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Camera angle variation in the range of motion's assessing by computerized photogrammetry

Variação do ângulo da câmera nas avaliações de amplitude articular por fotogrametria computadorizada

Variación del ángulo de la cámara en evaluaciones del rango articular mediante la fotogrametría computarizada

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ABSTRACT | The computerized photogrammetry has been highlighted as a non-invasive resource for evaluation, with good reproducibility of results, but its application parameters are still lacking standardization. This study compared outcomes of range of motion obtained with photogrammetric assessments from images photographed in different camera inclinations in relation to the object (0°, 5°, 10°, 15°, 20°, 25°, and 30°). The images were analyzed with computerized photogrammetry by six raters who assessed the joint range present in the images. The outcomes showed that even with 5° in camera inclination, there was significantly different results between assessments, and the margin of error increased as the camera inclination was intensifying.

Keywords | Range of Motion; Photogrammetry; Assessment.

RESUMO | A fotogrametria computadorizada tem se destacado como um recurso avaliativo não invasivo e de boa reprodutibilidade de resultados, contudo ainda carece de padronizações quanto aos parâmetros de sua aplicação. Este estudo comparou os resultados de análises fotogramétricas de amplitude articular obtidos a partir de imagens com diferentes inclinações da câmera fotográfica, em relação ao objeto (totalmente frontal ou 0°, 5°, 10°, 15°, 20º, 25º e 30º). As imagens foram analisadas pela técnica da fotogrametria computadorizada e por seis examinadores que realizaram a quantificação de uma medida angular presente nas imagens. Os resultados demostraram que mesmo com uma variação de 5° de inclinação de câmera, observou-se a presença de resultados significativamente diferentes entre as avaliações, com a margem de erro aumentando, conforme se acentuou a inclinação da câmera.

Descritores | Amplitude de Movimento Articular; Fotogrametria; Avaliação.

RESUMEN | La fotogrametría computarizada se ha destacado como un recurso evaluativo no invasivo y con buena reproducibilidad de resultados; sin embargo, aún carece de estándares en cuanto a los parámetros de su aplicación. Este estudio comparó los resultados de los análisis fotogramétricos del rango articular, obtenidos a partir de imágenes con distintas inclinaciones de la cámara fotográfica en relación al objeto (totalmente frontal o 0°, 5°, 10°, 15°, 20°, 25° y 30°). Las imágenes fueron analizadas por la técnica de fotogrametría computarizada y por seis examinadores que realizaron la cuantificación de una medida angular presente en ellas. Los resultados mostraron que incluso con una variación de 5° de inclinación de la cámara se observó resultados significativamente distintos entre las evaluaciones, aumentando el margen de error, mientras se acentuaba la inclinación de la cámara.

Palabras clave | Rango del Movimiento Articular; Fotogrametría; Evaluación.

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INTRODUCTION

The use of new technologies and methods that enable the measurement of body and human gestures, allowing for the interpretation of biomechanical parameters in a clear, dynamic, and reliable way, has become a challenge for scholars in this field of knowledge. In this context, computerized photogrammetry stands out in recent decades as a widespread and accepted technique by movement analysis professionals[1], being considered a noninvasive assessment resource, with low cost, high precision and good reproducibility of results[2,3].

Since its creation, computerized photogrammetry has demonstrated great versatility, with potential for numerous uses, such as: performing postural evaluations[4-6]; evaluating the individuals' flexibility[7];quantifying joint angles, or range of motion (ROM)[3,8];and performing morphometric analysis and standardization[9,10].

Despite the numerous advantages and potentialities of this evaluative technique, when analyzing the main national studies on the theme[2,3,11,12], it is clear the lack of standardization regarding the position of the camera in relation to the photographed object, in relation to the image to be analyzed. There are, although, some studies developed in this sense[13,14].

As such, further research is essential to provide more knowledge, and its results shall indicate a uniform direction to adequate camera positioning.

Therefore, this work aimed to compare the results of photogrammetric analyses of ROM, obtained from images with different cross inclinations of the camera, in relation to the object.

METHODOLOGY

The sample was divided into two categories: (1) Raters; and (2) Scanned images under analysis. It was necessary to perform previous training (8h workshop) of the raters (undergraduates of the physical therapy course), in order to ensure a similar skill and experience regarding the computerized photogrammetry software. This workshop was carried out by a professional with training and experience in the area.

