Original Articles

Postural Photogrammetry as Promising Tool for Clinical Use: A Reliability Study

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ABSTRACT

Many studies on postural photogrammetry had reported various intra-class correlation coefficients (ICC) across postural variable measurements, however no conclusive solution was given. This reliability and cross-sectional study was done in June 2016 at the Faculty of Medicine and Health Sciences, Universiti Malaysia Sabah. A total of 24 male adult subjects with mean age 28.5 years (± 4.8 years), body mass 24.97 kg (± 3.85 kg) and height 166.6 cm (± 6 cm) were evaluated for standing postural photogrammetry. Four sets of manually digitized posture image files (by 4 raters) were measured and statistically analyzed for inter-rater agreement as well as the influence of image resolution and camera height from the floor on various postural variable measurements. The ICC between 4 raters for all postural variables was excellent (the lowest ICC was 0.940 for Q Angle of the Right Knee measurements). Two-Way ANOVA showed that postural variable measurements were not affected by either image resolution or camera height from the floor. Scrupulous attempts done on standing postural photogrammetry amplified the potential for standing postural evaluation in clinical settings.

Keywords: photogrammetry, standing postural photography, posture

INTRODUCTION

Good posture creates musculoskeletal balance, a condition which would minimize wear and tear on the joints, muscles and ligaments. Conversely, bad or poor posture could be the reflection of the existence of musculoskeletal disorders or the potential risk for future musculoskeletal abnormalities. With those perspectives, an accurate and a reliable body posture evaluation is very important for therapeutic purpose, health promotion, prevention and rehabilitation.

It is a common practice in clinical setting that static human body posture evaluation is done by relying on clinician's subjective visual impression, aided by several simple tools such as plumb line, goniometer, postural grids, ruler, etc. The conventional method as aforesaid has advantages in its simplicity and low cost, however it is believed to have drawbacks with regard to objectivity, ease of recording and reliability.

As a method for evaluation body posture, digital photography combined with computer technology or known as postural photogrammetry,[1] potentially provides several advantages over the conventional method such as: ease of recording, simplicity, time saving, possibility of recording subtle changes, and an accurate measurement as well as higher interrater reliability. Although it possesses great potential advantages and growing acceptance in clinical use, such method nevertheless has some elements that may influence on data reliability, such as image distortion produced by the camera and lens unit, position of the camera as well as the subject, tagging of the anatomical markers, resolution of the captured image, and the digital measurement of postural variables. On the other side, current use of various photographic equipment as well as the evaluating computer software in many postural photogrammetry researches[2 – 12] may give rise to the impression of inherent simplicity within this technique.

However, proper application of this technique might not be very simple, knowing the facts that some validation studies on postural photogrammetry have reported various interrater reliability across postural variables.[7, 8, 10 – 12]

Nowadays, digital photography technology has entered the era of megapixel resolution, the picture quality, sharpness and resolution tend to continue to increase, and it is relatively more affordable as well as user friendly. However, it is still unknown how such advancements would improve the reliability of postural photogrammetry. With utilizing state of the art of imaging and computer technology, combined with careful application of photogrammetry while addressing all possible errors, the present study explored the extent to which the current common available technology would affect the reliability of the standing postural photogrammetry. This study also assessed the effect of camera resolution and camera vertical placement on the measurement of postural variables of standing adults. It is hypothesized that photographic postural measurements will not be affected by image resolution as well as camera height placement.

MATERIALS AND METHODS

Overview and Image Acquisition

This reliability and cross-sectional study was conducted in June 2016. The study population was known healthy subjects who were all male and used to be volunteers for Faculty of Medicine and Health Sciences clinical skill laboratory sessions. The male-only available subjects were related to the local socio norms. From 105 candidates listed (as per May 2016) on the registration book, subjects were randomly called and briefly explained by phone, and the 25 first responders who agreed were invited to join the study. This study required all subjects to expose their upper body, trunk, as well as all the limbs, wearing only tight shorts or tight underwear. The study approval "JKEtika 1/16(9)" was granted by the ethics committee of the Faculty of Medicine and Health Sciences, Universiti Malaysia Sabah (FMHS-UMS). On the time of data acquisition, 24 volunteers showed up. Half number of them was scheduled for morning session, and the rest were for the afternoon session. Briefing about details of the photo session was given at the subject waiting room. All subjects signed the informed consent form, and passed the standing Romberg test as the eligibility criteria for taking part in this study. Mean age of the study sample, body mass and height were 28.5 years (± 4.8 years), 24.97 kg (± 3.85 kg) and 166.6 cm (± 6 cm) respectively.

Data acquisition was carried out at the clinical skill laboratory of the FMHS-UMS. The subjects were called individually into the photo session room. The primary researcher was the only person responsible for the marker placement, in which hemispherical white markers with diameter of 1 cm were affixed on tip of acromio-clavicular joint, tip of spinous process of cervical vertebra VII, anterior superior iliac spine, central of patella, tibial tubercle, and left lateral malleolus of fibula; white paper sticker of diameter of $^{1}/_{2}$ cm was affixed to mark the tragus of the left ear. For the cloth covered body parts, stickers were affixed on clothing. In order to obtain adequate visualization, all necessary arrangements were made, and with bare feet, two anterior and two left lateral standing photos were taken on each subject.

