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Abstract

The aim of this study was to investigate the influence of image resolution manipulation on the photogrammetric measurement of the rearfoot static angle. The study design was that of a reliability study. We evaluated 19 healthy young adults (11 females and 8 males). The photographs were taken at 1536 pixels in the greatest dimension, resized into four different resolutions (1200, 768, 600, 384 pixels) and analyzed by three equally trained examiners on a 96-pixels per inch (ppi) screen. An experienced physiotherapist marked the anatomic landmarks of rearfoot static angles on two occasions within a 1-week interval. Three different examiners had marked angles on digital pictures. The systematic error and the smallest detectable difference were calculated from the angle values between the image resolutions and times of evaluation. Different resolutions were compared by analysis of variance. Inter- and intra-examiner reliability was calculated by intra-class correlation coefficients (ICC). The rearfoot static angles obtained by the examiners in each resolution were not different ($P > 0.05$); however, the higher the image resolution the better the inter-examiner reliability. The intra-examiner reliability (within a 1-week interval) was considered to be unacceptable for all image resolutions (ICC range: 0.08-0.52). The whole body image of an adult with a minimum size of 768 pixels analyzed on a 96-ppi screen can provide very good inter-examiner reliability for photogrammetric measurements of rearfoot static angles (ICC range: 0.85-0.92), although the intra-examiner reliability within each resolution was not acceptable. Therefore, this method is not a proper tool for follow-up evaluations of patients within a therapeutic protocol.

Key words: Physical therapy modalities; Photogrammetry; Reliability; Rearfoot angle

Introduction

According to the American Society for Photogrammetry and Remote Sensing (1), photogrammetry is the science of obtaining reliable information through pictures of physical objects and their environment that can be measured and interpreted. One advantage of photogrammetry is the possibility of recording subtle changes (2). The technique also quantifies the morphological variables related to posture and provides more reliable data than those obtained by observational evaluations (3-6). Another advantage of photogrammetry is the possibility of saving the files digitally, with consequent economy of space.

Photogrammetric postural evaluations have been frequently used in physical therapy assessments and can be considered a reliable option to evaluate posture (3,5,7-12) and even angle motion (13). However, postural evaluation by photogrammetry encompasses many elements that exert a direct influence on data reliability (6), such as camera position, resolution of the captured image, tagging of the anatomical markers used in postural evaluation, and the digital measurement of postural variables. Investigating each of these factors individually is an important way to ensure the quality of the photogrammetry evaluation, since they could cause errors in the measurement process, influencing its reliability (14).

Most studies concerned about the reliability of the method have focused on studying position and distance

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of the camera, anatomical mark identification and the measurement itself. This is because the photogrammetric two-dimensional (2-D) analysis has limitations compared to 3-D analysis, especially because of variations in the image perspective due to an incorrect image framework compared to the anatomical plan of the posture. Van Maanen et al. (11) and Iunes et al. (7) concluded that body posture evaluation via photogrammetry presents good intra-/inter-rater reliability. Penha et al. (8) evaluated and described the static spinal postural alignment of 7- and 8-year-old children using photogrammetry. Saad et al. (15) and Braun and Amundson (16) described the good reliability and repeatability of this method for evaluating spinal scoliosis and head and shoulder postural alignment in adults, and Sacco et al. (3) described the reliability of this method in the postural evaluation of lower limb alignment.

However, one important issue was that Iunes et al. (7) reported a poor reliability of photogrammetric evaluation of the rearfoot angle. In physical therapy clinics, the rearfoot valgus orientation has often proved to be related to the occurrence of dysfunctions (17-20). The poor general reliability found in this particular angle may be associated with the image resolution (14) that can reduce the sharpness of the image area in which the markers are located. In this particular case, the area is more susceptible to image resolution interference considering the lower location of the necessary markers. Although the photogrammetry method is capable of producing accurate and reliable 2-D measures, Moncrieff and Livingston (21) suggest that the captured image size could influence the intra-examiner reliability of the measures.

In postural photogrammetric clinical evaluation, the image size definition is related to the minimum pixel density necessary to satisfactorily identify the anatomical markers over specific body parts on a monitor screen. Therefore, the definition of the image pixels per screen unit (e.g., image resolution) is essential to guarantee the reliability of the angular and linear measures in a postural evaluation.