After the application of this training, students were then presented to the study objectives and methodological proposal. Then, they were asked to sign the informed consent form. Out of nine trained volunteers, six individuals were selected to compose this group.

A sample estimation, using the standard deviation value of 0.541 for ROM measurements obtained by computerized photogrammetry in a similar previous study[14], defined a minimum of 18 images to be analyzed for each camera position experienced in this study, in order to assure statistical validity of this sample and the reproducibility of this study.

Regarding the photographed objects, we decided to make banners with full-size images of an individual's upper limb, standing and in profile, with the elbow joint at different angles. Surface markers were previously positioned on the lateral edge of the acromion, lateral epicondyle of the humerus, and styloid process of the radio. In total, eight different angular positions of the elbow were used, therefore, eight banners were made.

The banners were fixed (one at a time) on a wall, facing the camera (Nikon Coolpix L810, with resolution of 16.1 megapixels), positioned on a tripod, at a distance of 2.4m from the banner, according to the description of Iunes et al.[11,15], and at the height of the elbow joint visualized in the banner, following Ricieri's suggestion[13] (Figure 1).

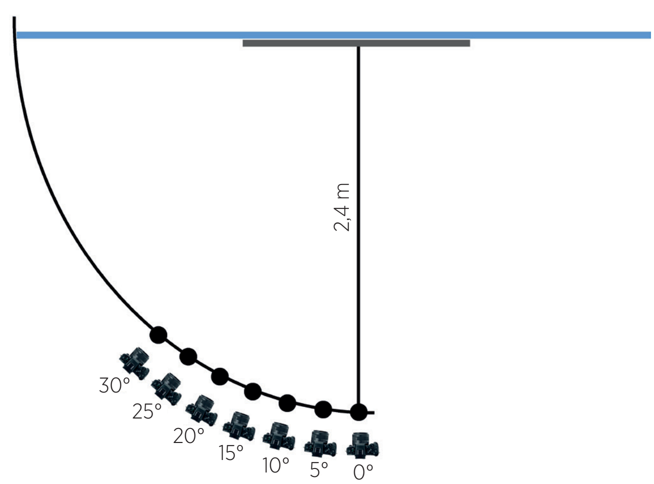

Figure 1. Camera positioning protocol for photographic records

Photographic records of each of the 8 banners were captured using these parameters and varying only the angle of the camera in each of the seven camera angles tested (0°, 5°, 10°, 15°, 20°, 25°, and 30°) in relation to the photographed banner (Figure 2).

The digital images obtained were transferred to notebooks equipped with three of the most used software for photogrammetric analysis (CorelDraw, AutoCAD, and ImageJ). Thus, the raters were invited to perform the ROM analyses of the elbow of the photographed model, using computerized photogrammetry. These analyses occurred on three non-consecutive days (three-day interval between each analysis), to prevent the raters from memorize their evaluations results. Note that in all days of analysis, raters received the same set of images. However, such images have been renamed and their order was changed in the digital folders.

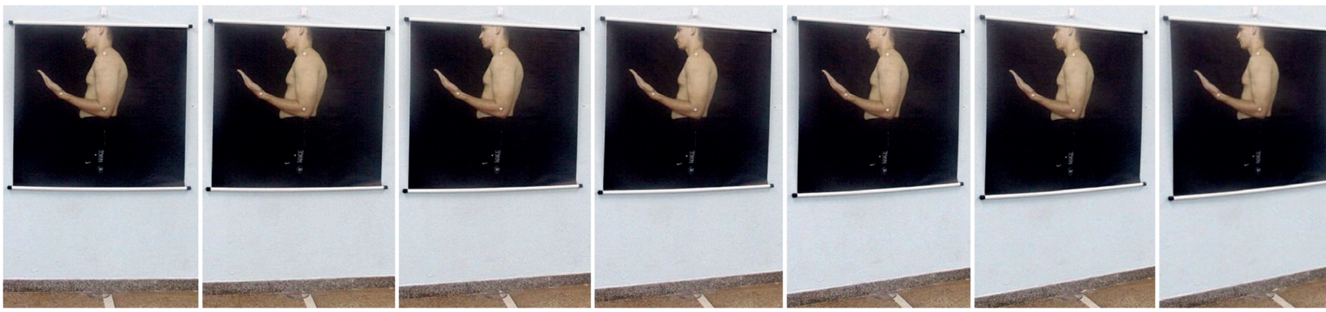

Figure 2. The seven camera angles used

It is also appropriate to clarify that although the raters were asked to perform photogrammetric analyses of several angular positions of elbow joints, only one of these angles was considered for variance analyses and to respond this research objectives. This key angle was defined by the researchers, but the raters were not informed about its existence.

