Repeatability and Reproducibility of Postural Variables by Photogrammetry

Cláudia Tarragô Candotti, PhD, Grazielle Martins Gelain, BSc(Chiro), Arthur Antoniolli, MS, Liliane Martini Araújo, MS, Adriane Vieira, PhD, and Jefferson Fagundes Loss, PhD

Abstract

Objective: This study aimed to examine the reliability of postural variables analyzed by photogrammetry obtained at different instances on the same day and between 2 different days.

Methods: A sample composed of 24 healthy adult individuals of both sexes was submitted to photogrammetric postural assessment. From 35 seconds of filming, 7 photographs (of time instance at 0 second, 05 seconds, 10 seconds, 15 seconds, 20 seconds, 25 seconds, and 30 seconds) were extracted and digitalized on digital image-based postural assessment software. One factor repeated-measures analysis of variance quantified the alterations in the magnitude of the variables within and between sessions (factor time and factor day, respectively). The intraclass correlation coefficient (ICC), standard error of measurement (SEM), and minimal detectable change (MDC) were calculated to verify the repeatability and reproducibility.

Results: The repeatability shows that postural variables did not present significant differences in the comparison among the 7 instances; all the variables had excellent and significant ICCs, and SEM and MDC values indicated measurement errors lower than 5%. The intrarater reproducibility shows that postural variables did not present significant differences between 2 days of evaluation; most of the variables had excellent and significant ICCs, and SEM and MDC values were between 0.9% and 12.5%.

Conclusion: The results for repeatability and reproducibility show that most of the variables have excellent and significant ICCs. Postural evaluation by photogrammetry can be performed at any time within a 30-second interval counting from the positioning of the participant for assessment. Therefore, we conclude that a single photograph can represent the static posture of an individual in the postural evaluation, which is reliable enough and useful to determine the effects of an intervention either in clinical practice or in research. (J Manipulative Physiol Ther 2019;42:372-378)

Key Indexing Terms: *Posture; Standing Position; Photogrammetry; Reproducibility of Results*

Introduction

Photogrammetry is defined by the American Society for Photogrammetry and Remote Sensing as the art, science, and technology of obtaining reliable information about physical objects and the environment through processes of recording, measuring, and interpreting images.[1] The use of photogrammetry as a tool for postural assessment has been defended by many researchers[2-10] because it is a relatively simple and objective method that presents accurate and precise results.[5,9-12]

Postural variability assessed by photogrammetry has been investigated. McEvoy and Grimmer[6] evaluated school-age children at 2 distinct times within 1 hour, and Stolinski et al,[9] also evaluating children, repeated the assessment 1 hour and 1 week after the first evaluation. Refshauge et al[13] evaluated 3 measurements on the cervical spine and repeated the assessment with a 1-minute interval on the same day and on distinct days. In all cases, a single photograph was used in each evaluation.

It is established that the upright standing posture is not completely static, and changes occur in short intervals of time[14,15] when evaluated using the center of pressure.[14,16,17] However, to the best of our knowledge, no studies have attempted to evaluate changes in the result of postural assessment from consecutive photographs.

Considering that photogrammetry conventionally uses only a single photo (representative of a single instance), it is questionable whether the postural variables extracted from that moment are affected by time. Therefore, the objectives of this study were as follows: (1) to compare the outcomes of a postural assessment (by means of photogrammetry) obtained at different instances on the same day and on different days, and

Physical Education, Physiotherapy and Dance School of Universidade Federal do Rio Grande do Sul, Porto Alegre, Rio Grande do Sul, Brazil.

Corresponding author: Grazielle Martins Gelain, BSc(Chiro), ESEFID/LAPEX/BIOMEC, Rua Felizardo, 750, Porto Alegre, RS, CEP 90450-190, Brazil. Tel.: +55 51 98151 7527. (e-mail: graziellegelain@gmail.com).

