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Validity of PostureScreen Mobile® in the Measurement of Standing Posture

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ABSTRACT

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Background: PostureScreen Mobile® is an app created to quickly screen posture using front and side-view photographs. There is currently a lack of evidence that establishes PostureScreen Mobile® (PSM) as a valid measure of posture. Therefore, the purpose of this preliminary study was to document the validity and reliability of PostureScreen Mobile® in assessing static standing posture. *Methods:* This study was an experimental trial in which the posture of 50 male participants was assessed a total of six times using two different methods: PostureScreen Mobile® and Vicon 3D motion analysis system (VIC). Postural deviations, as measured during six trials of PSM assessments (3 trials with and 3 trials without anatomical markers), were compared to the postural deviations as measured using the VIC as the criterion measure. Measurement of lateral displacement on the x-axis (shift) and rotation on the y-axis (tilt) were made of the head, shoulders, and hips in the frontal plane. Measurement of forward/rearward displacement on the Z-axis (shift) of the head, shoulders, hips, and knees were made in the sagittal plane. Validity was evaluated by comparing the PSM measurements of shift and tilt of each body part to that of the VIC. Reliability was evaluated by comparing the variance of PSM measurements to the variance of VIC measurements. The statistical model employed the Bayesian framework and consisted of the scaled product of the likelihood of the data given the parameters and prior probability densities for each of the parameters. *Results:* PSM tended to overestimate VIC postural tilt and shift measurements in the frontal plane and underestimate VIC postural shift measurements in the sagittal plane. Use of anatomical markers did not universally improve postural measurements with PSM, and in most cases, the variance of postural measurements using PSM exceeded that of VIC. The patterns in the intraclass correlation coefficients (ICC) suggest high trial-to-trial variation in posture. *Conclusions:* We conclude that until research further establishes the validity and reliability of the PSM app, it should not be used in research or clinical applications when accurate postural assessments are necessary or when serial measurements of posture will be performed. We suggest that the PSM be used by health and fitness professionals as a screening tool, as described by the manufacturer. Due to the suspected trial-to-trial variation in posture, we question the usefulness of a single postural assessment.

Keywords: posture, Vicon, body alignment, standing posture, PostureScreen Mobile

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TABLE OF CONTENTS

List of Tables

Table

List of Figures

Figure

INTRODUCTION

Advances in technology and automation in the past 30 y has contributed to significant changes in lifestyle. The infusion of computers, television and automation has affected personal and occupational physical activity behaviors of children, youth, and adults [1-4]. The majority of the population does not perform the recommended daily amount of physical activity [5] and large portions of the population sit at a computer or in front of a television for extended periods of time, even during nonworking hours [5, 6]. It is likely that the decline in physical activity and the repetitive habitual movements of daily living and work has contributed to the increase in complaints of musculoskeletal pain over the last 40 y [7]. Repetitive movements, musculoskeletal injury, and pain may result in muscle imbalances [10,14, 45-47] which can lead to inefficient movement patterns, muscular compensations, and poor posture [5, 6].

Muscular stability and mobility, skeletal structure, and muscular balance all influence postural alignment [8, 9]. The musculoskeletal structure is a kinetic chain, and therefore, muscle imbalances, injury or misalignments in one part of the body can cause compensations and postural misalignments in another part of the body [10, 11]. Postural misalignments include deviations from the ideal, asymmetry between the left and right sides of the body, or segmental rotations [8, 12] observed in the sagittal, transverse or frontal planes. Depending on the severity of the postural deviations, poor posture may result in pain and can affect physical function and the ability to perform activities of daily living [13].

Valid and reliable assessments of posture are important in that they provide information that can be used to develop an appropriate intervention to correct posture and can be used to monitor changes in posture during an intervention. Postural evaluations are done with subjective measurements[14], handheld tools [15, 16], photographs [9, 17] , x-ray images [9, 18], and three-dimensional images [19-21]. Three-dimensional motion analysis imaging requires the placement of passive retroreflective markers on anatomical landmarks. Near-infrared light emitted from near the camera lenses is reflected back to the cameras and is used to determine the position of the markers as X, Y and Z coordinates. The position of markers relative to each other can be used to determine distances between markers and angles of joints. Due to the precise measurement of the location of reflective markers, 3D imaging technology is a criterion measure for positional measurements of the human body [22, 23]. Although 3D imaging is often used for motion and gait analysis, it can also be used to determine the relative position of static anatomical landmarks [22-24], such as in postural assessments.

Three-dimensional imaging requires specialized training in the use of expensive equipment and calculation of results from thousands of data points. As such, 3D imaging is often reserved for clinical or laboratory use [25]. The assessment of posture by health professionals in either setting is often constrained by time and cost. Several studies have found low-cost photographic methods of assessing standing and sitting posture to have satisfactory reliability [17, 18, 26]. PostureScreen Mobile® (PostureCo, Inc., Trinity, FL) is a relatively new device that makes the assessment of posture in a variety of settings more efficacious. PostureScreen Mobile® (PSM) is designed for chiropractors, physical and manual therapists and other fitness professionals that screen clients for postural deviations [27]. It is user-friendly, quick, affordable and noninvasive for clients and patients. The PSM app can be installed on portable devices, such as an iPad. Using front and side-view photographs of the client or patient, the PSM directs the user in the identification of anatomical landmarks for a rapid assessment of posture. Designed as a screening tool, PSM has educational value for patients and clients for whom posture is being assessed. To the best of our knowledge the validity and reliability of PSM has yet to be reported in the literature. Therefore, the purpose of this study is to determine the validity and reliability of PSM in assessing static standing posture.

METHODS

Study Design

In this study, the Vicon 3D (VIC) motion analysis system (VICON Motion Systems Ltd, UK) was used as a criterion measure of postural alignment, to which the assessments of posture by the PSM were compared. The posture of each participant was assessed three times using VIC and PSM simultaneously while the subject was wearing anatomical reflective markers and an additional three times using PSM while the subject was not wearing anatomical reflective markers. To evaluate the bias, or validity of PSM assessments of posture, postural deviations as measured during all six trials using PSM were compared to the postural deviations as measured during the three trials using the VIC. We assessed posture during multiple trials to establish the reliability of each method.

Participants

Fifty male participants over 18 y of age participated in this study. All participants were recruited from the local community and University faculty, staff and students. Participants were recruited using flyers and classroom announcements. Participants with complaints of any type of current pain or the inability to stand pain-free for one hour were excluded from the study. There were no inclusion or exclusion posture criteria. This project was approved by the University Institutional Review Board for the use of Human Subjects in Research. After being informed of all procedures and any potential risk associated with participating in the research, each participant provided voluntary written informed consent prior to participating in the study.