- For the anterior view, right heel of the subject stepping on the floor marks prepared for this view. These marks were located at the right side of a midline (the line which divided equally the right and left field of the image in the camera viewfinder, see Figure 1). Subject was allowed to put his right heel on whichever point he likes, then arranged his left foot at equidistance with the right foot from the midline and standing relax. Subject was instructed to look straight ahead at a vertical line on 8 metre distance wall. Soon after the instruction: "Take a deep breath in and let out", one anterior view photo with camera at high position was taken, then subject was instructed to stand still for few seconds (± 6 seconds as recycle time required by the flash units), and a second anterior view photo was taken with the camera set at low position. Subsequently, the subject was requested to turn slowly for taking left lateral view photo.

- For left lateral view, the left heel of the subject stepping on the floor marks was prepared for this view. Subject was allowed to put his left heel on whichever point he likes, then arranged his right foot at equidistance with the left foot from a specified line on the floor for this view and standing relax. Subject was instructed to look straight ahead at a vertical line on 8 metre distance wall. Soon after the instruction: "Take a deep breath in and let out", one left lateral view photo with camera at high position was taken, then subject was instructed to stand still for few seconds, and a second left lateral view photo was taken with the camera set at low position.

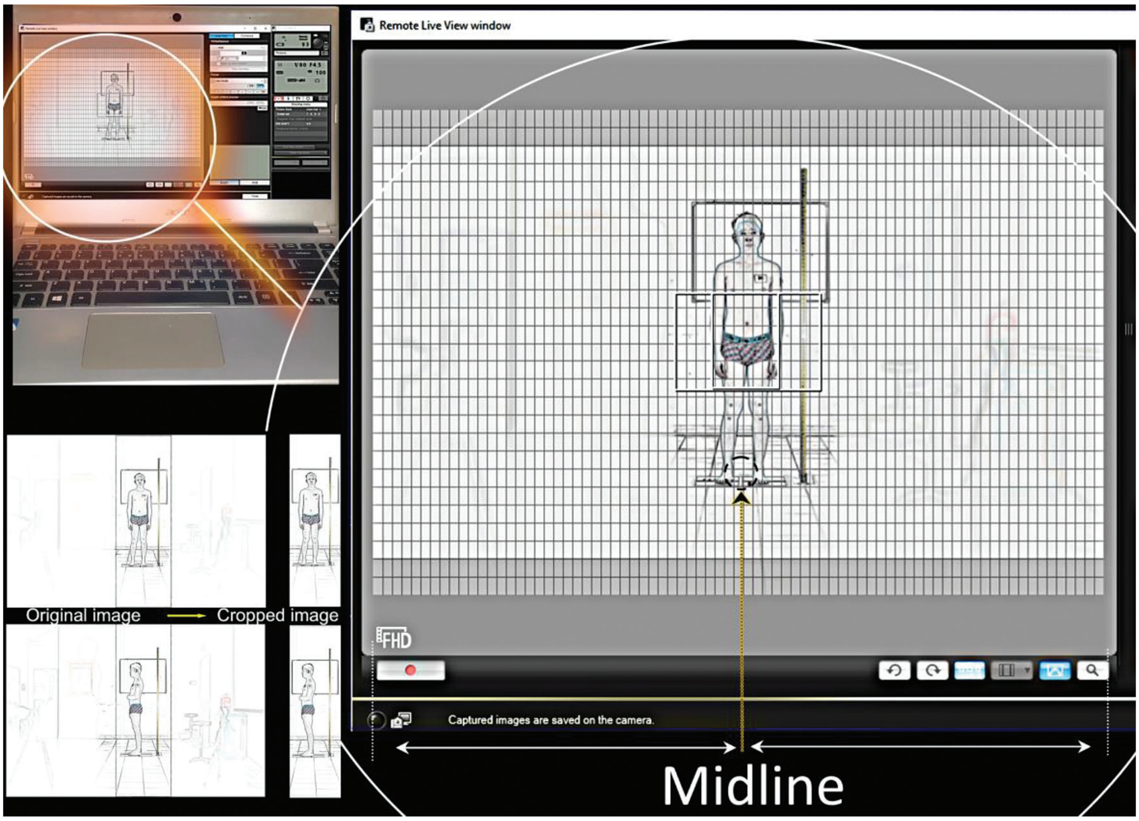


Figure 1 Grid lines and vertical calibration pole used for camera vertical calibration, consistent size of cropping.

