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ORIGINAL RESEARCH

Intra and inter-rater reliability of the projection of the body's center of mass obtained via photogrammetry

Análise intra e interavaliadores da projeção do centro de massa do corpo obtido por fotogrametria

Análisis intra e interevaluadores de la proyección del centro de masa del cuerpo obtenido por fotogrametría

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ABSTRACT | For optimal postural control, the center of mass (COM) of the body is a variable that is projected vertically between the legs, over a support base. This study had as aim assessing the inter- and intra-rater reliability of the projection of the COM over the support base, measured with the aid of the Postural Evaluation Software (SAPO). Fifty-seven volunteers were evaluated and all were subjected to photographic records taken from the anterior, left and right lateral views, at the same time. The pictures were handed over to two raters, who then used SAPO to analyze them. For the statistical analysis, the intra-class correlation coefficient (ICC) was used, and to estimate the minimum detectable change (MDC), the standard error (SE) was used. The results showed excellent levels of inter and intra-rater reliability for asymmetries in the frontal and sagittal planes, and for the projection of the center of gravity in the frontal and lateral planes (ICC>0.90; 95%CI>0.95; MDC between 2.16 – 4.87). The results of the study showed that the analysis of the COM obtained with SAPO had good inter- and intra-rater reliability.

Keywords | Photogrammetry; Postural Balance; Posture; Rehabilitation.

RESUMO | Para o ótimo controle postural, o centro de massa (COM) do corpo é uma variável que se projeta verticalmente entre os pés, dentro de uma base de suporte. Este estudo teve por objetivo avaliar a confiabilidade inter e intra-avaliadores da projeção do COM na base de sustentação, mensurada com auxílio do Software de Avaliação Postural (SAPO). Cinquenta e sete voluntárias foram avaliadas e todas foram submetidas ao registro fotográfico nas vistas anterior, lateral direita e esquerda, no mesmo instante temporal. As imagens foram entregues a dois examinadores, os quais utilizaram o SAPO. Para a análise estatística, foi utilizado o coeficiente de correlação intraclasse (ICC) e, para estimar a mínima mudança detectável (MMD), foi utilizado o erro padrão (EP). Os resultados demonstraram excelentes níveis de confiabilidade interexaminador e intraexaminador para assimetrias nos planos frontal, sagital e para a projeção do centro de gravidade no plano frontal e lateral (ICC>0,90; 95%IC>0,95; MDD entre 2,16 – 4,87). Os resultados do estudo demonstraram que a análise do COM obtida por meio do SAPO apresentou boa confiabilidade nas análises inter e intra-avaliadores.

Descritores | Fotogrametria; Equilíbrio Postural; Postura; Reabilitação.

RESUMEN | Para el óptimo control postural, el centro de masa (COM) del cuerpo es una variable que se proyecta verticalmente entre los pies, dentro de una base de soporte. Este estudio tuvo por objetivo evaluar la confiabilidad inter e intraevaluadores de la proyección del COM en la base de sostenimiento,

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medida con apoyo del Software de Evaluación Postural (SAPO). Se evaluaron cincuenta y siete voluntarias y todas han sido sometidas al registro fotográfico en las vistas anterior, lateral derecha e izquierda, en el mismo instante temporal. Las imágenes han sido entregadas a dos examinadores, que utilizaron SAPO. Para el análisis estadístico, se utilizó el coeficiente de correlación intraclase (ICC) y, para estimar el mínimo cambio detectable (MMD), se utilizó el error estándar (EP). Los resultados demostraron excelentes niveles de confiabilidad interexaminador e intraexaminador para asimetrías en los planos frontal y sagital y para la proyección del centro de gravedad en el plano frontal y lateral (ICC>0.90, 95% IC>0.95, MDD entre 2.16 – 4.87). Los resultados del estudio demostraron que el análisis del COM obtenido a través de SAPO presentó buena confiabilidad en los análisis inter e intraevaluadores.

Palabras clave | Fotogrametría; Equilibrio Postural; Postura; Rehabilitación.

INTRODUCTION

Human posture can be described as the positioning in equilibrium of all body segments in a given moment[1,2]. In this sense, the search for the correct posture is important for maintaining good health conditions[3].