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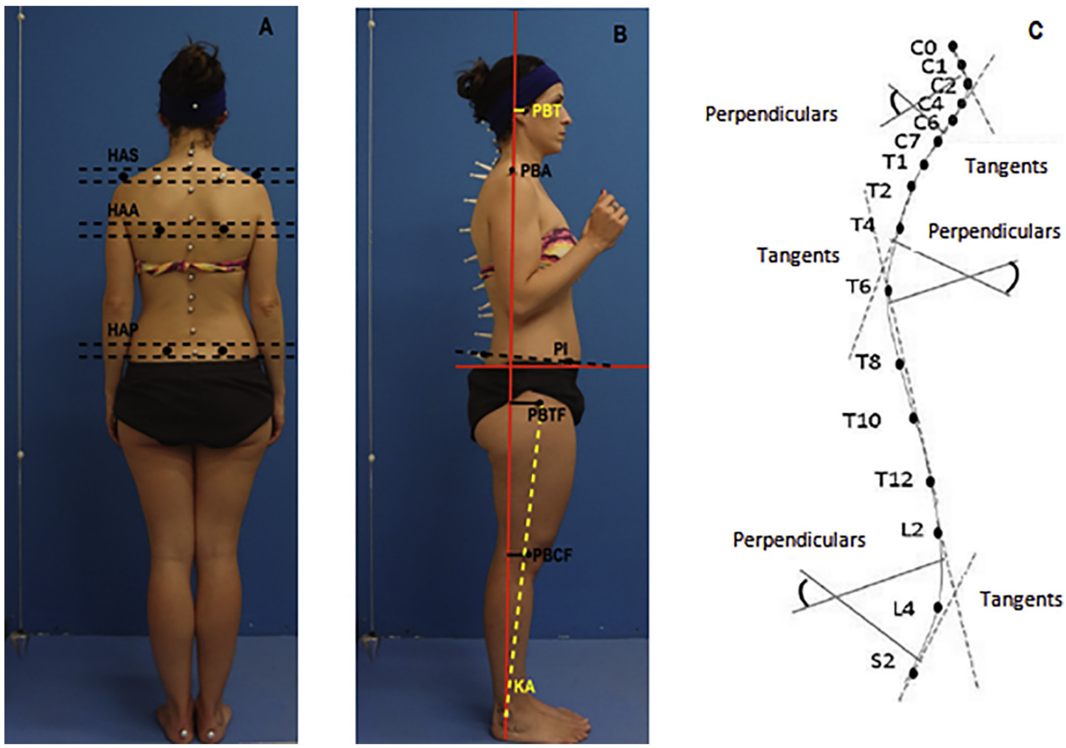

Fig 1. *Postural variables in the frontal plane (A) and in the sagittal plane (B); and spine curvatures analyzed in the sagittal plane (C).* HAA, *horizontal alignment of the scapulae;* HAP, *horizontal alignment of the pelvis;* HAS, *horizontal alignment of the shoulders;* KA, *knee angle;* PBA, *plumb line to acromion;* PBCF, *plumb line to condyle of the femur;* PBT, *plumb line to tragus;* PBTF, *plumb line to trochanter of femur;* PI, *pelvic inclination.*

(2) to evaluate the intrarater reproducibility and repeatability of the outcomes of the postural assessment. Assuming that a short period randomly affects postural variables, our null hypothesis stated that the measurements of the postural variables are not different when comparing the postural evaluations on different days and at different instances.

Methods

Sample

The intentional sample was composed of 24 nonobese healthy adults of both sexes (16 women, 8 men; age = 26.5 ± 4.4 years, mean mass = 65.0 ± 10.8 kg, mean height = 169.0 ± 8.9 cm) recruited via open invitation on social network platforms (eg, Facebook, Instagram).

To detect a moderate to large effect size (Cohen's d = 0.6) with an α level of 0.05 and 80% of power to be retained for a 1-way repeated-measures analysis of variance (ANOVA) set a priori, the sample size estimation revealed that 24 participants would be sufficient. Sample size was estimated using G*Power 3.1.7 (Universität Kiel, Kiel, Germany).

Inclusion and Exclusion Criteria

The inclusion criteria were young healthy adults (self-reported) between 20 and 50 years of age, with a cognitive level sufficient to understand the evaluation protocol. The exclusion criteria were pain of any sort at the moment of the evaluation, utilization of prosthesis, and a body mass index of over 30 kg/m^2.

Procedures for Data Collection

The postural evaluation was performed in the right sagittal and posterior frontal planes. In both planes, the individual maintained the feet and the lower limbs together and parallel, respecting the genus varus or valgus of the knees, as determined by the Digital Image-based Postural Assessment (DIPA) protocol.[11,12] This process was recorded with a Sony HD camera, model HDR-CX190 (Tokyo, Japan), attached on a tripod positioned at a distance of 2.80 m from the participant and the plumb line at a height of 0.95 m, with a sampling rate of 60 Hz.