Venue Set-up and Equipment

Photo session took place at the briefing hall of the faculty's clinical skill laboratory. One digital SLR full-frame camera, Canon™ D5 Mk II with Canon™prime lens EF 50 mm f/1.8 II, was used as the image capture device. Referring to lens distortion reviews,[13 – 16] the camera and subject were set at 7 metre distance in order to accomodate the image of 1.8 metre tall subject to fit in the area of free image distortion. Next to subject's position to stand, at the left hand side and at the same frontal plane, a 2-metre long vertical calibration pole was positioned securely in place. The camera was connected to Acer™ notebook, and with EOS Utility 2 Version 2.14.20.0 the live view of the image to be taken and the grid lines can be seen through the computer monitor screen. The grid lines with the vertical calibration pole as well as the hot shoe spirit bubble were used to guide adjusting the camera in horizontal and vertical orientations, so made it in perfect perpendicular to the subject. The camera vertical slider, camera remote shutter release cable, and wireless flash trigger were used to ensure a smooth and stable image capture process. The low position of the camera from the floor was set at 70 cm, while the high position was set at 100 cm. The camera was set to record each image in RAW and JPG modes simultaneously, hence in one time shoot, the image was recorded on large resolution (21 megapixels in RAW mode) and medium resolution (11.1 megapixels in JPG mode). All images were taken at ISO 100, f/4.5, shutter speed 1/80, with the automatic Canon™ lens peripheral illumination correction, and at a fixed focus (auto focusing on first image capture, then switching the lens to MF (manual focusing) mode, and afterward for the rest of photo session no more adjusment was made to the lens focusing ring).

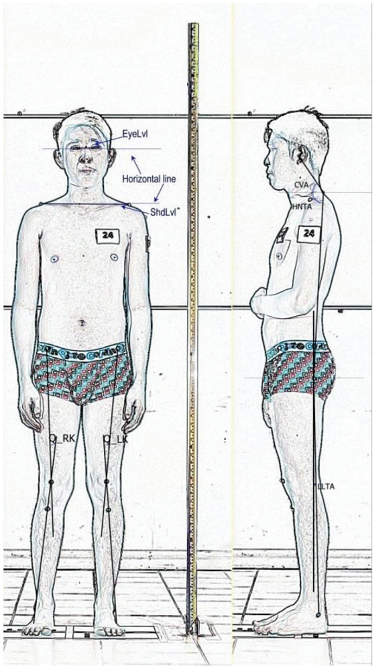
Data Management and Analysis

The principal researcher was responsible for setting up the image capture device, preparing files for digitization by four researcher members and did all the image measurement process and statistical analysis. RAW image files and JPG image files (medium resolution at 11.1 megapixels) were downloaded from camera to the computer, then the RAW files were converted and saved to files (with Digital Photo Professional 4 Version 4.4.30.2 by Canon™) with JPG extension at 21 megapixels (as large resolution) and 5.2 megapixels (as small resolution). Subsequently, with ImageJ 1.51f (Wayne Rasband National institutes of Health, USA) all image files underwent consistent size of cropping to the sides of image, while preserving one third middle working area (see Figure 1, anterior and lateral view). Each rater was responsible for digitization of all 288 cropped image files.

Raters were briefed about digitization process by the main researcher, and thereafter was given 45 minutes time for discussing and familiarizing with imageJ software for digitization. Zoom function was free to use, with encouragement of using the most convenient level for accuracy reason, and raters were given one month time to complete their duty. Every image file was digitized by each rater with consistent sequence, and accordingly the software numbered the point. Measurement process was done by selecting the points to be measured for angle and distance (“centroid” and 3 decimals sensitivity option were selected for ImageJ set measurements). All digitized images were saved in TIFF file and measurement process was carried out after all raters completed their duty. The image of the 2-metre vertical pole at the subject’s side was used for calibration during the image measurement process.

Statistical analysis was done using IBM® SPSS® Statistics Vs 21. From the markers on body surface and eye pupils, several postural variables (see Figure 2) were evaluated: eye level, shoulder level, Q angle of the right and left knee, CVA (cranio vertebral angle), HNTA (head on neck trunk angle), LLTA (lower limb on trunk angle). The level of significance was set at $p \leq 0.05$ for all tests, and Shapiro-Wilk test was used to assess normality of the variables. The intraclass correlation coefficient (ICC) two-way mixed model and absolute agreement type were used for interrater test for every kind of image resolution, taken either by camera at high or lower position.

By random selection, the all data derived from digitization done by rater 01 were used to test the effect of image resolution as well camera position on each of the postural measurements. The data were processed with Lavene's test to assess the homogeneity of variances, and Two-Way ANOVA (with R-E-G-W-Q post hoc test for camera resolution, comparing main effects of independent variables and Bonferroni confidence interval adjusment).



Postural Variable:

EyeLvl (Eye level)

ShdLvl (Shoulder level)

Q_RK (Q angle of right knee)

Q_LK (Q angle of left knee)

CVA (Cranio vertebra angle): formed at the intersection of the horizontal line through the spinous process of C7 and a line through the tragus of the ear.

HNTA (Head and neck on trunk angle): formed by a line drawn through the markers at C7 and the tragus of the ear, and the line drawn through the anatomical markers at C7 and the greater trochanter.

LLTA (Lower limb on trunk angle): formed by the line drawn through the anatomical markers placed at the greater trochanter and the ankle (malleolus lateralis), and the vertical line drawn through the greater trochanter.

Figure 2 Postural variable

RESULTS

Data on each of postural variable measurements were assumed as approximately normally distributed, as shown on Shapiro-Wilk test results (*p*-value > 0.05, Tables 1 and 2 show test results on postural variable measurements derived from images taken by camera at high position and low position respectively). Interrater reliability between 4 raters were excellent across all postural variable measurements as shown on Table 3. Levene's test (see Table 4) shows that error variance of the dependence variable is equal across groups, and Two-Way ANOVA (Table 5), shows no statistical significant effect of image resolution as well as camera height from the floor on the postural variable measurements. There is also no interaction effect of image resolution and camera position on the postural variable measurements.