Procedures

Before participants entered the lab, all static and dynamic calibrations were performed on the VIC. Qualified participants came to the research lab wearing exercise clothing appropriate for data collection. Participants read and signed all necessary consent forms. Participants' height was measured to the nearest 0.5 cm using a standard wall scale and body mass was measured to the nearest 0.1 kg using a digital scale (Ohaus Model CD-33, Ohaus Corporation, Pine Brook, NJ, USA). For all trials, participants wore shorts and no shirt, socks or shoes.

Posture was assessed during 6 trials on the same day, separated by 3 to 10 min. Three of the 6 trials were performed on each participant using the VIC and all 6 trials were performed on each participant using the PSM. Three of the PSM trials were performed at the same time as the VIC while the participant was wearing retroreflective markers that identified anatomical landmarks used in the postural analysis. The remaining 3 PSM trials were performed while the participant was not wearing anatomical markers. The order of the 6 trials was randomized. The participant drew one piece of paper out of a box that identified the nature of the trial to the investigator and the paper was not returned to the box after it was drawn. After completing each trial, the participant picked another paper from the box to determine the next trial. To minimize any possible bias in standing posture by the participants, they were informed that one of the purposes of the research was to evaluate their ability to balance on one leg; however, the actual purpose of the assessment was to evaluate bilateral standing posture.

<u>*PostureScreen Mobile®*</u>. In a nonresearch setting, markers are not typically employed to identify anatomical landmarks before photographs are taken. When using PSM, photographs are taken using an iPad and saved for later analysis of posture. During the analysis, the examiner identifies anatomical landmarks using the touchscreen on the iPad. In this study, 3 of the 6 trials

included digital photographs of the participant while wearing retroreflective markers and the remaining 3 trials included digital photographs of the participant when he was not wearing retroreflective markers. The 3 trials with retroreflective markers were included in the study so posture could be assessed using the VIC and PSM using identical anatomical markers. The 3 trials without retroreflective markers were included in the study to simulate the typical assessment of posture by practitioners.

Participants were asked to stand on a specific area of the floor directly in front of and to the side of the two iPad cameras. Participants were then asked to balance on the right leg for 10 seconds, the left leg for 10 seconds and then to stand stationary on both legs. While the participant was standing stationary on both legs, one digital photograph was taken of the frontal view, while another photograph was taken of the right lateral view (Figure 1). Photographs were taken with two iPads that were mounted on identical tripods throughout the entire study to minimize variability among photographs. After both photos were taken, the participant was instructed to leave the room and walk to the end of the hallway and return to the lab. Once they returned to the lab, they were instructed to pick another paper from the box.

Vicon 3D Motion Analysis System. The participant was fitted with sixteen 12.5 mm retroreflective markers that were used as reference points for the VIC. Retroreflective markers were placed bilaterally on the following anatomical landmarks: slightly anterior to the tragus, acromion process, anterior superior iliac spine (ASIS), greater trochanter, knees on the medial and lateral sides and medial and lateral malleolus (Figure 2). Six MX 13+, two F20 and two T20 cameras were used to record marker position. A daily-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.

Following the same pattern as with the PSM, participants were instructed to balance on the right leg for 10 seconds, the left leg for 10 seconds and then to stand stationary on both legs. The VIC captured their standing posture while standing on both legs. While the VIC was collecting this data, the test administrators captured photos with the two iPads in the PSM program. All the retroreflective markers were then removed. The participant was instructed to leave the room, walk to the end of the hallway, and then return to the lab. Once they returned to the lab, they were instructed to pick another paper from the box. Retroreflective markers were removed after each trial since the randomization of trials may result in the subsequent trial not requiring the use of retroreflective markers. Participants were dismissed after the 6 trials were completed.

Data Analysis

PostureScreen Mobile®. After data collection, PSM digital photographs were analyzed by one examiner. To analyze the posture of each participant using PSM, the photographs from the frontal view and the lateral view were used. Using the photograph from the frontal view, PSM first prompts the examiner to mark the right pupil of the eye with the touchscreen of the iPad. All marking prompts include a zoom-in tool and a sample photo of the proper marker placement. The zoom-in tool was used for proper placement of the marker. To create a horizontal line between the eyes, the system then prompts the marking of the left pupil with the same zoom-in tool. This line calculates the measurement of the head tilt (right or left) in degrees. The system then prompts the marking of the upper lip, the left acromioclavicular (AC) joint, episternal notch and the right AC joint. Another horizontal line is created between the left and right AC joints. The administrator is then prompted to mark the left and right sides of the rib cage; at approximately the 8^{th} rib. The left and right ASIS are then identified and marked. The last two markings are on the center of the left and right ankles.

Using the photograph from the lateral view, PSM prompts the examiner to mark the tragus with the touchscreen. This is followed by the marking of the AC joint, the greater trochanter, the center of the lateral knee joint, and the lateral malleolus.

Postural deviation data taken from the PSM included frontal plane measurements of the 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 two ankles. A shift to the right side of the body was recorded as a positive value, whereas a shift to the left side of the body was recorded as a negative value. Frontal plane measurements also included tilt, in degrees, of the head, shoulders, and hips relative to true horizontal. A tilt to the right side of the body was recorded as a positive value, whereas a tilt to the left side of the body was recorded as a negative value.

Postural deviations of the head, shoulders, hips, and knees were also measured from the sagittal plane from the right side of the body. The anterior or posterior shift of the head, shoulders, hips, and knees were measured relative to the joint below. Hence, head shift was measured relative to the AC joint of the right shoulder, shoulder shift was measured relative to the right ASIS, hip shift was measured relative to the right knee, and knee shift was measured relative to the lateral malleoli of the right 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. To properly evaluate PSM, all landmarks used during imaging with the VIC (where possible) were the same as those used by PSM. Thus, shift and tilt measurements from the VIC data followed the same pattern as measurements taken using the PSM. There were some markers that required modification. For example, the eyes could not be marked with sticky retroreflective markers, so markers were placed on the tragus. This placement still allowed calculation of head tilt and proper analysis of the sagittal plane postural assessment. The retroreflective markers placed on the lateral and medial malleolus were used to determine the center of the ankles.

Data taken from the VIC included shift and tilt measurements from the frontal plane and shift measurements taken from the sagittal plane. Data gathered was 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 s of data or 600 frames were collected. The averages of the X, Y, and Z coordinates of the middle 3 s (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 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 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, shoulder, hip and knee shift was calculated relative to the anatomical landmark below it. Thus, 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 (i.e., PSM and/or VIC): 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. 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 following equations formed the basis for the analysis. We assumed:

$$Y_{VICij} \sim N(\mu_{VICi}, \sigma^2_{VIC}) \qquad \text{Equation 1}$$

That is, the j^{th} measurement on the i^{th} individual using the VIC is normally distributed with a mean (μ_{VICi}) and variance (σ^2_{VIC}).