The full DIPA protocol was conducted on 1 day (day 1) and repeated on a second day (day 2), by the same rater (a physiotherapist with 8 years' experience in postural assessment), in the same place, and at the same time of the day. The interval between assessments was around 5 and 7 days.

Data Processing

The continuous recording of 35 seconds, totaling 1800 frames (60 Hz × 30 s) had the initial 3 seconds and the last 2

Table 1. *Mean, Minimal, and Maximal Values, F Statistics,* P *Values, and Estimated Effect Size (η^2_p) When Comparing the 7 Instances (T0, T5, T10, T15, T20, T25, and T30 on Day 2) (n = 24)*

Postural Variables	Mean Values	Min-Max Values	F	*P*	η^2_p
DK (°)	44.7	27.0-70.0	1.289	.266	0.053
PI (°)	9.2	3.6-19.5	0.743	.536	0.031
CL (°)	61.0	37.0-87.0	1.192	.314	0.049
LL (°)	46.0	10.0-81.0	0.622	.713	0.026
KA (°)	177.7	167.0-192.0	1.641	.140	0.067
HAP (cm)	0.4	0.0-1.3	2.008	.069	0.080
HAA (cm)	0.9	0.0-1.8	0.556	.765	0.024
HAS (cm)	1.2	0.0-2.3	1.391	.271	0.317
PBA (cm)	3.7	0.1-12.1	1.381	.227	0.057
PBT (cm)	7.1	0.5-18.4	1.476	.191	0.060
PBTF (cm)	6.5	1.3-14.4	0.929	.476	0.039
PBCF (cm)	4.2	0.1-11.4	2.304	.098	0.091

CL, cervical lordosis; *DK*, dorsal kyphosis; *HAA*, horizontal alignment of the scapulae; *HAP*, horizontal alignment of the pelvis; *HAS*, horizontal alignment of the shoulders; *KA*, knee angle; *LL*, lumbar lordosis; *PBA*, plumb line to acromion; *PBCF*, plumb line to condyle of the femur; *PBT*, plumb line to tragus; *PBTF*, plumb line to trochanter of femur; *PI*, pelvic inclination.

seconds excluded. So, the postural analysis was performed based on digital frames extracted from the continuous recording from day 2 at 7 specific points: 0 second (T0), 5 seconds (T5), 10 seconds (T10), 15 seconds (T15), 20 seconds (T20), 25 seconds (T25), and 30 seconds (T30).

The frames extracted from the video recording were digitalized in the DIPA software following the protocol recommendations.[12] Regarding the frontal plane, the following postural variables were used: difference between the horizontal alignment of the shoulders, defined by the difference between the height of the acromia; difference between the horizontal alignment of the inferior angle of the scapulae (HAA), defined by the difference between the height of the inferior angle of the scapulae; and difference between the horizontal alignment of the pelvis (HAP), defined by the difference between the height of the posterior superior iliac spines (Fig 1).

In the sagittal plane, the following postural variables were analyzed: angle of the cervical lordosis (CL), defined by the angle between the tangent lines of C1 and C7 (the location of C1 was considered the point equidistant between the occipital protuberance and the spinous process of C2); angle of the dorsal kyphosis, defined by the angle between the lines tangents of T2 and T12; angle of the lumbar lordosis, defined by the angle between the lines tangents of L2 and S2; angle of pelvic inclination, defined by the angle between a line that connects the posterior superior iliac spine and the anterior superior iliac spine and a horizontal line; knee angle, defined by the angle between the greater trochanter of the right femur, the tuberosity of the lateral condyle of the right femur, and the right lateral malleolus; and horizontal distances between the plumb line and the right tragus, the right acromion, the greater trochanter of the right femur, and the lateral condyle of the right femur (Fig 1).

Statistical Analysis

The statistical analysis was conducted with the aid of Statistical Package for the Social Sciences software, version 20.0 (IBM Corp, Armonk, New York). The normality of the data was confirmed using the Shapiro-Wilk test. The significance level adopted was .05 in all tests.