The image size usually adopted by studies that use methods of photogrammetric evaluation is 1600 x 1200 pixels (3,7,22). This pixel matrix makes it possible to represent each image component by at least two pixels without interpolation on an 800 x 600-pixel screen. However, no studies have justified or explained so far why this image size is adopted in photogrammetric procedures, or what the consequences for the measurement process are. One of the most popular types of software for quantitative posture evaluation is the Postural Assessment Software (SAPO) (8,22). This software performs an interpolation of the image that reduces the highest resolution of the image to fit a 1-Mb file size to optimize data processing time. Therefore, even if the researcher captures the image with a higher resolution, using this software the posture image resolution will decrease to fit the file size established by the SAPO algorithm.

The broad usage of this method in physical therapy and the weak intra-tester reliability of visual and manual assessments make digital photogrammetry a possible method to use in clinical environment. Several procedures need to be followed to guarantee the minimum quality of the photogrammetric analysis, such as: a suitable environment and clothes, a proper camera position, a correct tagging of anatomical markers, and image resolution (7,13,23-26). A better understanding of its potential interference factors, such as image resolution, is needed in order to improve the reliability and repeatability of the postural assessment.

The aim of the present study was to determine the influence of image resolution manipulation on the photogrammetric measurement of a rearfoot static angle. Our hypothesis was that, considering a fixed marker size, a minimal image resolution would be accepted to assure the reliability of postural assessments of the rearfoot angle of an adult using photogrammetric measurements.

Material and Methods

A sample power calculation was done using the GPower 3.0 software. The sample size calculation was based on the primary outcome (rearfoot angle), considering a statistical design of an *F*-test for repeated measures (within effects), with a moderate size effect (f = 0.25), a power of 80%, and an alpha error of 5%. The resulting sample size was 20 individuals. We had to exclude one individual from the final statistical analysis due to errors in the instrumentation. Therefore, 19 healthy young adults, 8 men (42%, 20 ± 3.5 years old, 62.0 ± 3.7 kg, 173 ± 10 cm) and 11 women (58%, 23 ± 4.8 years old, 54.8 ± 5.1 kg, 161 ± 3 cm) were studied. They were all asymptomatic, with no history of neurological disease, or leg length discrepancies of more than 1 cm (umbilicus-medial malleolus) (27). The Ethics Committee of the Hospital das Clínicas, Faculdade de Medicina, Universidade de São Paulo approved the study (Protocol No. 1237/05) and all subjects gave written informed consent to participate.

Image acquisition

A digital camera (focal length relative: 33 mm, Sony DSC-P41, Brazil) was used for standing posture photography. The camera was positioned 1 m above the ground, centralized and horizontally placed at a distance of 2 m posterior to the subject. Although we focused on the rearfoot measure, we defined the camera position based on its focal length and depth of field, and on a regular clinical evaluation of the entire body posture. A plumb line was fixed on the roof, to the side of the subject, for posterior image calibration.

The vertical dimensions of a 17-inch monitor screen was adopted to establish the initial image resolution (reference; resolution 3, 768 pixels); based on that initial resolution, four other resolutions were later defined in the Adobe Photoshop v. 7.0 on the basis of pixel density per screen unit: 1536 (resolution 1), 1200 (resolution 2), 600 (resolution 4), and 384 (resolution 5). In order to ensure equality of conditions, image acquisition was performed at the highest resolution (resolution 1), before the images were re-dimensioned using a bicubic interpolation mode in Adobe Photoshop v. 7.0, a software for artistic purposes but with tools that allow a proper image assessment. The proportion of the images was maintained in all resizings (aspect ratio = 1).

Rearfoot angle postural evaluation

The subjects were placed in the orthostatic position, barefoot, in front of an opaque wall, to evaluate the rearfoot angle in the posterior view of the frontal plane. To maintain uniform inter-subject positioning, they were told to maintain their feet parallel to each other, and an ethylene vinyl acetate rectangle (7.5 x 30 cm) was placed between each subject's feet. Also, we standardized the distance between feet for each subject and drew the support base freely adopted for each subject on a draft card in the first evaluation. We used it to perform the second evaluation 1 week later, and then we could keep the same chosen support base and foot positioning of each subject in both evaluations. With a demographic pencil and white marks every 9 mm, the following anatomical landmarks were identified by an experienced physiotherapist on the inferior and posterior aspects of both legs: the centers of the posteroinferior and posterosuperior portions of the calcaneus, and the center of the posteroinferior third of the leg.

Once the photography was completed, 3 additional equally trained examiners (examiners 1, 2, and 3) measured the rearfoot angle (2,3). Each subject image was marked and analyzed in Photoshop v. 7.0. The evaluation process (anatomical landmark palpation and label fixation, photograph registration, and angle measurement) was performed at 1-week intervals to provide data for the determination of inter- and intra-examiner reliability.