PSM data were collected under two scenarios: three trials using markers to identify anatomical landmarks and three trials without markers. We further assumed:

$$Y_{PSMij} \sim N(\mu_{VICi} + \delta_2, \sigma^2_{VIC}/T_2) \qquad \text{Equation 2}$$

$$Y_{PSMij} \sim N(\mu_{VICi} + \delta_3, \sigma^2_{VIC}/T_3) \qquad \text{Equation 3}$$

That is, the j^{th} measurement on the i^{th} individual using PSM with markers is normally distributed with the mean equal to $\mu_{VICi} + \delta_2$ and variance equal to σ^2_{VIC}/T_2. Thus, Delta$_2$ (δ_2) is a measure of the bias of PSM with markers relative to VIC, while Tau$_2$ (T_2) is a measure of the variance inflation (or deflation) of PSM with markers relative to VIC. Similarly, Delta$_3$ (δ_3) is a measure of the bias of PSM without markers relative to VIC, and Tau$_3$ (T_3) is a measure of the variance inflation (or deflation) of PSM without markers relative to VIC. We are using Delta, or the bias, as a measure of validity. A Delta of zero would indicate that there is no bias between the means. A positive Delta value indicates that PSM overestimated the VIC measurement, whereas a negative Delta value indicates that PSM underestimated the VIC measurement. An 80% credible interval (CI) was calculated for δ_2 and δ_3. The 80% CI defines the range within which we have an 80% probability that the true value of Delta lies. Since a Delta of zero (0) indicates no bias, if zero (0) fell within the 80% CI of Delta, we concluded that the estimate of the mean by PSM was an unbiased, or valid estimate of the value measured by the VIC.

In equations 2 and 3, Tau$_2$ (T_2) and Tau$_3$ (T_3) represent the ratio of the variance of the VIC data to the variance of the PSM data with and without markers, respectively. We are using Tau as a measure of reliability. A Tau of 1 would indicate that the variance of the data is equivalent between the two methods. A Tau value that is greater than 1 indicates that the variance of PSM data is less than the variance of VIC data. A Tau value that is less than 1 indicates that the variance of PSM data is greater than the variance for the VIC data. For example, a Tau of 0.5 indicates that the variance of PSM measurements is twice as large as the variance of VIC measurements (i.e., 1 / 0.5 = 2). An 80% CI was calculated for T_2 and T_3. If one (1) fell within the 80% CI of Tau, we concluded that PSM produces measurements with the same level of variability as the VIC, or in other words, is equally reliable.

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 [28, 29]. Current practice to analyze such a model is to implement a Markov Chain Monte Carlo (MCMC) procedure to produce samples from the posterior distributions of interest [30, 31]. The program Just Another Gibbs Sampler (JAGS) [32] was used to generate the samples from the posterior distributions using MCMC. The sampling chains were then analyzed using the program R [33].

RESULTS

Fifty male participants with a mean age of 24.04 ± 1.81 y, mean height of 181.5 ± 6.7 cm, mean body mass of 80.9 ± 17.0 kg, and a mean body mass index of 24.5 ± 4.0 kg/m^2 participated in this study. All 50 participants completed three trials during which posture was assessed using the VIC and PSM. All 50 subjects also completed three additional trials during which posture was assessed using PSM without anatomical markers placed on the body. For each trial of all 50 subjects, the 10 standing postural assessments previously described were measured. These included: head tilt, head shift, shoulder tilt, shoulder shift, hip tilt and hip shift from the frontal view; and head shift, shoulder shift, hip shift and knee shift from the sagittal view.

The means and variances for each of the ten postural measurements using the VIC and the PSM are shown in Tables 1 and 2. Included in each table are Delta and Tau values (and their 80% CI), which are indicators of validity and reliability, respectively. Table 1 includes postural measurements using PSM with anatomical markers and Table 2 includes postural measurement using PSM without anatomical markers. Mean intraclass correlation coefficients (ICC) of VIC and PSM postural measurements are shown in Table 3.

Frontal Plane Measurements

Head Shift. Compared to VIC measurements, there was no bias (δ_2 = -0.03 ± 0.03 inches) in the PSM measurements of head shift when anatomical markers were used (Table 1). When anatomical markers were not used (Table 2), PSM significantly overestimated (δ_3 = 0.09 ± 0.03 inches) the VIC measurement of head shift. Compared to the VIC, there was significantly greater variance in the measurement of head shift when it was measured using PSM both with (Table 1) and without (Table 2) anatomical markers. The variance of head shift measurements using PSM with (T_2 = 0.46) and without (T_3 = 0.43) anatomical markers was nearly twice as large as the variance when using the VIC. The variance in head shift measurements using PSM with and without anatomical markers was nearly identical and appears to be independent of whether anatomical markers were used or not. The VIC and PSM ICCs ranged from fair (0.41 to 0.60) to moderate (0.61 to 0.80) (Table 3).

Head Tilt. Measurements of head tilt were significantly overestimated using PSM both when using (δ_2 = 0.58 ± 0.27 degrees) (Table 1) and not using (δ_3 = 0.78 ± 0.24 degrees) (Table 2) anatomical markers. The variance in the measurement of head tilt using PSM with and without anatomical markers was significantly greater than the variance in the VIC measurement of head tilt. The small Tau values (T_2 = 0.26; T_3 = 0.21) indicate that the variance of PSM measurement of head tilt with and without anatomical markers was 3.8 to 4.7 times as large as the variance of VIC measurements. The variance components of PSM measurements of head tilt were not statistically significant from each other, therefore the use of anatomical markers had no effect on the variance of PSM measurements of head tilt. Use of the VIC to assess posture resulted in a strong ICC (> 0.8) while PSM measurements resulted in fair ICCs (Table 3).

Shoulder Shift. The measurements of shoulder shift as measured by VIC were significantly overestimated by PSM when using markers ($\delta_2 = 0.41 \pm 0.04$ inches) (Table 1) and when not using markers ($\delta_3 = 0.39 \pm 0.04$ inches) (Table 2). The Tau values ($T_2 = 1.75$; $T_3 = 1.33$) indicate that shoulder shift measurements using PSM with and without anatomical markers were significantly less variable than the VIC measurements of shoulder shift. Both VIC and PSM measurements of shoulder shift demonstrated poor to fair ICCs (Table 3).