Table 1 Shapiro-Wilk test results on postural variable – High Camera Position

Variable	Shapiro-Wilk **Sig.	Variable	Shapiro-Wilk **Sig.	Variable	Shapiro-Wilk **Sig.
EyeLvl_Hp_Lr_01	0.436	EyeLvl_Hp_Mr_01	0.187	EyeLvl_Hp_Sr_01	0.490
EyeLvl_Hp_Lr_02	0.262	EyeLvl_Hp_Mr_02	0.763	EyeLvl_Hp_Sr_02	0.198
EyeLvl_Hp_Lr_03	0.735	EyeLvl_Hp_Mr_03	0.473	EyeLvl_Hp_Sr_03	0.370
EyeLvl_Hp_Lr_04	0.656	EyeLvl_Hp_Mr_04	0.797	EyeLvl_Hp_Sr_04	0.201
ShdLvl_Hp_Lr_01	0.481	ShdLvl_Hp_Mr_01	0.390	ShdLvl_Hp_Sr_01	0.508
ShdLvl_Hp_Lr_02	0.420	ShdLvl_Hp_Mr_02	0.479	ShdLvl_Hp_Sr_02	0.402
ShdLvl_Hp_Lr_03	0.471	ShdLvl_Hp_Mr_03	0.407	ShdLvl_Hp_Sr_03	0.590
ShdLvl_Hp_Lr_04	0.549	ShdLvl_Hp_Mr_04	0.558	ShdLvl_Hp_Sr_04	0.418
Q-RK_Hp_Lr_01	0.381	Q-RK _Hp_Mr_01	0.747	Q-RK_Hp_Sr_01	0.660
Q-RK_Hp_Lr_02	0.449	Q-RK _Hp_Mr_02	0.663	Q-RK_Hp_Sr_02	0.671
Q-RK_Hp_Lr_03	0.514	Q-RK _Hp_Mr_03	0.690	Q-RK_Hp_Sr_03	0.787
Q-RK_Hp_Lr_04	0.514	Q-RK _Hp_Mr_04	0.563	Q-RK_Hp_Sr_04	0.703
Q_LK_Hp_Lr_01	0.075	Q_LK _Hp_Mr_01	0.077	Q_LK_Hp_Sr_01	0.194
Q_LK_Hp_Lr_02	0.052	Q_LK _Hp_Mr_02	0.112	Q_LK_Hp_Sr_02	0.165
Q_LK_Hp_Lr_03	0.086	Q_LK _Hp_Mr_03	0.188	Q_LK_Hp_Sr_03	0.189
Q_LK_Hp_Lr_04	0.168	Q_LK _Hp_Mr_04	0.153	Q_LK_Hp_Sr_04	0.198
CVA_Hp_Lr_01	0.700	CVA_Hp_Mr_01	0.498	CVA_Hp_Sr_01	0.252
CVA_Hp_Lr_02	0.692	CVA_Hp_Mr_02	0.513	CVA_Hp_Sr_02	0.634
CVA_Hp_Lr_03	0.708	CVA_Hp_Mr_03	0.459	CVA_Hp_Sr_03	0.519
CVA_Hp_Lr_04	0.486	CVA_Hp_Mr_04	0.698	CVA_Hp_Sr_04	0.594
HNTA_Hp_Lr_01	0.662	HNTA_Hp_Mr_01	0.713	HNTA_Hp_Sr_01	0.554
HNTA_Hp_Lr_02	0.548	HNTA_Hp_Mr_02	0.637	HNTA_Hp_Sr_02	0.764
HNTA_Hp_Lr_03	0.621	HNTA_Hp_Mr_03	0.593	HNTA_Hp_Sr_03	0.693
HNTA_Hp_Lr_04	0.627	HNTA_Hp_Mr_04	0.539	HNTA_Hp_Sr_04	0.754
LLTA_Hp_Lr_01	0.869	LLTA_Hp_Mr_01	0.932	LLTA_Hp_Sr_01	0.943
LLTA_Hp_Lr_02	0.938	LLTA_Hp_Mr_02	0.930	LLTA_Hp_Sr_02	0.908
LLTA_Hp_Lr_03	0.917	LLTA_Hp_Mr_03	0.928	LLTA_Hp_Sr_03	0.950
LLTA_Hp_Lr_04	0.917	LLTA_Hp_Mr_04	0.902	LLTA_Hp_Sr_04	0.948

**** Sig. = Significance = *p*; Statistically significant difference if $p \leq 0.05$**
EyeLvl_Hp*_Lr_01 = Eye level, large resolution by rater 01;
ShdLvl_Hp_Lr_01 = Shoulder level, large resolution by rater 01;
Q_RK_Hp_Lr_01 = Q angle of right knee, large resolution by rater 01;
Q_LK_Hp_Lr_01 = Q angle of left knee, large resolution by rater 01;
CVA_Hp_Lr_01 = Cranio vertebra angle, large resolution by rater 01;
HNTA_Hp_Lr_01 = Head and neck on trunk angle, large resolution by rater 01;
LLTA_Hp_Lr_01 = Lower limb on trunk angle, large resolution by rater 01 ...
02 ~ rater 02; 03 ~ rater 03; 04 ~ rater 04
Mr ~ medium resolution; Sr ~ small resolution; Hp ~ photo taken by camera at High position