The results of these analyses were later tabulated, and their statistical analysis was performed with BioEstat 5.4. Descriptive statistics was used to characterize the data set of photogrammetric analyses. The analysis of data normality was performed by using the Shapiro-Wilk test and it indicated the use of non-parametric variance analysis tests (Kruskal-Wallis for the analysis of inter-rater and Friedman variance for intra-examiner variance analysis). Finally, to test the variance between the angular measurements obtained from images in different angular positions, the Kruskal-Wallis test was used. The level of significance was 5%.

RESULTS

Firstly, it was necessary to establish whether any of the software used (AutoCAD, Corel Draw or ImageJ) could favor obtaining inconsistent results. Similarly, it was also necessary to establish whether any of the six raters would present inconsistent results of their photogrammetric analyses (Table 1).

Table 2 presents the descriptive statistics and the normality of the photogrammetric measurements obtained by raters with Corel Draw software, from images of the elbow joint captured with the camera at different inclinations.

Table 1. Significance values of the variance analyses of photogrammetric evaluations

	Inter-rater variance			
	1st day	2nd day	3rd day	All days
AutoCAD	0.270	0.081	9.022	13.467
Corel Draw	0.316	0.442	0.108	0.149
ImageJ	0.341	0.149	0.117	0.108

	Intra-rater variance					
	Rater 1	Rater 2	Rater 3	Rater 4	Rater 5	Rater 6
AutoCAD	0.861	0.819	0.638	0.442	0.117	0.805
Corel Draw	0.7	0.86	0.89	0.27	0.7	0.86
ImageJ	1	0.64	0.86	0.21	0.82	0.26

Table 2. Descriptive statistics and normality of data of the photogrammetric analyses

Inclinations	0°	5°	10°	15°	20°	25°	30°
n	18	18	18	18	18	18	18
Minimum	66	66	66	66	67	66	67
Maximum	69	69	70	69	70	70	70
Mean	67.22	67.33	68.17	68.17	68.55	68.83	68.94
SD	0.73	0.84	0.86	1.04	0.78	0.92	0.80
Shapiro-Wilk	0.82	0.84	0.83	0.77	0.82	0.76	0.84
p	0.01	0.01	0.01	0.01	0.01	0.01	0.01

p: significance level

Table 3 demonstrates all comparisons between angular measurements performed by computerized photogrammetry in different camera inclinations tested in this experiment. The table shows the comparisons among which a significant variation in angular values obtained by computerized photogrammetry was identified.

Table 3. Variance between angular measurements from images with different variations of the transverse angular positioning of the camera

	Comparison between camera inclinations	p	% of significant variances
5° variations	25°×30°	0.836	16.66%
	20°×25°	0.380	
	15°×20°	0.345	
	10°×15°	0.797	
	05°×10°	0.029*	
	00º×05°	0.742	
10° variations	20°×30°	0.277	40%
	15°×25°	0.068	
	10°×20°	0.229	
	05°×15°	0.015*	
	00°×10°	0.012*	
15° variations	15°×30°	0.042*	100%
	10°×25°	0.037*	
	05°×20°	0.001*	
	00°×15°	0.006*	
20° variations	10°×30°	0.022*	100%
	05°×25°	0.000*	
	00°×20°	0.000*	
25° variations	05°×30°	0.000*	100%
	00°×25°	0.000*	
30° variations	00°×30°	0.000*	100%

p: significance level; *significant variances

DISCUSSION

Data in Table 1 indicate that no software favored inconsistent results, since no significant variation of its results was observed in any of the analysis.