Shoulder Tilt. The PSM measurements of shoulder tilt significantly overestimated VIC measurement of shoulder tilt when using markers (0.49 ± 0.15 degrees) (Table 1) and when not using markers (0.91 ± 0.13 degrees) (Table 2). The bias of PSM measurements of shoulder tilt was significantly greater when not using anatomical markers than when using anatomical markers. Compared to VIC measurements, the variability of PSM measurements of shoulder tilt was significant and about 1.4 times the variance of VIC measurements ($T_2 = 0.74$; $T_3 = 0.69$) (Tables 1 and 2). The VIC and PSM ICCs of shoulder tilt measurements were fair to moderate (Table 3).

Hip Shift. The PSM measurements of hip shift significantly overestimated hip shift as measured by the VIC both when using markers ($\delta_2 = 0.43 \pm 0.08$ inches) (Table 1) and when not using markers ($\delta_3 = 0.41 \pm 0.06$ inches) (Table 2). The large Tau values ($T_2 = 1.39$; $T_3 = 1.81$) indicate that hip shift measurements using PSM with and without anatomical markers were significantly less variable than the VIC measurements of hip shift. The VIC and PSM ICCs of hip shift measurements were poor to fair (Table 3).

Hip Tilt. The PSM measurements of hip tilt significantly overestimated measurements of hip tilt using the VIC both when using markers ($\delta_2 = 0.57 \pm 0.18$ degrees) (Table 1) and when not using markers ($\delta_3 = 0.60 \pm 0.16$ degrees) (Table 2). The variance in the PSM measurements of hip tilt with anatomical markers ($T_2 = 0.92$) and without anatomical markers ($T_3 = 0.86$) were similar to VIC measurements of hip tilt. The VIC and the PSM (with and without anatomical markers) demonstrated fair ICCs in the measurement of hip tilt (Table 3).

Sagittal Plane Measurements

Head Shift. The PSM significantly overestimated head shift in the sagittal plane when anatomical markers were used ($\delta_2 = 0.09 \pm 0.05$ inches) (Table 1) and significantly underestimated head shift when anatomical markers were not used ($\delta_3 = -0.14 \pm 0.06$ inches) (Table 2). Compared to VIC measurements, the variance of head shift measurements using PSM was 1.6 times less ($T_2 = 1.61$) (Table 1) when using the same anatomical markers and about 1.6 times greater ($T_3 = 0.63$) (Table 2) when not using any anatomical markers. The measurement of head shift resulted in moderate to high ICCs (Table 3). PSM, with markers, resulted in a very strong ICC (0.84) (Table 3).

Shoulder Shift. Compared to the VIC, there was no bias in the measurement of shoulder shift with the PSM when using anatomical markers ($\delta_2 = -0.01 \pm 0.07$ inches) (Table 1). When not using anatomical markers, PSM significantly underestimated shoulder shift ($\delta_3 = -0.34 \pm 0.06$ inches) (Table 2). The variability in the measurement of shoulder shift using PSM was similar to that of VIC when using ($T_2 = 0.99$) (Table 1) and not using ($T_3 = 0.94$) (Table 2) anatomical markers. The measurement of shoulder shift resulted in fair to moderate ICCs for the VIC and PSM (Table 3).

Hip Shift. Compared to the VIC, there was no indication of bias in hip shift measurement using the PSM with anatomical markers ($\delta_2 = 0.04 \pm 0.07$ inches) (Table 1). When anatomical markers were not used to measure hip shift, PSM significantly overestimated hip shift ($\delta_3 = 0.65 \pm 0.06$ inches) (Table 2). The variability in the measurement of hip shift using PSM was similar to that of VIC when using ($T_2 = 1.05$) (Table 1) and not using ($T_3 = 1.32$) (Table 2) anatomical markers. PSM and VIC measurements of hip shift resulted in moderate ICCs (Table 3).

Knee Shift. The PSM significantly underestimated knee shift as measured by the VIC when using markers (-0.32 ± 0.07 inches) (Table 1) and when not using markers (-1.07 ± 0.05 inches) (Table 2). Compared to the variance of measuring knee shift using the VIC, the variance in the PSM measurement of knee shift was approximately 2.5 times ($T_2 = 0.39$) (Table 1) to 1.8 times ($T_3 = 0.54$) (Table 2) greater than that of the VIC when using and not using anatomical markers, respectively. Moderate to high ICCs were observed in the measurement of knee shift for both the VIC and PSM (Table 3).

DISCUSSION

In this study, we report data on multiple trials of ten standing postural measurements using VIC and PSM in 50 male subjects. To the best of our knowledge, this is the first study to report measures of validity and reliability of the PSM app, a postural screening tool designed for use by health professionals in clinical and nonclinical settings. The primary findings of this study are that (a) with markers, PSM postural measurements of head, shoulder, hip, and knee shift were within 10 mm of VIC, and PSM measurement of head, shoulder, and hip tilt were within 5 degrees of VIC, (b) use of anatomical markers did not universally improve postural measurements with PSM, (c) patterns in the ICCs suggest high trial-to-trial variation in posture and (d) in most cases, the variance of postural measurements using PSM exceeded that of VIC.

It is clear that not all of the PSM postural measurements of shift and tilt that were statistically significant were of clinical significance or of practical importance. Harrison et al. evaluated the validity of PosturePrint® in assessing the known position of a mannequin pelvis [36]. PosturePrint® was created by the same developers as PSM and is a web-based tool that assesses postural rotations or translations in 3-D [34]. Compared to known positions of the mannequin, there were average errors in the measurement of translations of pelvic position in the frontal and sagittal planes of 1.2 and 0.09 mm, respectively. There was an average error of 0.5 degrees of rotation of the pelvic position [35]. Harrison et al. also reported average errors of less than 1.2 degrees for all rotations and less than 1.6 mm for all translations of the thoracic cage [37]. 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 degrees are acceptable for clinical use [35]. In this study, when posture was assessed using PSM with anatomical markers (Table 1), 7 out of the 10 postural measurements met this criteria. Moderate bias was observed in shoulder and hip shift in the frontal plane and knee shift in the sagittal plane ranging from -0.32 to 0.43 inches (8.13 mm to 10.92 mm) (Table 1). When posture was assessed using PSM without anatomical markers (Table 2), 5 of the 10 postural measurements fell within the previously reported criteria of being within 5 mm [36]. Moderate bias was observed in shoulder and hip shift in the frontal plane and shoulder, hip, and knee shift in the sagittal plane ranging from 0.39 to 1.07 inches (9.9 mm to 27.18 mm) (Table 2). 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, but we suspect that the range of acceptable values should be greater when studying living humans who normally, in the standing position, have various degrees of sway. We suggest that the range of bias in PSM shift measurements in the frontal and sagittal plane using anatomical markers reported in this study are acceptable in clinical settings and in postural screenings in nonclinical settings. The larger range of bias when PSM is used without anatomical markers is acceptable when the PSM is used as a screening tool, especially in nonclinical settings.