Table 2 Shapiro-Wilk test results on postural variable – Low Camera Position

Variable	Shapiro-Wilk **Sig.	Variable	Shapiro-Wilk **Sig.	Variable	Shapiro-Wilk **Sig.
EyeLvl_Lp_Lr_01	0.549	EyeLvl_Lp_Mr_01	0.443	EyeLvl_Lp_Sr_01	0.549
EyeLvl_Lp_Lr_02	0.283	EyeLvl_Lp_Mr_02	0.437	EyeLvl_Lp_Sr_02	0.508
EyeLvl_Lp_Lr_03	0.693	EyeLvl_Lp_Mr_03	0.197	EyeLvl_Lp_Sr_03	0.107
EyeLvl_Lp_Lr_04	0.496	EyeLvl_Lp_Mr_04	0.362	EyeLvl_Lp_Sr_04	0.394
ShdLvl_Lp_Lr_01	0.583	ShdLvl_Lp_Mr_01	0.599	ShdLvl_Lp_Sr_01	0.682
ShdLvl_Lp_Lr_02	0.728	ShdLvl_Lp_Mr_02	0.693	ShdLvl_Lp_Sr_02	0.536
ShdLvl_Lp_Lr_03	0.601	ShdLvl_Lp_Mr_03	0.547	ShdLvl_Lp_Sr_03	0.688
ShdLvl_Lp_Lr_04	0.626	ShdLvl_Lp_Mr_04	0.702	ShdLvl_Lp_Sr_04	0.643
Q-RK_Lp_Lr_01	0.723	Q-RK_Lp_Mr_01	0.641	Q-RK_Lp_Sr_01	0.767
Q-RK_Lp_Lr_02	0.734	Q-RK_Lp_Mr_02	0.895	Q-RK_Lp_Sr_02	0.506
Q-RK_Lp_Lr_03	0.499	Q-RK_Lp_Mr_03	0.628	Q-RK_Lp_Sr_03	0.680
Q-RK_Lp_Lr_04	0.501	Q-RK_Lp_Mr_04	0.536	Q-RK_Lp_Sr_04	0.487
Q_LK_Lp_Lr_01	0.131	Q_LK_Lp_Mr_01	0.476	Q_LK_Lp_Sr_01	0.212
Q_LK_Lp_Lr_02	0.206	Q_LK_Lp_Mr_02	0.307	Q_LK_Lp_Sr_02	0.058
Q_LK_Lp_Lr_03	0.299	Q_LK_Lp_Mr_03	0.244	Q_LK_Lp_Sr_03	0.084
Q_LK_Lp_Lr_04	0.306	Q_LK_Lp_Mr_04	0.051	Q_LK_Lp_Sr_04	0.305
CVA_Lp_Lr_01	0.111	CVA_Lp_Mr_01	0.155	CVA_Lp_Sr_01	0.129
CVA_Lp_Lr_02	0.138	CVA_Lp_Mr_02	0.124	CVA_Lp_Sr_02	0.062
CVA_Lp_Lr_03	0.078	CVA_Lp_Mr_03	0.136	CVA_Lp_Sr_03	0.114
CVA_Lp_Lr_04	0.103	CVA_Lp_Mr_04	0.091	CVA_Lp_Sr_04	0.098
HNTA_Lp_Lr_01	0.514	HNTA_Lp_Mr_01	0.415	HNTA_Lp_Sr_01	0.649
HNTA_Lp_Lr_02	0.741	HNTA_Lp_Mr_02	0.535	HNTA_Lp_Sr_02	0.314
HNTA_Lp_Lr_03	0.701	HNTA_Lp_Mr_03	0.463	HNTA_Lp_Sr_03	0.404
HNTA_Lp_Lr_04	0.706	HNTA_Lp_Mr_04	0.590	HNTA_Lp_Sr_04	0.638
LLTA_Lp_Lr_01	0.832	LLTA_Lp_Mr_01	0.780	LLTA_Lp_Sr_01	0.809
LLTA_Lp_Lr_02	0.871	LLTA_Lp_Mr_02	0.830	LLTA_Lp_Sr_02	0.783
LLTA_Lp_Lr_03	0.838	LLTA_Lp_Mr_03	0.842	LLTA_Lp_Sr_03	0.839
LLTA_Lp_Lr_04	0.858	LLTA_Lp_Mr_04	0.808	LLTA_Lp_Sr_04	0.815