Postural evaluation in the orthostatic position has been widely used both in clinical practice and in researches, as a diagnostic tool for planning and monitoring physiotherapeutic treatment[4,5]. Various methods have been used to evaluate upright posture with the body's natural oscillation[6]. Stabilometry is a method that allows registering the natural oscillation of the human body and estimating possible postural changes[7]. Other methods have been described to quantify posture, such as the inclinometer, video cameras and radiography[8]. However, it is not common to use these methods in clinical practice due to the unavailability of such equipment to professionals[4], in addition to problems related to radiation exposure for this last method[9].

Another resource used for postural evaluation is computerized photogrammetry[10]. This technique is a useful tool, with low cost, good reliability for postural evaluation[4,11,12] and is accessible to the majority of physical therapists.

In clinical practice, the method of postural evaluations is part of a physical examination's routine[13]. Commonly these evaluations and interpretations are conducted in the form of visual and subjective inspection[8,12]. In the quantitative assessments performed by health professionals and researchers it is not only the measurement of postural changes that occurs, but also the improvement in the monitoring of patients[12]. Thus, new studies aimed at validating and estimating the reliability of the different postural and static balance evaluation systems in clinical environments are needed.

The use of photogrammetry has good reliability for postural evaluation as a method of analysis of body angles[4,12]. However, there are several tools that result in partial validations for specific regions of the body or that analyze a small sample[12]. A study conducted by Ferreira et al.[12] demonstrates that SAPO exhibits good intra- and inter-rater reliability for all measures carried out with regard to the analysis of body angles and distances. However, the same study did not assess the other tool available in the software which allows the static analysis of the COM.

The COM is a variable that can be measured via computerized photogrammetry[14], its trajectory being a measure used to understand the mechanisms of postural control in different motor actions[6]. The COM is defined as the point of application of the resulting gravitational force on the body[15] that acts over the base of support, the area delimited by the lateral sides of the feet. This base of support provides a stability threshold, over which several tasks and movements may be performed without the loss of balance, expressing thus the individual's base of functional support[15].

Therefore, this study had as aim assessing the inter- and intra-rater reliability of the projection of the COM on the support base, via photographic records measured with SAPO.

METHODOLOGY

Casuistry

Fifty-seven volunteers participated in the study, aged 23.38±2.96 years old, with 1.64±0.06 m in height and BMI: 22.27±4.51 Kg/m^2. The criteria for inclusion were: healthy women; aged 18 to 30 years old; with no cognitive disorders; serious infectious and contagious diseases; neuromuscular abnormalities; history of abdominopelvic surgery; changes in the visual, vestibular and somatosensory systems limiting the maintenance of orthostatic position.

Projection of the COM via photogrammetry

The projection of the COM was measured via photogrammetry, with the aid of three professional Nikon cameras®, with 14.1 megapixels each, positioned around the volunteer and synchronized for a single shot. Markings with 30 mm in diameter were used on the tragus of the ear; the acromion; the anterior superior iliac spine; the greater trochanter of the femur; the joint line of the knee; the lateral malleolus and the region between the head of the second and third metatarsals, bilaterally. All markings of the anatomical landmarks were carried out by the same rater.

The collection of the photographic images was held in a calm and appropriate environment. In the picture plane, a 1-m-long plumb line with a 0.10 m marking was used (Figure 1).

Each volunteer was placed in orthostatism beforehand for 20s on an ethylene-vinyl acetate (EVA) mat with the tibial malleoli positioned in parallel at a 0.10m distance. The photos were taken with eyes open and directed towards a white wall. The cameras were positioned at a 2.40 m distance from the volunteer, perpendicularly, at a 1.20 m height from the ground. Each camera obtained an image corresponding to the anterior, right and left lateral views.

After the acquisition of the photographic records, the images were stored on a computer and handed over to two raters acquainted with SAPO v. 0.68. The guidelines given to the raters were: Open SAPO > Create new project > Open image (anterior view initially) > ok > vertical calibration and scaling of the image (according to the plumb line in the photo) > draw a line above the marking on the plumb line > Apply > Calibration of this line: 0.10 m > Calibrate > Verify calibration and image rotation > yes > ok > Leave > Analyses > Marking of landmarks on the image in accordance with the protocol.