It is an important observation that statistically and clinically significant bias was only apparent when measuring horizontal translation in the x-axis and forward/rearward translation in the *y*-axis (i.e., shift). All of the measurements of rotational translation in the *y*-axis (i.e., tilt) had acceptable levels (< 5 degrees) of bias (Tables 1 and 2). This may be explained in part by the differences in how shift measurements were made between the VIC and the PSM. With the VIC and the PSM, shift was measured relative to the body part below. With the VIC, head shift was measured as the lateral displacement of the center of the head (the center point between the right and left tragus) compared to the center of the shoulders (the center point between the right and left AC joint). With the PSM, head shift is measured relative to the episternal notch. Although the center of the right and left AC joints should align with the episternal notch, there may be some differences in the measurement of head shift depending on the point of reference. Prior communications with the developers of PSM indicated that use of the bisection of the two AC joints would be appropriate for measuring head shift. Likewise, with the VIC, shoulder shift was measured as lateral displacement of the shoulders (measured as the center point of the right and left AC joints) relative to the center of the joint below; the hips (measured as the center point between the right and left ASIS). With the PSM, shoulder shift is measured as the horizontal translation of the episternal notch relative to the center point of the right and left sides of the rib cage. In this study, the center of the shoulders (center point between AC joints) was used to measure head shift and shoulder shift whereas PSM uses the episternal notch to measure head shift and shoulder shift. In this study, we chose to use the center point of the shoulders (rather than the episternal notch) so the AC joint markers could be used for the measurement of both shoulder shift and shoulder tilt. Prior communication with the developers of PSM indicated that the rib cage was used as the reference for shoulder shift because PSM users marked the ASIS incorrectly, which could result in erroneous measures of shoulder shift. In this study, a single trained investigator was responsible for the placement of markers when using the VIC, thus minimizing the error due to marker displacement.

We hypothesized that the use of anatomical markers would result in more reliable measurements of posture when using the PSM app. However, the results of this study suggest that the use of anatomical markers did not universally improve the measurement of postural deviations. This suggests that the PSM app is appropriate as currently designed; that is, using a zoom feature on the app to visually identify anatomical landmarks rather than palpating anatomical landmarks and placing markers prior to taking photos. This is of practical importance in that it saves time in clinical and other settings in which postural screenings are conducted. Forgoing palpation and placement of markers also preserves patient or client privacy. Nevertheless, we recommend that postural assessments be made in clothing that permits visual identification of anatomical landmarks, specifically those of the shoulders, hips, and knees. In this study, subjects wore only spandex shorts and the chest, shoulders, legs, and feet were bare. Only men were recruited for participation in this preliminary study to allow wearing of minimal attire. However, because excessive bias was observed in this study in spite of the fact that subjects were wearing minimal clothing, it is logical to expect that assessing posture in patients or clients who are wearing loose shorts, t-shirts, leg length pants, blouses, etc., could potentially introduce greater bias and variability in postural measurements.

Several trends can be observed in the ICC values calculated in this study (Table 3). ICC values between 0.21 and 0.4 indicate fair agreement; 0.41 to 0.6 indicates moderate agreement; 0.61 to 0.8 indicates strong agreement; and an ICC greater than 0.8 indicates almost perfect agreement [36]. In this study, ICCs of PSM measurements ranged from 0.37 to 0.84 and the

ICCs of VIC measurements ranged from 0.31 to 0.82. The wide range of ICCs in this study concurs with Dunk et al. who previously reported ICCs between 0.13 and 0.69 when using photographs to measure posture [17].

As anticipated, when compared to PSM with or without markers, VIC tended to have greater agreement (higher ICCs) within postural measurements (Table 3). Postural measurements using the PSM with markers had higher ICCs than when using PSM without markers in 7 of the 10 measurements (Table 3). This would be expected since the use of markers could potentially reduce error in the trial-to-trial identification of landmarks using a touch screen. The higher ICCs when using PSM without markers in 3 of the measurements was likely due to chance. Overall, 27 of the 30 ICC calculations amongst VIC and PSM had moderate to strong agreement. Shoulder and hip shift in the frontal plane had the lowest ICCs using VIC (0.31 to 0.38) and the lowest ICCs using PSM with markers (0.43 to 0.46) (Table 3). The low ICCs in shoulder and hip shift measurements, regardless of the method, suggests either high trial-to-trial variance in these segments of posture as the individual tries to balance and reduce sway in the standing position or an inherent difficulty in identification of anatomical landmarks used to measure shoulder and hip position. Since the same pattern is not apparent in shoulder and hip tilt in the frontal plane (which use the same anatomical landmarks), we suspect that the low ICCs are a result of postural sway in the standing position [37]. It is reasonable to expect some naturally occurring variability in posture between trials.

The VIC and PSM measurements (with and without markers) of tilt in the frontal plane had higher ICCs than the measurements of shift in the same body part. In other words, in all methods of assessment, head, shoulder, and hip tilt had higher ICCs than head, shoulder, and hip shift (Table 3). Since the same markers are used in the measurement of shift and tilt, this trend cannot be explained by marker placement. As discussed above, we suggest that there are greater normal trial-to-trial variation in shift (lateral displacement or sway) than in tilt in the standing position.

Low ICCs were not necessarily associated with postural measurements that had excessive variance (Tau < 1.0 and 1 falls outside of CI) (Tables 1 and 2). This can be expected since the ICCs (Table 3) are an indication of the reproducibility of repeated measurements, whereas the Tau values (Tables 1 and 2) represent a comparison of the variance of PSM measurement to those of VIC.