The repeatability is a condition of measurement in which the same measurement procedure is performed consecutively, considering the same raters, same measuring system, and replicate measurements over a short period (within-day reliability).[18] Hence, based on the random nature of the sample recruited, the precision in consecutive measurements, from each postural variable, was analyzed using the following: (1) 1-way repeated-measures ANOVAs with 7 levels (T0, T5, T10, T15, T20, T25, and T30) performed with Bonferroni post hoc using the values obtained on day 2, and (2) intraclass correlation coefficient $(ICC)_{1,7}$ (1-way random, 7 situations) in each of the 7 instances obtained on day 2.

The intrarater reproducibility reflects the precision of data measured by 1 rater across 2 or more trials, with the same measuring system and replicate measurements over at

Table 2. *Repeatability of the Postural Variables When Comparing the 7 Time Instances (T0, T5, T10, T15, T20, T25, and T30 on Day 2)*

Postural Variables	ICC	95% CI	*P*	SEM	MDC
DK (°)	0.998	0.997-0.999	<.001	0.05	0.09
PI (°)	0.998	0.997-0.999	<.001	0.02	0.04
CL (°)	0.967	0.942-0.984	<.001	0.65	1.28
LL (°)	0.994	0.989-0.997	<.001	0.26	0.52
KA (°)	0.997	0.995-0.998	<.001	0.05	0.09
HAP (cm)	0.918	0.856-0.960	<.001	0.04	0.08
HAA (cm)	0.955	0.921-0.978	<.001	0.04	0.08
HAS (cm)	0.972	0.951-0.986	<.001	0.04	0.08
PBA (cm)	0.989	0.981-0.995	<.001	0.08	0.15
PBT (cm)	0.992	0.986-0.996	<.001	0.08	0.16
PBTF (cm)	0.995	0.992-0.998	<.001	0.04	0.07
PBCF (cm)	0.994	0.990-0.997	<.001	0.03	0.06

CI, confidence interval; *CL*, cervical lordosis; *DK*, dorsal kyphosis; *HAA*, horizontal alignment of the scapulae; *HAP*, horizontal alignment of the pelvis; *HAS*, horizontal alignment of the shoulders; *ICC*, intraclass correlation coefficient; *KA*, knee angle; *LL*, lumbar lordosis; *MDC*, minimal detectable change; *PBA*, plumb line to acromion; *PBCF*, plumb line to condyle of the femur; *PBT*, plumb line to tragus; *PBTF*, plumb line to trochanter of femur; *PI*, pelvic inclination; *SEM*, standard error of measurement.

least a 24-hour period (between-day reliability).[18] The intrarater precision, from each postural variable, was analyzed using the following: (1) 1-way repeated-measures ANOVAs with 2 levels (day 1 and day 2) using the values obtained in T5, and (2) $ICC_{1,2}$ (1-way random, 2 situations) at T5 instance obtained on day 1 and on day 2.

In addition to the ICC, the standard error of measurement (SEM) and minimal detectable change (MDC) were used to evaluate the reliability of the measurements. The SEM reflects the extent to which the measurement may have varied owing to error in the measurement process, thus it quantifies the precision of individual scores if the same units of measurement are applied as in the variable of interest.[19] The SEM was estimated using the formula: $SEM = SD \sqrt{(1 - ICC)}$, where SD is the standard deviation of the measurements. The MDC is the amount of change necessary to determine whether a real change or merely a measurement error existed.[20] The MDC was estimated based on a 95% CI, where $MDC = 1.96 \times SEM$. The ICC score was classified in accordance with the literature[21] as weak (ICC <0.40), moderate (ICC 0.40- 0.75), and excellent (ICC > 0.75).

Ethical Aspects

This study was approved by the research ethics committee of the Universidade Federal do Rio Grande do Sul (approval number 45753615-6-0000-5347), and all participants gave informed consent before the assessments.

Results

Repeatability

Postural variables did not present significant differences when comparing the 7 instances on the same day (Table 1). In addition, all variables have excellent and significant ICCs. The SEM and MDC values were small, indicating measurement error lower than 5%, except for the difference between the HAP (Table 2).

Reproducibility

Postural variables did not present significant differences when comparing the 2 evaluation days (Table 3). In addition, most variables have excellent and significant ICCs (Table 4). Four variables presented moderate and significant correlation (angle of the pelvic inclination, angle of the CL, difference between the HAP, and difference between the HAA) in the intrarater reproducibility. The SEM and MDC values were small, indicating measurement error between 0.9% and 12.5%, except for the difference in horizontal alignment of the pelvis and the scapulae (Table 4).