To identify the systematic errors associated with image resolution in the measurement of the rearfoot angle, we calculated the difference between the measure obtained in the reference image (resolution 3) and those obtained in all other resolutions. In addition, considering the presence of random errors in the measurement results, we evaluated the measurements' reliability in all resolutions, performed by 3 independent examiners (1, 2, and 3) in different environments, in order to avoid information exchange between them. Each examiner evaluated the images in five different resolutions and at both evaluation times (1-week interval).

Statistical analysis

Reliability tests and inferential statistical analysis were performed after confirming the normal distribution (Shapiro-Wilk test) and homogeneity of variances (Levene's test) of the rearfoot angle. The comparisons among i) different examiners and ii) different resolutions of the images for each examiner were performed by ANOVA for repeated measures, with the level of significance set at 5%.

The intra-rater reliability at each level of resolution for the rearfoot angle was verified using the intra-class correlation coefficients ($ICC_{3,1}$) (28) for each examiner's measurements at both evaluation times. The inter-rater reliability of each resolution for the rearfoot angle was calculated with the $ICC_{2,1}$ (28), using the first data set from 3 independent examiners. The first data set was selected randomly by simple draw. ICC scores below 0.70 were considered to be unacceptable, scores from 0.71 to 0.79 were acceptable, 0.80 to 0.89 were very good, and scores over 0.90 were excellent (28).

In order to determine the systematic error of the measurement process for each examiner (intra-examiner reliability), we calculated the standard error of measurement (SEM) (28). The intra-examiner reliability SEM was calculated as the ratio between the variability (standard deviation, or SD) of the mean difference scores between the two times of evaluation and √2, since there were two repeated measures. In order to determine the systematic error of the measurement process for each resolution (inter-examiner reliability), we calculated the standard error of prediction (SEP). The inter-examiner reliability SEP was calculated as indicated in Equation 1: the product of the variability (SD) of the measure obtained by each examiner in each resolution and $\sqrt{1\text{-}ICC^2}$ (28).

$$SEP = \mathrm{SD} \times \sqrt{1 - \mathrm{ICC}_{2,1}} \qquad \text{(Equation 1)}$$

where $ICC_{2,1}$ = ICC types 2 and 1.

Results and Discussion

The aim of this study was to investigate the influence of image resolution manipulation on the intra- and inter-examiner reliability of photogrammetric measurements of static rearfoot angles. To our knowledge, no previous reports of the influence of image resolution on lower limb photogrammetric measurements are available in literature. Our main results showed that an image size of 768 pixels was sufficient to ensure a very good inter-examiner reliability for rearfoot static measurements, and that image resolutions higher than 768 pixels improved the inter-examiner reliability of photogrammetric measurement (Table 1). Finally, the unacceptable intra-rater reliability results in all resolutions (ICC from 0.08 to 0.52) associated with a high SEM (from 0.07 to 0.70) led us to discard this method of analysis to follow up patients in clinical practice, but can still be used as a posture diagnostic tool.

Although photogrammetric studies in the current literature have established a standard image resolution of 1600 x 1200 pixels, in order to minimize the influence of this factor on postural assessments (3,7,21), the present study showed that higher or lower resolutions than 768 pixels did not influence rearfoot outcome measures when the same

Table 1. Means ± SD, inter-examiner intra-class correlation coefficient (ICC), standard error of prediction, and P value of the inter-examiner and intra-examiner comparison for the rearfoot angle in the first evaluation of different image resolutions.

Image resolution (pixels)	Rearfoot angle (degree)			P^1 (ANOVA)	$ICC_{2,1}$	Reliability
	Examiner 1	Examiner 2	Examiner 3			
1536	1.8 ± 3.3 (1.32)	2.5 ± 3.1 (1.24)	2.7 ± 3.7 (1.48)	0.563	0.92	Excellent
1200	2.0 ± 3.3 (1.47)	3.1 ± 2.4 (1.07)	2.7 ± 3.7 (1.65)	0.346	0.90	Excellent
768	2.1 ± 3.2 (1.75)	2.9 ± 2.2 (1.20)	3.0 ± 3.2 (1.75)	0.333	0.85	Very good
600	1.9 ± 3.3 (2.28)	3.0 ± 2.4 (1.66)	3.1 ± 2.9 (2.00)	0.163	0.76	Acceptable
384	2.0 ± 3.6 (2.59)	3.1 ± 2.9 (2.09)	3.7 ± 4.3 (3.10)	0.112	0.74	Acceptable
P^2 (ANOVA)	0.970	0.189	0.221			