We found greater variance of the postural measurements using PSM compared to the VIC. Because markers were removed following each trial in this study, the variance associated with VIC postural assessments reflects both the naturally occurring trial-to-trial variability in posture as well as the trial-to-trial variability in marker placement. Thus, it is assumed to be error associated with using the PSM program. Some PSM measurements had a variance component that was less than the VIC measurements (Tau > 1.0) (Tables 1 and 2). We speculate that the smaller variance observed in some PSM measurements may have been due to chance. Only those PSM postural measurements which had a variance component greater than that of VIC measurements (Tau < 1 and 1 falls outside of the CI of Tau) would be concerning. Such levels of variance suggest sources of error other than naturally occurring variation in posture or placement of markers. When posture was measured with PSM using anatomical markers, excessive variance was apparent only in head shift and tilt measurements in the frontal plane and knee shift measurements in the sagittal plane (Table 1). When posture was measured with PSM as would be in a practical setting (i.e., without anatomical markers), excessive variance was apparent in the same three locations as well as shoulder tilt in the frontal plane and head shift in the sagittal plane (Table 1). It is interesting to note that forward/rearward translation of the knee in the sagittal plane (i.e., knee shift) was the only postural measurement that, when compared to VIC measurements, exhibited excessive bias and excessive variability when measured by PSM with and without the use of anatomical markers. Excessive variance in postural measurements using PSM suggests an inherent difficulty in identifying the exact location of the marker or anatomical landmark in the PSM app. This may simply be due to the size of the finger print in using a touch screen. The use of a fine-tip stylus may reduce variability. When using the PSM app, if photographs are taken obliquely to the subject (rather than square to the subject) errors may occur in the postural measurements. The PSM app includes measures to assure that the iPad camera is positioned correctly; specifically, when taking photographs, a set of cross hairs appear on the screen which turn green when the camera is level. Problems arise when the camera is positioned obliquely to the subject—in which case the camera can be leveled correctly but photos may result in erroneous postural measurements [38]. For the most accurate data, the camera must be positioned square to the subject. In this study, photos were taken with subjects standing on the same marked area of the floor with the iPad camera directly in the front of them or directly perpendicular to them.

This study is not without its limitations. Only male subjects were included in this study; consequently, the results and conclusions can apply only to males. Although it is reasonable to assume that if landmarks can be accurately identified on the female body, similar results could be expected. Nevertheless, similar validation and reliability studies are warranted in females and in mixed samples of subjects to determine if gender differences exist. In this study, participants were relatively young. We anticipate that bias and variation in postural measurements would be greater in populations who had difficulty maintaining a standing position, for example, the elderly and frail or individuals with complaints of pain. Although in this study only one investigator was responsible for placement of the retroreflective markers on the subjects, some variability in the placement of markers between trials could be expected. In studies that use three-dimensional imaging, such as gait analysis research, marker displacement is a major source of error [39, 40]. Another limitation is that VIC measurements represented an average of 3 sec of X, Y, Z coordinate data. Averaging 3 sec 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. As we previously explained, retroreflective anatomical markers were removed after each trial. This prevented the determination of the naturally occurring variance in posture from trial-to-trial. Naturally occurring postural deviations could be addressed by the use of mannequins and humans in the same study. For example, after evaluating a three-dimensional portable postural analysis tool using mannequins and high school students, Brink et al. [18] concluded that differences in repeated measures of postural angles in high school students could be attributed to trial-to-trial variability in posture rather than operator errors. Mannequins could be used in future studies to separate administrator error and normal trial-to-trial variation in posture. Furthermore, future studies could more effectively report the trial-to-trial variation in posture by leaving retroreflective markers attached when images are taken with the VIC and photographs are taken with the PSM app. As previous research has evaluated the ability of PosturePrint® to assess posture, it would be valuable to compare the postural assessments of PSM and PosturePrint®. Additionally, this study only evaluated the variability in posture as assessed by a single technician. We suspect that the use of multiple investigators would increase variation. Thus, future studies can evaluate the variance due to a single investigator evaluating the same images multiple times, multiple investigators analyzing the same images, or multiple investigators taking and analyzing their own images of the same subjects.

CONCLUSIONS

The PSM app is affordable, user friendly, and can be used in a timely manner to assess posture. Based on the results of this study, we conclude that PSM is an acceptable screening tool for health and fitness professionals to assess posture. We suggest that PSM should not be used in research or clinical applications when highly accurate postural assessments are necessary. In these situations, other postural assessment instruments may provide greater levels of accuracy and reliability. Due to the suspected trial-to-trial variation in posture, we question the usefulness of a single postural assessment in a clinical setting. Serial measurements intended to detect improvement in posture over the course of an intervention should be interpreted with caution. Additional research is required to advance valid and reliable postural assessment tools.

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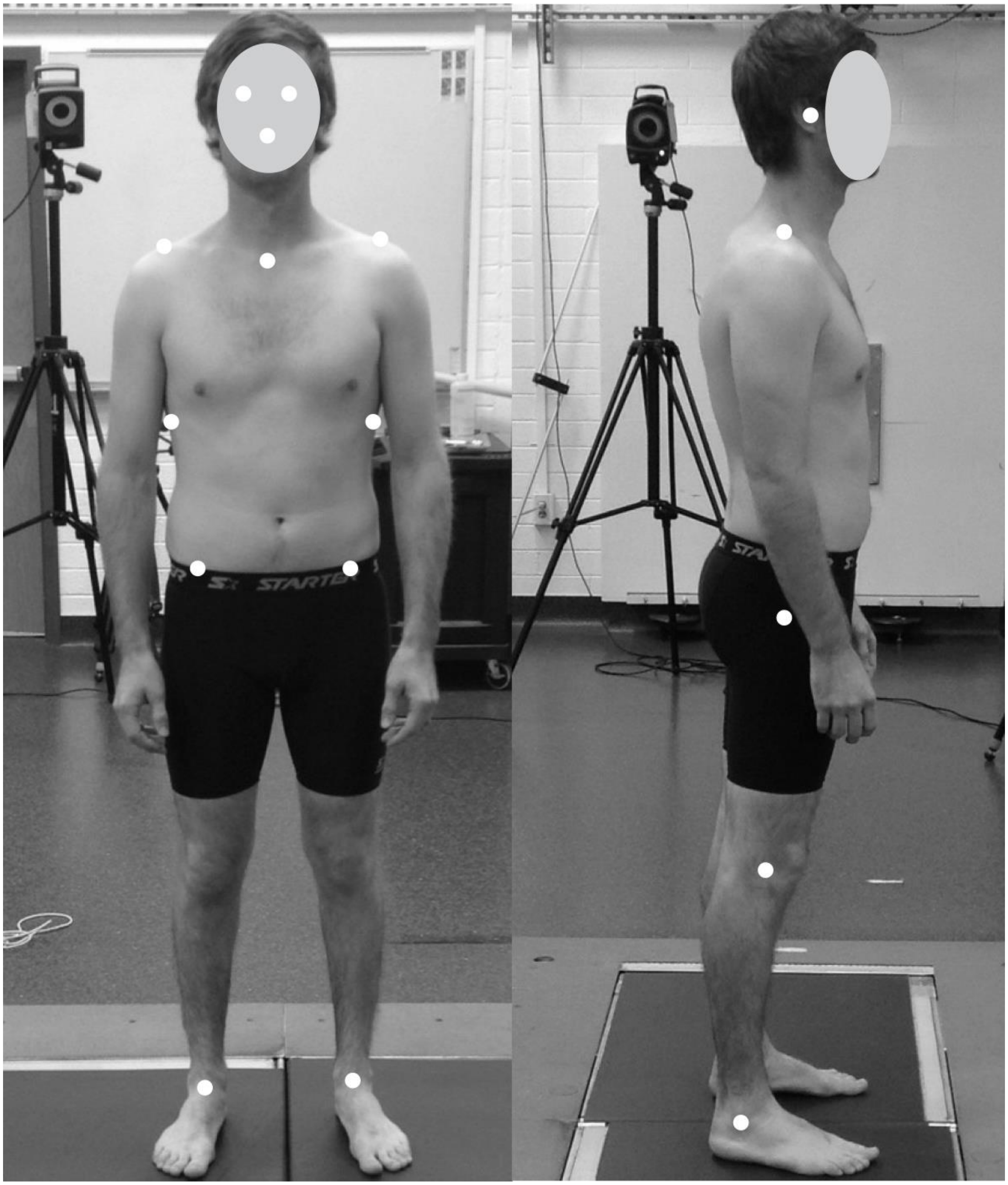