Discussion

Our results show that the data extracted from photogrammetry, in a single instance, are representative of the erect posture of an individual. Despite a small variability in the

Table 3. *Mean and Mean Difference (Between Days), CI 95% of Mean Difference, F Statistics,* P*, and Estimated Effect Size (η^2_p) When Comparing the 2 Evaluation Days (at the 5-Second Time Instance—T5) (n = 24)*

Postural Variables	Mean	Mean Difference (Day 1 – Day 2)	95% CI (Mean Difference)	F	*P*	η^2_p
DK (°)	44.3	-1.3	(-8.4 to 5.7)	3.300	.082	0.125
PI (°)	8.9	-0.4	(-6.8 to 6.0)	0.371	.549	0.016
CL (°)	61.4	1.8	(-19.7 to 23.3)	0.642	.431	0.027
LL (°)	45.2	-2.0	(-26.4 to 22.4)	0.618	.440	0.026
KA (°)	178.8	1.8	(-8.3 to 12.0)	3.025	.095	0.116
HAP (cm)	0.5	0.1	(-0.6 to 0.7)	0.932	.345	0.039
HAA (cm)	1.0	0.0	(-1.0 to 1.1)	0.212	.649	0.009
HAS (cm)	1.0	-0.2	(-1.2 to 0.8)	3.413	.078	0.129
PBA (cm)	4.2	0.3	(-3.6 to 4.3)	0.676	.419	0.029
PBT (cm)	7.3	0.2	(-5.2 to 5.7)	0.141	.711	0.006
PBTF (cm)	6.7	0.5	(-4.4 to 5.4)	0.948	.340	0.040
PBCF (cm)	3.8	-0.4	(-3.7 to 2.9)	1.223	.280	0.050

CI, confidence interval; *CL*, cervical lordosis; *DK*, dorsal kyphosis; *HAA*, horizontal alignment of the scapulae; *HAP*, horizontal alignment of the pelvis; *HAS*, horizontal alignment of the shoulders; *KA*, knee angle; *LL*, lumbar lordosis; *PBA*, plumb line to acromion; *PBCF*, plumb line to condyle of the femur; *PBT*, plumb line to tragus; *PBTF*, plumb line to trochanter of femur; *PI*, pelvic inclination.

postural variables investigated, over 30 seconds on the same day, there was no significant change in the outcomes obtained (Table 1). The effect size obtained using the partial η^2 values[22] also shows no influence of time in the postural variables.

All ICCs presented excellent scores and above .91 (Table 2), higher than the within-day values obtained by Refshauge et al[13] for CL. Refshauge et al[13] analyzed 3 photographs with a 1-minute interval, whereas we analyzed 7 photographs with a 5-second interval. Despite the methodological differences between the study from Refshauge et al[13] and ours, the results show that postural variables assessed through photogrammetry can be used in clinical practice and in research. It means that the changes observed over time can be attributed to an intervention rather than to the normal variation of the variables. However, Refshauge et al[13] does not show how much variation is necessary so that a change will not be considered by chance. In this way, our study improves knowledge because we have shown the SEM and MDC values.

The comparison between distinct days also shows no significant change in the outcomes obtained (Table 3). Considering the ANOVA and the effect size results, there does not appear to be strong evidence for the existence of systematic changes in posture.

All ICCs values were moderate or excellent (Table 4). The variables HAP and HAA presented lower ICCs than those reported by Saad et al[4] and Fortin et al.[7] We believe that the low ICC values obtained in our study may be related to the small distances measured, associated with the resolution used in the photograph. Thus, we speculate that small changes in the position of the mouse cursor during the digitalization of the points might be responsible for the higher SEM and MDC values found for these variables, as well as the lower ICCs. Of particular interest is the angle of CL, which obtained the highest SEM and MDC values in our data (Table 4). Given that the posterior tubercle of C1 in general cannot be palpated, we estimated its location. This may have influenced the reproducibility of the CL angle.

For instance, the knee angle presented very low measurement errors, with SEM and MDC values around 1.4° and 2.8°, representing less than 2% of the average magnitude of the measured angle (Table 4). Therefore, in clinical evaluations conducted with DIPA software, alterations greater than 2.8° in the sagittal evaluation of the knee can be considered real postural alterations and not simply measurement errors. On the other hand, 7.6° of difference between 2 different assessments are required for measurements of CL not to be considered to exist by chance. Thus, the information provided by the SEM and MDC values demonstrated the clinical relevance of the present study because they are essential for health care professionals to be able to evaluate the differences occurred during the posture assessments in a safe and objective way.