After performing the markings on the anterior, right and left lateral views, the analysis report was generated, including: COM, asymmetry in the frontal and sagittal planes, and the projection of the position of the COM in relation to the average position of the malleoli in the frontal and lateral planes. The photographic analysis was collected after a week; rater 1 was responsible for repeating the analysis of the pictures. The marking of the anatomical landmarks on the software followed the criteria established by SAPO, as shown in Figure 2, always held by the same rater.

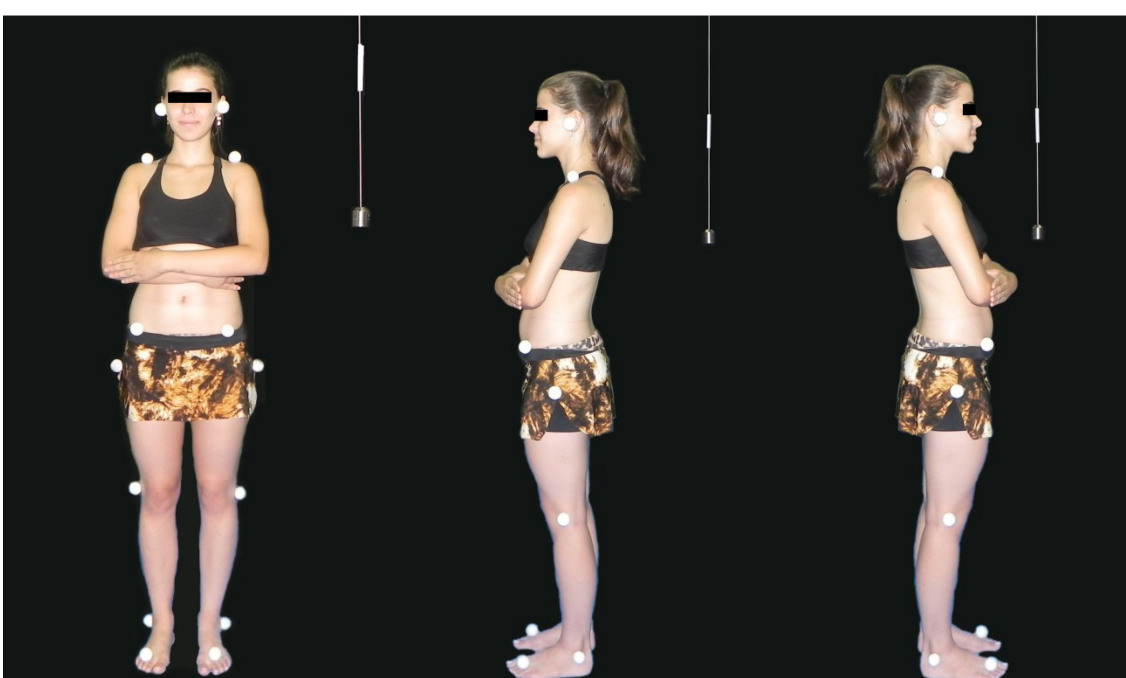

Figure 1. Anatomical landmarks used in the analysis of the anterior, left and right lateral views, in accordance with SAPO's protocol. In the detail, the 1m plumb line with a 0.10m marking is depicted