Figure 1 Landmarks used to assess posture using the PostureScreen Mobile®

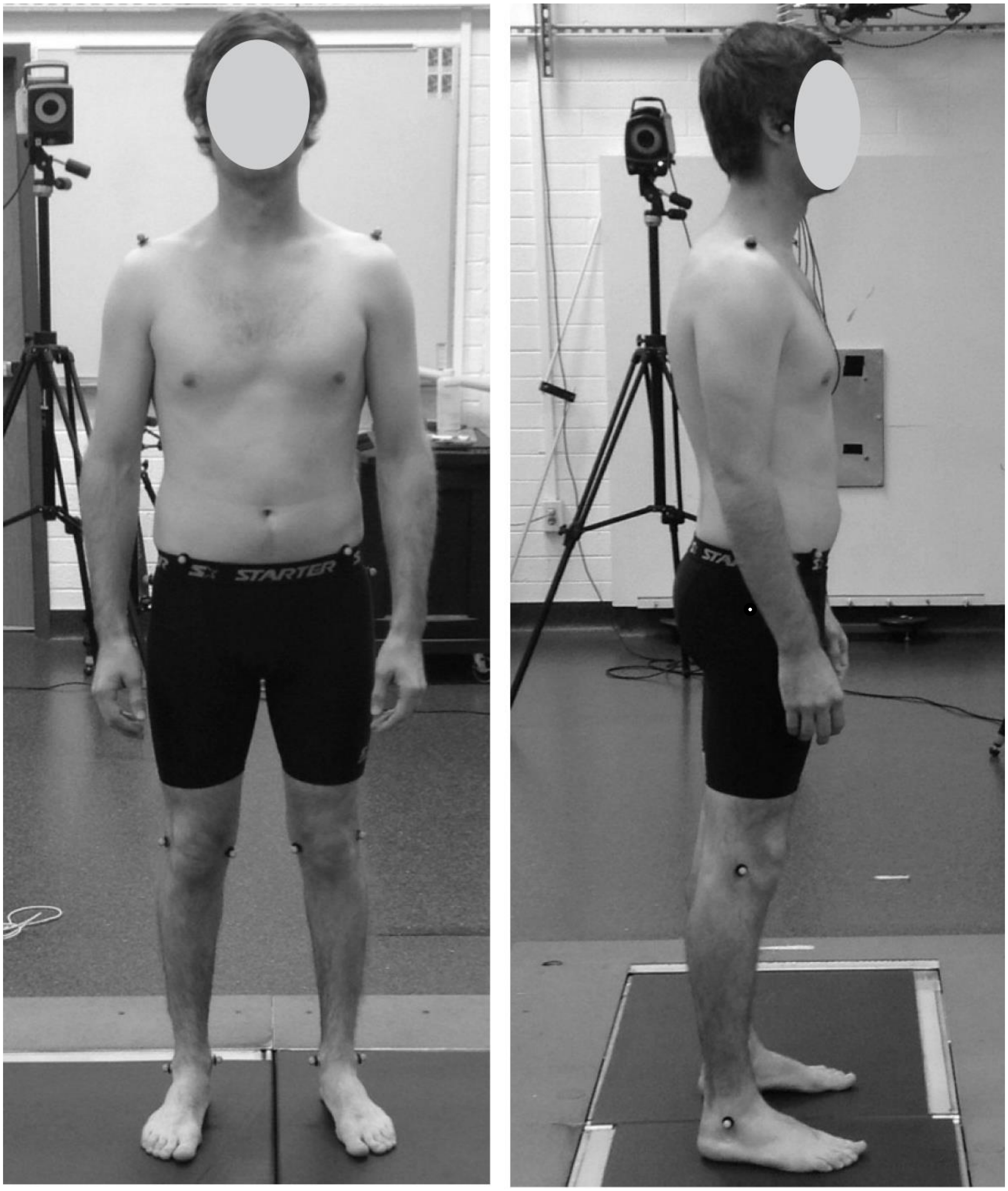

Figure 2 Landmarks used to assess posture using the Vicon 3D Motion Analysis System.

Table 1

Estimates of validity and reliability of postural assessments using PostureScreen Mobile® with anatomical markers.

	Vicon 3D		PostureScreen Mobile® with markers			
	Mean	Variance	Mean	Variance	Bias	Tau
Plane						
Head Shift	0.14 ± 0.04	0.03 ± 0.01	0.11 ± 0.05	0.08 ± 0.01	-0.03 ± 0.03 (-0.07; 0.02)	0.46 ± 0.19 (0.24; 0.72) [cd]
Head Tilt	0.71 ± 0.37	1.48 ± 0.24	1.29 ± 0.43	5.97 ± 0.94	0.58 ± 0.27 (0.24; 0.93) [a]	0.26 ± 0.06 (0.18; 0.34) [cd]
Shoulder Shift	-0.20 ± 0.04	0.12 ± 0.01	0.21 ± 0.04	0.07 ± 0.01	0.41 ± 0.04 (0.36; 0.46) [ab]	1.75 ± 0.19 (1.48; 1.96) [c]
Shoulder Tilt	0.68 ± 0.21	1.00 ± 0.19	1.17 ± 0.23	1.39 ± 0.25	0.49 ± 0.15 (0.29; 0.69) [a]	0.75 ± 0.23 (0.48; 1.05)
Hip Shift	-0.17 ± 0.09	0.39 ± 0.04	0.26 ± 0.09	0.29 ± 0.05	0.43 ± 0.08 (0.33; 0.53) [ab]	1.40 ± 0.25 (1.06; 1.74) [c]
Hip Tilt	0.14 ± 0.23	1.69 ± 0.25	0.71 ± 0.25	1.89 ± 0.33	0.57 ± 0.18 (0.34; 0.81) [a]	0.92 ± 0.20 (0.67; 1.20)
Sagittal Plane						
Head Shift	1.69 ± 0.12	0.19 ± 0.02	1.77 ± 0.12	0.12 ± 0.02	0.09 ± 0.05 (0.02; 0.16) [a]	1.61 ± 0.24 (1.28; 1.92) [c]
Shoulder Shift	-0.23 ± 0.10	0.27 ± 0.04	-0.23 ± 0.11	0.28 ± 0.05	-0.01 ± 0.07 (-0.10; 0.08)	0.99 ± 0.21 (0.73; 1.26)
Hip Shift	0.24 ± 0.11	0.30 ± 0.04	0.28 ± 0.12	0.29 ± 0.05	0.04 ± 0.07 (-0.05; 0.14)	1.05 ± 0.21 (0.80; 1.33)
Knee Shift	2.15 ± 0.12	0.13 ± 0.02	1.83 ± 0.13	0.36 ± 0.06	-0.32 ± 0.07 (-0.41; -0.23) [ab]	0.39 ± 0.09 (0.28; 0.51) [cd]