Table 4. *Intrarater Reproducibility of the Postural Variables Between 2 Evaluation Days (at Instance 05 Seconds—T5)*

Postural Variables	ICC	95% CI	*P*	SEM	MDC
DK (°)	0.964	0.919-0.985	<.001	0.42	0.83
PI (°)	0.665	0.235-0.854	.005	0.88	1.73
CL (°)	0.565	0.008-0.811	.024	3.91	7.66
LL (°)	0.879	0.724-0.947	<.001	2.19	4.30
KA (°)	0.773	0.482-0.901	<.001	1.43	2.81
HAP (cm)	0.568	0.014-0.812	.023	0.13	0.25
HAA (cm)	0.513	-0.101 to 0.790	.041	0.20	0.40
HAS (cm)	0.799	0.542-0.913	<.001	0.15	0.29
PBA (cm)	0.850	0.657-0.935	<.001	0.45	0.88
PBT (cm)	0.843	0.643-0.932	<.001	0.62	1.21
PBTF (cm)	0.754	0.438-0.893	.001	0.73	1.44
PBCF (cm)	0.872	0.708-0.944	<.001	0.32	0.62

CL, cervical lordosis; *DK*, dorsal kyphosis; *HAA*, horizontal alignment of the scapulae; *HAP*, horizontal alignment of the pelvis; *HAS*, horizontal alignment of the shoulders; *ICC*, intraclass correlation coefficient; *KA*, knee angle; *LL*, lumbar lordosis; *MDC*, minimal detectable change; *PBA*, plumb line to acromion; *PBCF*, plumb line to condyle of the femur; *PBT*, plumb line to tragus; *PBTF*, plumb line to trochanter of femur; *PI*, pelvic inclination; *SEM*, standard error of measurement.

Limitations

One limitation of this study was that the number of women was twice as large as the number of men, which impeded the evaluation of any differences that might exist between the sexes. Another limitation was the small standard deviation of age, not covering much of the age spectrum considered as inclusion criteria in the study. Also, we have not measured the magnitude of body sway to be compared with the results we have obtained.

Also, the posture was analyzed in only 1 support base, with the lower limbs united (respecting the genus valgus or varus of the knee). In the literature, the proportionality between the body stability and the support base of the body that corresponds to the polygon formed by the lateral borders of the feet is well reported. In that case, the more apart the feet are, more stability and less body oscillation occur.[23] Although it has not been investigated, we infer that the position adopted in this study constitutes the worst case among the bipedal support situations used in the postural evaluation, that is, in other positions any influence of sway would be even smaller.

Conclusion

The postural variables investigated did not present significant differences when comparing the 7 instances in the same day nor between 2 evaluation days. The results for repeatability and reproducibility show that most of the variables have excellent and significant ICCs. The SEM and MDC values were small. Postural evaluation by photogrammetry can be performed at any instance within a 30-second interval counting from the positioning of the participant for assessment. Therefore, we conclude that a single photograph can represent the static posture of an individual in the postural evaluation, which is reliable enough and useful to determine the effects of an intervention either in clinical practice or in research.

Funding Sources and Conflicts of Interest

No funding sources or conflicts of interest were reported for this study.

Contributorship Information

Concept development (provided idea for the research): C.T.C., A.A.
Design (planned the methods to generate the results): C.T.C., A.A.
Supervision (provided oversight, responsible for organization and implementation, writing of the manuscript): C.T.C., A.V., J.F.L.
Data collection/processing (responsible for experiments, patient management, organization, or reporting data): A.A., L.M.A.

Analysis/interpretation (responsible for statistical analysis, evaluation, and presentation of the results): C.T.C., G.M.G.
Literature search (performed the literature search): C.T.C., G.M.G.
Writing (responsible for writing a substantive part of the manuscript): C.T.C., G.M.G.
Critical review (revised manuscript for intellectual content, this does not relate to spelling and grammar checking): C.T.C., A.V., J.F.L.

Practical Applications

- This study found that body sway did not interfere with postural assessment.
- Postural variables were classified as stable during 30 seconds of assessment.
- A small magnitude of alternation values was found for most of the postural variables.

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