**** Sig. = Significance = *p*; statistically significant difference if $p \leq 0.05$**
EyeLvl Lp**_Lr_01 = Eye level, large resolution by rater 01;
ShdLvl_Lp_Lr_01 = Shoulder level, large resolution by rater 01;
Q_RK_Lp_Lr_01 = Q angle of right knee, large resolution by rater 01;
Q_LK_Lp_Lr_01 = Q angle of left knee, large resolution by rater 01;
CVA_Lp_Lr_01 = Cranio vertebra angle, large resolution by rater 01;
HNTA_Lp_Lr_01 = Head and neck on trunk angle, large resolution by rater 01;
LLTA_Lp_Lr_01 = Lower limb on trunk angle, large resolution by rater 01...
02 ~ rater 02; 03 ~ rater 03; 04 ~ rater 04
Mr ~ medium resolution; Sr ~ small resolution; Lp** ~ photo taken by camera at Low position

Table 3 Interrater reliability findings

Images taken by camera at high position

Variable	ICC (95% CI)	
EyeLvl_Hp_Lr	0.987	(0.976 – 0.994)
ShdLvl_Hp_Lr	0.999	(0.998 – 1.000)
Q_RK_Hp_Lr	0.940	(0.888 – 0.971)
Q_LK_Hp_Lr	0.998	(0.995 – 0.999)
CVA_Hp_Lr	0.999	(0.998 – 1.000)
HNTA _Hp_Lr	0.999	(0.998 – 1.000)
LLTA_Hp_Lr	1.000	(1.000 – 1.000)
EyeLvl_Hp_Mr	0.986	(0.974 – 0.993)
ShdLvl_Hp_Mr	0.999	(0.998 – 0.999)
Q_RK_Hp_Mr	0.997	(0.995 – 0.999)
Q_LK_Hp_Mr	0.996	(0.993 – 0.998)
CVA_Hp_Mr	0.999	(0.998 – 1.000)
HNTA_Hp_Mr	0.999	(0.999 – 1.000)
LLTA_Hp_Mr	1.000	(1.000 – 1.000)
EyeLvl_Hp_Sr	0.986	(0.974 – 0.993)
ShdLvl_Hp_Sr	0.998	(0.997 – 0.999)
Q_RK_Hp_Sr	0.996	(0.992 – 0.998)
Q_LK_Hp_Sr	0.995	(0.990 – 0.997)
CVA_Hp_Sr	0.998	(0.995 – 0.999)
HNTA_Hp_Sr	0.998	(0.996 – 0.999)
LLTA_Hp_Sr	1.000	(0.999 – 1.000)

Images taken by camera at low position

Variable	ICC (95% CI)	
EyeLvl_Lp_Lr	0.990	(0.982 – 0.995)
ShdLvl_Lp_Lr	0.999	(0.999 – 1.000)
Q_RK_Lp_Lr	0.998	(0.997 – 0.999)
Q_LK_Lp_Lr	0.998	(0.997 – 0.999)
CVA_Lp_Lr	0.999	(0.999 – 1.000)
HNTA_Lp_Lr	0.999	(0.999 – 1.000)
LLTA_Lp_Lr	1.000	(1.000 – 1.000)
EyeLvl_Lp_Mr	0.990	(0.980 – 0.995)
ShdLvl_Lp_Mr	0.999	(0.998 – 1.000)
Q_RK_Lp_Mr	0.998	(0.996 – 0.999)
Q_LK_Lp_Mr	0.997	(0.994 – 0.998)
CVA_Lp_Mr	0.999	(0.998 – 1.000)
HNTA_Lp_Mr	0.999	(0.998 – 1.000)
LLTA_Lp_Mr	1.000	(1.000 – 1.000)
EyeLvl_Lp_Sr	0.986	(0.975 – 0.994)
ShdLvl_Lp_Sr	0.998	(0.997 – 0.999)
Q_RK_Lp_Sr	0.997	(0.994 – 0.998)
Q_LK_Lp_Sr	0.995	(0.990 – 0.997)
CVA_Lp_Sr	0.998	(0.997 – 0.999)
HNTA_Lp_Sr	0.998	(0.997 – 0.999)
LLTA_Lp_Sr	1.000	(0.999 – 1.000)

Hp = High camera position
Lp = Low camera position
Lr = Large resolution
Mr = Medium resolution
Sr = Small resolution
ICC = Intraclass correlation coefficients
CI = Confidence interval

Table 4 Levene's test of equality of error variances[a]

Dependent variable	F	df 1	df 2	Sig.
EyeLvl_Rater01	0.282	5	138	0.922
ShdLvl_Rater01	0.061	5	138	0.998
Q_RK_Rater01	0.120	5	138	0.988
Q_LK_Rater01	0.030	5	138	1.000
CVA_Rater01	0.027	5	138	1.000
HNTA_Rater01	0.010	5	138	1.000
LLTA_Rater01	0.051	5	138	0.998

Tests the null hypothesis that the variance of the dependent variable is equal across groups.
a. Design: Intercept + Resolution + Cam_position + Resolution*Cam_position

Table 5 Two-Way ANOVA

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Resolution	0.096	2	0.048	0.008	0.992	0.000
Cam_position	1.643	1	1.643	0.261	0.610	0.002
Resolution*Cam_position	0.483	2	0.241	0.038	0.962	0.001

Dependent Variable: ShdLvl_Rater01

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Resolution	0.008	2	0.004	0.001	0.999	0.000
Cam_position	0.174	1	0.174	0.051	0.822	0.000
Resolution*Cam_position	0.022	2	0.011	0.003	0.997	0.000