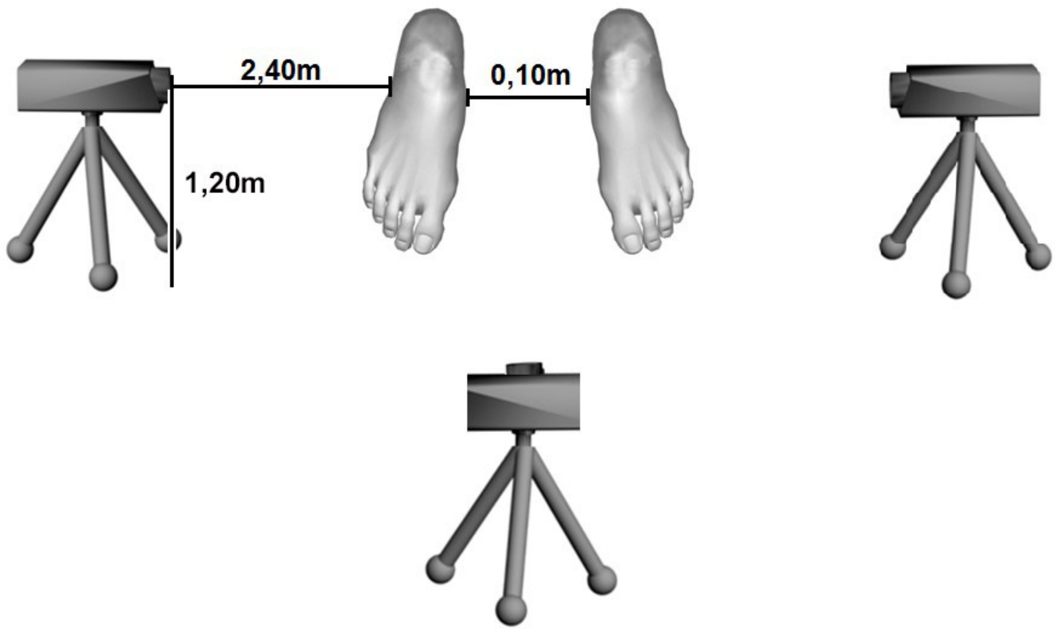

Figure 2. Placement of tripods, cameras and volunteer at the time of collection of the photographs in the anterior, right and left lateral views

Ethical considerations

The study was approved by the Research Ethics Committee at Universidade Federal de Alfenas (CAAE: 08317312.5.0000.5142). All volunteers were informed about the purpose of the study and of the procedures to be carried out; after agreeing, they all signed an Informed Consent Form.

Statistical analysis

For the statistical analysis, the software Statistical Package for the Social Sciences (SPSS v.20.0) for Windows was used. Intra-and inter-rater reliability was analyzed using the Intraclass Correlation Coefficient – type 1.1 and type 1.2 – (ICC). The interpretation of the ICC was carried out in accordance with Lexell[16], with reliability <0.40 being deemed as poor; 0.40-0.75 as good, and >0.75 as excellent. The 95% Confidence Interval (95%) was calculated, values above 0.70[17] being considered as excellent. The calculation of the Standard Error of Measurement (SE) was carried out using the formula: SE=Standard Deviation×√(1-ICC). The minimum detectable change (MDC) was calculated using the formula: MDC=1.96×Highest Standard Deviation×√(2[1-test-retest])[16]. A 0.05% significance level (α) was used in all tests.

RESULTS

In Table 1, the mean values and standard deviation of the variables obtained with the two raters' analysis of the photogrammetry and the retest performed by rater 1 are shown.

Table 1. Values of mean and standard deviation of the analyses obtained with SAPO by raters 1 (test-retest) and 2

	Means (SD)		
	Rater 1	Rater 2	Retest 1
AFP (%)	7.60 (16.39)	8.12 (16.91)	7.95 (16.47)
ASP (%)	31.07 (10.44)	31.36 (10.17)	31.29 (10.10)
PCOMFP (cm)	6.15 (14.19)	6.05 (13.93)	6.46 (14.20)
PCOMLP (cm)	33.28 (11.85)	31.97 (11.24)	33.48 (11.46)

AFP: asymmetry in the frontal plane; ASP: asymmetry in the sagittal plane; PCOMFP: projection of the center of mass in the frontal plane; PCOMLP: projection of the center of mass in the lateral plane

The analyses demonstrate that inter- and intra-rater reliability (Table 2) was excellent for all the variables obtained, with (p<0.01).

Table 2. Values of intra-raters and inter-raters intraclass correlation (ICC) according to the measurements obtained

	Inter-rater					Intra-rater				
	$ICC_{1,2}$	CI95%	SE	MDC	Level	$ICC_{1,1}$	CI95%	SE	MDC	Level
AFP (%)	0.995	0.992-0.997	1.20	3.31	E	0.997	0.995-0.998	0.90	2.50	E
ASP (%)	0.986	0.976-0.992	1.24	3.42	E	0.986	0.977-0.992	1.24	3.42	E
PCOMFP (cm)	0.995	0.991-0.997	1.00	2.78	E	0.997	0.995-0.998	0.78	2.16	E
PCOMLP (cm)	0.978	0.957-0.988	1.76	4.87	E	0.986	0.977-0.992	1.40	3.89	E

AFP: asymmetry in the frontal plane; ASP: asymmetry in the sagittal plane; PCOMFP: projection of the center of mass in the frontal plane; PCOMLP: projection of the center of mass in the lateral plane; 95%CI: 95% confidence interval; SE: standard error; MDC: Minimal Detectable Change; E: Excellent

DISCUSSION

Initially, an extensive literature search was performed and no references were found about the reliability of the use of SAPO for estimating the projection of the COM. Some studies show that the use of photogrammetry produces satisfactory results for postural evaluation[4,11,12], when compared to other techniques, such as the use of radiological examinations[18].