Data are reported as means ± SD with standard error of prediction within parentheses and were analyzed by ANOVA for repeated measures. P^1 ANOVA among examiners; P^2 ANOVA among resolutions. $ICC_{2,1}$ = intra-class correlation coefficients (inter-rater $ICC_{2,1}$ test).

examiner evaluated a single image twice at 1-week intervals (intra-examiner reliability). The fact that the resolution did not change intra-examiner reliability when measuring the rearfoot angle in the same image at different times leads us to conclude that this is probably not the most important factor of the photogrammetric process. This conclusion is in line with other studies that found poor intra-examiner reliability in postural assessment under the same conditions, when a single image was assessed over time by the same examiner (7,21).

An interesting finding of our study was that resolutions higher than 768 pixels (1200 and 1536) improved the inter-examiner reliability of the rearfoot angle measurement. This leads us to conclude that it is highly desirable to have larger image sizes when many examiners are involved in clinical assessment, as in multicenter studies. Larger image sizes, however, require longer data processing times and larger storage space.

Regardless of the resolution, all examiners demonstrated unacceptable intra-examiner reliability of the measurement when the whole photogrammetry process was performed twice. In the present study, systematic errors such as perspective, positioning/repositioning of subject in the scene, positioning/repositioning and also anatomical landmarking and intra-individual variability of the posture may have influenced our results and could indeed be considered as a study limitation. Our findings agree with another study (7) that confirmed that photogrammetry is not a proper tool for follow-up evaluations of patients within a therapeutic protocol.

Our study contributes to the literature by investigating the influence of an important factor that, although only superficially approached in the literature, interferes with the inter- and intra-examiner reliability of photogrammetric studies (21) in clinical practice, i.e., image resolution. Image sizes higher than 768 pixels should be adopted in all clinical protocols defined to evaluate the whole body posture of an adult (5,7,10,14), but not to other postural assessment protocols defined to evaluate only a specific angle, as observed in studies by Ribeiro et al. (9,26), McPoil and Corwall (29), and Cornwall and McPoil (30).

Although the rearfoot angle is an important postural variable and has been associated with common musculoskeletal dysfunctions (17-20), we suggest that the same reliability design protocol should be performed for other postural static angles.

For photogrammetric postural studies of the whole body of an adult, any image size analyzed on a 96-ppi monitor screen does not influence the rearfoot static angle measurement. In addition, images with vertical dimensions of 768 pixels still provide very good inter-examiner reliability. However, higher resolutions than 768 pixels (1536 and 1200) further improve the inter-examiner reliability of measurements. Regardless of the image resolutions, the intra-examiner reliability was not acceptable and this method is not a proper tool for follow-up evaluations of patients within a therapeutic protocol.

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References

1. ASPRS American Society for Photogrammetry and Remote Sensing. What is ASPRS? Bethesda: American Society for Photogrammetry and Remote Sensing [cited 21/12/2007] [http://www.asprs.org/a/society/about.html].