Dependent Variable: Q_RK_Rater01

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Resolution	3.372	2	1.686	0.059	0.943	0.001
Cam_position	0.344	1	0.344	0.012	0.913	0.000
Resolution*Cam_position	2.594	2	1.297	0.045	0.956	0.001

Dependent Variable: Q_LK_Rater01

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Resolution	0.231	2	0.115	0.006	0.994	0.000
Cam_position	0.349	1	0.349	0.017	0.897	0.000
Resolution*Cam_position	0.102	2	0.051	0.002	0.998	0.000

Dependent Variable: CVA_Rater01

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Resolution	0.417	2	0.208	0.008	0.992	0.000
Cam_position	15.476	1	15.476	0.560	0.455	0.004
Resolution*Cam_position	0.143	2	0.072	0.003	0.997	0.000

Dependent Variable: HNTA_Rater01

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Resolution	0.342	2	0.171	0.005	0.995	0.000
Cam_position	26.548	1	26.548	0.751	0.388	0.005
Resolution*Cam_position	0.168	2	0.084	0.002	0.998	0.000

Dependent Variable: LLTA_Rater01

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Resolution	9.375E-006	2	4.688E-006	0.000	1.000	0.000
Cam_position	0.059	1	0.059	0.018	0.894	0.000
Resolution*Cam_position	0.005	2	0.002	0.001	0.999	0.000

DISCUSSION

The ultimate goals of postural photography technique or known as postural photogrammetry[1, 17]are accurate measurement results which lead to correct interpretation of the postural images. Recording accuracy, by the same token is believed to benefit clinicians and clients. Since currently no gold standard of how the best to conduct postural photogrammetry, then sensible decisions about certain areas have to be taken. Digital SLR camera Canon™ 5D Mk II with Canon™ EF-50 mm f1.8-II lens was chosen as image capture device. The image capture device selection was based on two aspects, namely: practical thinking and serious consideration on photographic expert reviews about the camera and lens. Some aspects such as common resolution of digital camera currently available in the market, availability of the supporting software for this research, versatility for use in research, compatibility with the currently available computer system and affordability have been carefully considered.

The ImageJ 1.51f [18, 19] as a Java-based image processing program was chosen for image measurement due to several reasons: its capability to handle big image size, macros and Java plugins extensibility as well as availability as public domain, and relatively user friendly. Throughout this study, macro programming had been used for batch cropping the whole images, automatic measurement for the digitized points as well as saving the measured images (with the line drawn between points). With batch cropping, all images underwent same size of cropping, and eventually same size of digital images were provided for digitizing and measuring. With automatic measurement, the possibility of human error had been minimized and the automatic post processing saved-measured images allowing cross-checking when necessary.

Interrater reliability, irrespective of the image resolution for all postural variables were excellent. These findings were expected and similar to the results of study done by Codarin et al.[20] which had studied the influence of image resolution of 3, 5, and 10 megapixels. Prior to that, Mota et al.[6] had reported that set of measurements for postural assessment did not suffer global effects of the image resolution (3.2 megapixels vs 12.1 megapixels). However, this study had evaluated multiple angles which distributed across the whole body of standing adults, in contrast to the study on inanimate object done by Codarin and Mota. In addition, all of the 24 male subjects were randomly selected. Excellent interrater reliability findings of all postural variables using this method would provide more confidence to its use. Nonetheless, some other researchers had reported various results across the postural variables.[7, 10 – 12] Without clear cut explanation on those variability findings, the use of postural photogrammetry even might be confronted with more fundamental questions such as why the phenomenon occurs, how accountable it is for clinical use and research, is there any justifiable anticipation need to be done, and perhaps much more. It is absolutely necessary for researchers and users to overcome the many possible sources of error in order to have an acceptable validity and reliability of this method. In fact, postural photogrammetry technique has been used due to practical reasons, cost effective, and its high value for mass and field setting study, health promotion and rehabilitation. It has been used for recording the impact of school bags on the spine of developing children, measuring spine curvature for scoliosis follow-up, and evaluating impact of temporo-mandibular joint problems to head positioning.[2,17, 21 – 26]

This study found not only excellent ICC across all postural variable measurements but also a much stronger, and a more homogenous results compared to findings from other studies. From images taken with high camera position, the lowest ICC was found for Q angle measurements of the right knee: 0.940 (95% CI: 0.888 – 0.971), while from images taken with low camera position, the lowest ICC was found for eye level measurements: 0.986 (95% CI: 0.975 – 0.994). Ruivo,[7] Sacco,[8] Ferreira,[10] Niekerk,[11] Nguyen[12] reported ICC ranging from 0.88 – 0.96, 0.85 – 0.92, 0.21 – 0.97, 0.78 – 0.99, and 0.64 – 0.99 respectively. The recommendations on the above facts were due to the implementation of stringent protocols and appropriate photography and computer technology in this study had prevented some significant potential errors to emerge.