The use of external markings shows correlation when compared to radiographic measures[21-23]. A study conducted with 766 teenagers compared the angles and curves of the spine, measured via radiography and photogrammetry, having concluded that the use of photogrammetry is feasible for the assessment of body alignment, in addition to avoiding the exposure of the volunteers to radiation[9]. A prerequisite to ensure better results in the evaluations of the projection of the COM is the choice of anatomical landmarks to be used in the research and the correct positioning of the markings[4,12,18-20]. Commonly, it is recommended that a single previously trained rater performs the procedure for fixing the markings[18].

With the use of photogrammetry for evaluating specific angles in the human body, low reliability for 15 out of the 22 angles measured was demonstrated, suggesting possible errors inherent to the repetition of the analyses. It is believed that these errors are related to the experimental procedure, which involves the environment's conditions, the placement of the tripod, camera and volunteer, the placement of the markings and the digital photographic record being of suboptimal quality[4]. All these aspects were considered in the present study, in an attempt to minimize possible errors concerning the technique used.

The results demonstrate that the proposed method to quantify the projection of the COM via photogrammetry had excellent intra- and inter-rater reliability levels in the analyses with SAPO, with low minimally detectable difference, less than 0.5 of the standard deviation[24]. SAPO proves itself to be a reliable tool, with the possibility of obtaining similar results after repeating the analyses, small variations of a single variable being accepted[25].

In this study, we chose to standardize the distance between the medial malleoli to validate the technique for obtaining the COM via photogrammetry. This standardization requires an extensive and reflective discussion[26], as it may be able to induce postural changes[12], as well as reduce the support base and increase body oscillation[15]. The projection of the support base of individuals must be measured in a position regarded as the most natural and comfortable, to reflect the actual body alignment[27]. Thus, we stress that in static equilibrium analyses obtained with this method, the support base must be measured in the natural alignment position of the feet.

In orthostatic resting position, even if the individual tries to stay as still as possible, oscillations of the body still happen, which is called postural balance[6]. The variable responsible for measuring this condition is the projection of the COM, as it may assist in the understanding of the mechanisms involved in postural control[28]. The oscillation of the COM is a value that indicates the body's balance. However, the use of photogrammetry may undervalue the analysis of postural balance conditions. Despite the results obtained, we stress that photogrammetry is a complementary technique for postural assessment, simple to perform and, when accompanied by scientific tutorials, it can be used in clinical practice, as well as in researches[12].

SAPO includes other parameters associated with the projection of the COM, displayed in the software as the projection of the center of mass in the frontal (PCOMPF) and lateral (PCOMPL) planes. Both projections take into account the average position of the COM in relation to the medial malleoli. The measure in the frontal plane demonstrates the anteroposterior dislocation, and the measure in the lateral plan demonstrates the mediolateral dislocation of the COM. A study without the validation of this technique demonstrated that the projections of the COM are correlated with plantar dorsiflexor and flexor isometric force in young adults[29]. In our study, young volunteers were evaluated, who could naturally exhibit a lower value of oscillation, but such data were not associated in the sagittal and frontal planes. Future studies with different age groups are essential for a better contribution of the technique to the evaluation of static equilibrium, for the identification of the risks of falls, to prevent the emergence of secondary lesions and other comorbidities[30], as in older adults, balance corrections occur in the regions of the hip, adductors and abductors, which may influence the mediolateral projection of the COM[31].

Study limitations

This study has some limitations that may be related to the number of raters used, which could allow that new studies find different results than ours.

In this research, the moment of projection of the COM was assessed in orthostatic position only, in a specific population. Therefore, it creates the possibility for the development of new studies that estimate the time of projection of the COM for different health conditions, age groups and genders. We stress the need to correlate this technique with data pertaining to force platforms for evaluating the projection of the COM in different situations, to ensure greater validity of the technique for obtaining the COM.

CONCLUSIONS

Based on the results of the time of projection of the COM, determined with SAPO, intra and inter-rater reliability was excellent for all variables evaluated in the study.

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