2. Kernozek TW, Greer NL. Quadriceps angle and rearfoot motion: relationships in walking. *Arch Phys Med Rehabil* 1993; 74: 407-410.
3. Sacco I, Alibert S, Queiroz B, Pripas D, Kieling I, Kimura A, et al. Confiabilidade da fotogrametria em relação a goniometria para avaliação postural de membros inferiores. *Rev Bras Fisioter* 2007; 11: 411-417.
4. Dunk NM, Chung YY, Compton DS, Callaghan JP. The reliability of quantifying upright standing postures as a baseline diagnostic clinical tool. *J Manipulative Physiol Ther* 2004; 27: 91-96.
5. Lima LC, Barauna MA, Sologurem MJ, Canto RS, Gastaldi AC. Postural alterations in children with mouth breathing assessed by computerized biophotogrammetry. *J Appl Oral Sci* 2004; 12: 232-237.
6. Domholdt E. *Physical therapy research: principles and applications*. Philadelphia: WB Saunders Company; 1993.
7. Iunes D, Castro F, Salgado H, Moura I, Oliveira A, Bevilaqua-Grossi D. Intra and inter-examiner reliability and method repeatability of postural evaluation via photogrammetry. *Rev Bras Fisioter* 2005; 9: 327-334.
8. Penha PJ, Baldini M, João SM. Spinal postural alignment variance according to sex and age in 7- and 8-year-old children. *J Manipulative Physiol Ther* 2009; 32: 154-159.
9. Ribeiro AP, Trombini-Souza F, Tessutti V, Rodrigues LF, Sacco IC, João SM. Rearfoot alignment and medial longitudinal arch configurations of runners with symptoms and histories of plantar fasciitis. *Clinics* 2011; 66: 1027-1033.
10. Saad KR, Colombo AS, Ribeiro AP, João SM. Reliability of photogrammetry in the evaluation of the postural aspects of individuals with structural scoliosis. *J Bodyw Mov Ther* 2012; 16: 210-216.
11. Van Maanen CJ, Zonnenberg AJ, Elvers JW, Oostendorp RA. Intra/interrater reliability of measurements on body posture photographs. *Cranio* 1996; 14: 326-331.
12. Pereira OS. A utilização da análise computadorizada como método de avaliação das alterações posturais: um estudo preliminar. *Fisioter Mov* 2003; 16: 17-25.
13. Sato TO, Vieira ER, Gil Coury HJC. Análise da confiabilidade de técnicas fotométricas para medir a flexão anterior do tronco. *Rev Bras Fisioter* 2003; 7: 53-99.
14. Ballantyne BT, French AK, Heimsoth SL, Kachingwe AF, Lee JB, Soderberg GL. Influence of examiner experience and gender on interrater reliability of KT-1000 arthrometer measurements. *Phys Ther* 1995; 75: 898-906.
15. Saad KR, Colombo AS, Joao SM. Reliability and validity of the photogrammetry for scoliosis evaluation: a cross-sectional prospective study. *J Manipulative Physiol Ther* 2009; 32: 423-430.
16. Braun BL, Amundson LR. Quantitative assessment of head and shoulder posture. *Arch Phys Med Rehabil* 1989; 70: 322-329.
17. Shama SS, Kominsky SJ, Lemont H. Prevalence of non-painful heel spur and its relation to postural foot position. *J Am Podiatry Assoc* 1983; 73: 122-123.
18. Rome K, Howe T, Haslock I. Risk factors associated with the development of plantar heel pain in athletes. *The Foot* 2001; 11: 119-125.
19. Tauton JE, Ryan MB, Clement DB, McKenzie DC, Lloyd-Smith DR. Plantar fasciitis: a retrospective analysis of 267 cases. *Phys Ther Sports* 2002; 3: 57-65.
20. Levinger P, Gilleard W. An evaluation of the rearfoot posture in individuals with patellofemoral pain syndrome. *J Sports Sci Med* 2004; 3: 8-14.
21. Moncrieff MJ, Livingston LA. Reliability of a digital-photographic-goniometric method for coronal-plane lower limb measurements. *J Sport Rehabil* 2009; 18: 296-315.
22. Ferreira EA, Duarte M, Maldonado EP, Burke TN, Marques AP. Postural assessment software (PAS/SAPO): Validation and reliabiliy. *Clinics* 2010; 65: 675-681.
23. Iunes DH, Bevilaqua-Grossi D, Oliveira AS, Castro FA, Salgado HS. Análise comparativa entre avaliação postural visual e por fotogrametria computadorizada. *Rev Bras Fisioter* 2009; 13: 308-315.
24. Farkas LG, Bryson W, Klotz J. Is photogrammetry of the face reliable? *Plast Reconstr Surg* 1980; 66: 346-355.
25. Watson AW, Mac Donncha C. A reliable technique for the assessment of posture: assessment criteria for aspects of posture. *J Sports Med Phys Fitness* 2000; 40: 260-270.
26. Ribeiro AP, Trombini-Souza F, Iunes DH, Monte-Raso VV. Confiabilidade inter e intra-examinador da fotopodometria e intra-examinador da fotopodoscopia. *Rev Bras Fisioter* 2006; 10: 435-439.
27. Hoppenfeld S. *Physical examination of the spine and extremities*. 2nd edn. New York: Appleton-Century-Crofts; 1997.
28. Weir JP. Quantifying test-retest reliability using the intraclass correlation coefficient and the SEM. *J Strength Cond Res* 2005; 19: 231-240.
29. McPoil TG, Cornwall MW. Relationship between three static angles of the rearfoot and the pattern of rearfoot motion during walking. *J Orthop Sports Phys Ther* 1996; 23: 370-375.
30. Cornwall MW, McPoil TG. Influence of rearfoot postural alignment on rearfoot motion during walking. *The Foot* 2004; 14: 133-138.