The use of the full-frame digital SLR camera Canon 5D Mk II was particularly based on its potential to produce the best possible image,[27 – 31] while the fixed focal lens was selected due to its fixed capture field. It was believed that variability in capture field as could occur with the use of zoom lens would impair the accuracy of image measurement. One camera and one single lens for the whole image data collection could reduce variability related to the equipment. The lens used in this study though cheap in price, yet having good reputation as a sharp lens.[13, 32 – 34] As an ideal thought, the image capture device (camera body and lens) must be able to produce distortion free, clear and detailed image from head to toe, and having consistent good quality of image from one capture to another. In order to minimize error due to variability on equipment set-up, all images had been captured in a single set-up, and with a "fixed focus" lens. Subsequently, errors could arise from the later phase when computer system taking its role. As the system consisting of hardware, software and brainware[35] then every item should be well managed and identified as source of error. All possible errors on this domain had been mitigated by using one dedicated notebook computer (Acer V5-431-987B4G50Mass, RAM 8 GB with Windows 10

64 bit OS), one Dell USB 3-button optical mouse MS 111 with 1000 dpi resolution, and Dell(R) E 2014H as second computer monitor screen (at 1600 × 900 resolution). Since digitization was done manually, it reasonably could be affected by the image quality, clarity and contrast of computer monitor, reliability of the computer input peripheral, operator or the rater and the image measurement software. For eye comfort, meeting accuracy expectation and uniformity reasons, the second monitor screen had been mandatory to be used during the digitization process. The image files for digitization had been handled very carefully as explained above under section "Data Management and Analysis". The stable and reliable computer hardware, with all reasonably selected peripherals were essential to the excellent interrater agreement. For the brainware, all raters although new to imageJ software, were senior persons in their respective field and had been active computer user for routine daily job for more than 20 years. It is assumed that the brainware component had contributed greatly to the agreement between raters due to the fact that cursor movement within a 1 cm distance (diameter of the body marker) on the image contributed greatly to the translation of the digital (X, Y) coordinate. Similar to this, Ferreira[17] suggested that computer experience and exposure rate to computer science as well as the age of raters were contributed to the level of agreement.

Standing Romberg test (1 minute) as eligibility criteria for this study was to ensure that the subject would be able to stand still during the duration of the image capture session. Since it was required a 6-second waiting time from first to second capture for the same subject (for flash unit recycling time), then subject's inability to stand still would be an important source of error in identifying the influence of camera position on the measurement results. Repeated image capture as a source of error when assessing the influence of image resolution on measurement was eliminated since only a single capture was done for having 3 kinds of image resolution. Digital Photo Professional 4 Version 4.4.30.2, the genuine photo application made by Canon™, was used to process and convert the image file to the required resolution as if produced by the camera itself. With this photo application software, taking repeated photos at different resolutions were not necessary.

The larger the image resolution, the bigger the zooming level possible during the digitization process. The assumption that bigger zooming level would increase interrater reliability was not proven in this study, since Two-Way ANOVA shows that image measurements were not statistically affected by the resolution. Perhaps the limit of accuracy had been reached with the smallest image resolution used in this study, therefore a larger resolution no longer provide chance for improvements. Camera height placement was also not proven to be a variable to affect the image measurements. This finding occurred due to two possible conditions: firstly, subjects were significantly able to maintain their still position during the 6 seconds time, secondly, the image capture device had produced accurate and consistent images either at high or low camera positions. It was also found that resolution and camera position as independent variables having no interaction one to another.

The longer the camera distance from the subject, the more resolution needed in order to record the good quality of target image.[36 – 38] Since the camera was put at a longer distance (7 metre) compared to the studies done by Codarin[19] and Mota[6], then the posture image was examined at resolution of 5.2, 11.1, and 21 megapixels; a much bigger resolution compared to any of the researchers ever done before. In this study, 5.2 megapixels (as the smallest recordable resolution by Canon™ 5D Mk II) seemed appropriate for standing postural photogrammetry. The lens distortion area was the main limiting factor for camera placement, either on vertical (high and low) or horizontal (distance) dimension.

The most crucial part of postural photogrammetry was the marker placement, which neither the target to test nor to evaluate for its validity by this study. However some research had reported the validity of marker placement by palpation bony surface with reference to the bone position on radiograph. Niekerk et al.[11] reported the Pearson correlation *r* values ranging from 0.67 to 0.95. Furlanetto et al.[21] found no significant differences between the points ($X^2 = 9.366$, $p = 0.404$). In any case, it was assumed that marker placement is an expert dependent matter.

Limitation

The small number of sample as well as the male-only subject in this study may be part of the limitations, in which the statistical results cannot with fully confident generalized to adult population, however this study has showed that sensible decision about the method of the image acquisition, equipment selection and computer software could improve the quality of postural variable measurement.

The findings might be inherent with the equipment and software used in this research. The excellent ICC findings across all postural variable measurements were not a direct justification for clinical use, since questions can still arise from either body marker placement, or image measurement software accuracy. Further validation study on those issues is needed.

CONCLUSION

This study has recorded postural image of 24 standing male adults with a very strict protocol, utilizing state of the art of imaging and computer technology, and rigorously examined the total of 288 postural images. Excellent interrater reliability across all postural variables of standing adults opens up opportunities for a new standard on how to apply postural photogrammetry and concurrently amplify its potential for standing postural evaluation in clinical settings. Neither resolution nor vertical position of camera from the floor affect the postural measurements. This study would contribute to the betterment of standing postural photogrammetry.

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