment in time, depicting a single point within the normal variance in posture. Mannequins could be used in future studies to separate administrator error and normal trial-to-trial variation in posture. Although in this study only 1 investigator was responsible for placement of the retroreflective markers on the participants, some variability in the placement of markers between trials could be expected. In studies that use 3D imaging, such as gait analysis research, marker displacement is a major source of error.[37,38] Future studies could report the trial-to-trial variation in posture by leaving retroreflective markers attached between trials. This study only evaluated the variability in posture as assessed by a single administrator. Although 2 recent studies reported high ICC values between examiners,[23,24] further evaluation of the bias and variability of postural measurements by multiple investigators is warranted.

Conclusion

The use of the PSM app introduced significant bias in postural measurements in the frontal and sagittal planes. Until further research reports additional validity and reliability data of the PSM app, we suggest caution in the use of PSM app when highly accurate postural assessments are necessary.

Funding Sources and Conflicts of Interest

No funding sources or conflicts of interest were reported for this study.

Contributorship information

Concept development (provided idea for the research): B.B.H., P.R.V.
Design (planned the methods to generate the results): B.B.H., P.R.V., G.W.F., J.D.G., R.H.
Supervision (provided oversight, responsible for organization and implementation, writing of the manuscript): P.R.V.
Data collection/processing (responsible for experiments, patient management, organization, or reporting data): B.B.H., S.T.R.
Analysis/interpretation (responsible for statistical analysis, evaluation, and presentation of the results): G.W.F.
Literature search (performed the literature search): B.B.H., P.R.V.
Writing (responsible for writing a substantive part of the manuscript): B.B.H., P.R.V.
Critical review (revised manuscript for intellectual content, this does not relate to spelling and grammar checking): J.D.G., R.H., S.T.R.

Practical Applications

- The present study showed that postural measurements in the frontal and sagittal planes using the PSM app were biased.
- A high variability in standing posture between trials may make it difficult to assess improvement in posture after an intervention.
- Bias and reliability of assessments of posture using photographic methods may be affected by clothing worn by the participants.

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