Values are mean ± SD (80% Credible Interval). Shifts are measured in inches. Tilts are measured in degrees.
Bias = mean difference between PostureScreen Mobile® with anatomical markers and the Vicon 3D motion analysis system.
Tau = ratio of variance between Vicon 3D motion analysis system and PostureScreen Mobile® with anatomical markers.
a = statistical bias between PostureScreen Mobile® and the Vicon 3D motion analysis system
b = bias is greater than clinically acceptable (> 5 mm or 5 degrees)
c = statistical differences in variance between PostureScreen Mobile® and the Vicon 3D motion analysis system
d = variance is excessive (Tau < 1.0 and 1 falls outside of CI).

Table 2

Estimates of validity and reliability of postural assessments using PostureScreen Mobile® without anatomical markers.

	Vicon 3D		PostureScreen Mobile® without markers			
	Mean	Variance	Mean	Variance	Bias	Tau
Frontal Plane						
Head Shift	0.14 ± 0.04	0.03 ± 0.01	0.23 ± 0.04	0.08 ± 0.01	0.09 ± 0.03 (0.05; 0.13) [a]	0.43 ± 0.18 (0.22; 0.69) [cd]
Head Tilt	0.71 ± 0.37	1.48 ± 0.24	1.48 ± 0.41	7.08 ± 0.91	0.78 ± 0.24 (0.47; 1.08) [a]	0.21 ± 0.05 (0.16; 0.28) [cd]
Shoulder Shift	-0.20 ± 0.04	0.12 ± 0.01	0.19 ± 0.04	0.09 ± 0.01	0.39 ± 0.04 (0.34; 0.44) [ab]	1.33 ± 0.24 (1.04; 1.67) [cd]
Shoulder Tilt	0.68 ± 0.21	1.00 ± 0.19	1.59 ± 0.21	1.49 ± 0.23	0.91 ± 0.13 (0.75; 1.08) [a]	0.69 ± 0.21 (0.45; 0.97) [cd]
Hip Shift	-0.17 ± 0.09	0.39 ± 0.04	0.25 ± 0.08	0.22 ± 0.02	0.41 ± 0.06 (0.33; 0.50) [ab]	1.82 ± 0.16 (1.57; 1.98) [c]
Hip Tilt	0.14 ± 0.23	1.69 ± 0.25	0.74 ± 0.24	2.02 ± 0.29	0.60 ± 0.16 (0.40; 0.80) [a]	0.86 ± 0.21 (0.62; 1.13)
Sagittal Plane						
Head Shift	1.69 ± 0.12	0.19 ± 0.02	1.54 ± 0.12	0.32 ± 0.04	-0.14 ± 0.06 (-0.20; -0.07) [a]	0.63 ± 0.13 (0.48; 0.81) [cd]
Shoulder Shift	-0.23 ± 0.10	0.27 ± 0.04	-0.56 ± 0.10	0.29 ± 0.05	-0.34 ± 0.06 (-0.42; -0.26) [ab]	0.94 ± 0.24 (0.64; 1.26)
Hip Shift	0.24 ± 0.11	0.30 ± 0.04	0.89 ± 0.11	0.24 ± 0.04	0.65 ± 0.06 (0.58; 0.73) [ab]	1.32 ± 0.30 (0.96; 1.76)
Knee Shift	2.15 ± 0.12	0.13 ± 0.02	1.08 ± 0.12	0.26 ± 0.04	-1.07 ± 0.05 (-1.14; -1.00) [ab]	0.54 ± 0.15 (0.36; 0.75) [cd]

Values are mean ± SD (80% Credible Interval). Shifts are measured in inches. Tilts are measured in degrees.
Bias = mean difference between PostureScreen Mobile® without anatomical markers and the Vicon 3D motion analysis system.
Tau = ratio of variance between Vicon 3D motion analysis system and PostureScreen Mobile® without anatomical markers.
a = statistical bias between PostureScreen Mobile® and the Vicon 3D motion analysis system
b = bias is greater than clinically acceptable (> 5 mm or 5 degrees)
c = statistical differences in variance between PostureScreen Mobile® and the Vicon 3D motion analysis system
d = variance is excessive (Tau < 1.0 and 1 falls outside of CI).

Table 3

Intraclass correlation coefficients of VIC and PostureScreen Mobile® measurements of posture.

	Vicon 3D	PostureScreen Mobile® (with markers)	PostureScreen Mobile® (without markers)
Frontal Plane			
Head Shift	0.67 ± 0.07	0.47 ± 0.07	0.45 ± 0.07
Head Tilt	0.80 ± 0.04	0.51 ± 0.66	0.47 ± 0.06
Shoulder Shift	0.31 ± 0.06	0.43 ± 0.07	0.37 ± 0.07
Shoulder Tilt	0.64 ± 0.06	0.56 ± 0.07	0.54 ± 0.71
Hip Shift	0.38 ± 0.06	0.46 ± 0.08	0.53 ± 0.07
Hip Tilt	0.55 ± 0.07	0.53 ± 0.27	0.51 ± 0.06
Sagittal Plane			
Head Shift	0.77 ± 0.05	0.84 ± 0.04	0.67 ± 0.05
Shoulder Shift	0.62 ± 0.06	0.61 ± 0.06	0.59 ± 0.06
Hip Shift	0.64 ± 0.06	0.64 ± 0.06	0.69 ± 0.05
Knee Shift	0.82 ± 0.04	0.64 ± 0.06	0.71 ± 0.52

Fair agreement	0.21 to 0.40
Moderate agreement	0.41 to 0.60
Strong agreement	0.61 to 0.80
Almost perfect agreement	0.81 to 1.00