Guariglia et al.[16] attest good reliability for SAPO, AutoCAD, and Corel Draw software in photogrammetric analyses for angular hip measurement, suggesting that the researcher should chose a software based on their familiarity with it. Good results on reliability and diagnostic accuracy regarding SAPO, AutoCAD, and Corel Draw were also confirmed in Furlanetto's et al. review[4], which aimed to evaluate the mathematical procedures employed by different software already validated for postural evaluation by computerized photogrammetry. In relation to the, ImageJ software, literature exploration demonstrated that its application for posture and ROM analyses is less frequent, however, its application is very prominent in morphometric evaluation studies, in which it is used for identification, quantification, and measurement of structures[9,10].

In addition to the software reliability, Guariglia et al.[16] emphasize the significance of the raters' previous experience regarding the software use to perform photogrammetric analyses, as evidenced in the experiment by Paes et al.[6]. These authors declare that familiarization becomes even more necessary when dealing with software such as AutoCAD and Corel Draw, which were not originally designed for this practice. This same opinion is shared by several other authors[17,18], who reaffirm that the lower the experience of a rater with the chosen software, the highest the chance of weaken the analysis reliability.

Generally, this difficulty is usually overcome with a small specific training using the software tools, as observed in the study by Batista et al.[19] and Gutterres[20]. It was also found in this study that no rater presented inconsistent results of analyses (Table 1), thus defining that the previously performed training was sufficient and effective to qualify them.

However, when evaluating Furlanetto's et al.[4] and Singla's et al. reviews[5], it is clear that in addition to the competence regarding the use of the software for photogrammetric analysis, the raters' technical experience regarding the protocol of evaluation (the individual's correct positioning and the identification of anatomical landmarks in postural or ROM evaluations, for example) is equally relevant. This statement is supported by the research of Carneiro et al.[17] and Gutterres[20] who linked low inter-rater reliability in their studies to the heterogeneity of raters' experience, in relation to the technical evaluation procedures.

This fact was decisive for the methodological planning of this study, removing from the raters the technical responsibility for the positioning of the evaluated object and body surface markers, thus avoiding the procedure bias.

The next step of this research occurred Once it was identified that all three software and the six raters presented sufficient consistency of results. Then, the comparison of angular measurements of the elbow in images captured at different camera inclinations was carried out, using the Corel Draw, after a democratic choice among raters.

When observing the results of Table 2, it is observed that the mean angular value identified by the raters for elbow position was approximately 67° (67.22°) for images obtained with the camera in the front of the banner (position 0°). This angular value clearly demonstrates a distance from the initial value, as the camera inclination increases, reaching the mean angulation of almost 69° (68.94°), with the camera inclined to 30° in relation to the object.

According to Ricieri[21], image distortions can disqualify the analysis. Therefore, when carrying out a photographic interpretation of angle it is important to validate the instrument and method. Iunes et al.[11] are equally assertive when they state that the proper use of computerized photogrammetry requires several methodological care in order to standardize the photos and avoid distortion effects, since such effects can mislead an analysis.

Regarding the results presented in Table 3, note that even in the comparison group—which compared angular measurements with a 5° variation of camera inclination (the lowest variation in this experiment)—significant variations of results were observed.

In a similar study, Mota et al.[22] sought to investigate the interference of the object positioning, in relation to the plane of the camera. In this study, an articulated mannequin was photographed in different positions (frontal plane and rotated to the right and left). Based on these images, it was verified that the measurements obtained without rotation obtained the lowest error and dispersion of measurement, whereas the rotations to the left and right presented higher errors.

Despite the methodological difference between Mota's et al.[22] study and this research, it is quite clear that the intention of both is similar and, therefore, their results are easily comparable, considering that they highlight that: even small variations in camera inclination can affect the reliability of photogrammetric analyses.

Also, as presented in Table 3, the percentage frequency of significant variations increased gradually, as the variation in the inclination of the camera positioning was also increased, reaching 100% of significant variations in comparisons, with a difference of 15° inclination and higher.

Once again the study by Mota et al.[22] follows the results of this investigation, since its results also indicated a greater error of photogrammetric measurement in situations in which the greatest misalignments between camera and object (8^{th} right and left) were tested. Thus, both studies clearly indicate that the greater the misalignment between camera and object, the greater the image distortion and, therefore, the greater the probability of error in computerized photogrammetry measurements.

CONCLUSION

Therefore, it is concluded that even small variations in camera inclination can affect the reliability of photogrammetric analyses and the greater the misalignment between camera and object, the greater the image distortion as well as the probability of error in computerized photogrammetry measurements.

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