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The manuscript, in a draft version prior to its acceptance by the publisher (under revision), is reproduced here as it appears in the first author's Ph.D. thesis, entitled *Développement et validation d'un outil clinique pour l'analyse quantitative de la posture auprès de personnes atteintes d'une scoliose idiopathique*. The thesis citation is as follows:

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Chapitre5 Étude de fidélité

5.1 Article 2 : Reliability of a quantitative clinical posture assessment tool among persons with idiopathic scoliosis

Carole Fortin, Debbie Feldman, Farida Cheriet, Denis Gravel,
Frédérique Gauthier, Hubert Labelle
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Article en révision, juin 2010

L'auteur principal confirme sa contribution majeure à la préparation et à la rédaction de cet article scientifique (90%). L'auteur principal a également contribué de façon majeure à l'élaboration du protocole expérimental, au financement du projet, à l'acquisition, au traitement, à l'analyse et à l'interprétation des données ayant mené à la rédaction de cet article. Une brève description de la contribution des coauteurs est présentée ci-dessous.

Les docteurs Feldman, Cheriet et Labelle ont dirigé l'étudiante pour la réalisation de cette étude. Dre Feldman a contribué à l'élaboration du protocole expérimental, au financement et à la rédaction de l'article. Dre Cheriet a contribué à l'élaboration du protocole expérimental et à la rédaction de l'article. Denis Gravel a contribué à l'analyse des données et à la rédaction de l'article. Mme Gauthier a participé à l'acquisition des données. Dr Labelle a contribué à l'élaboration du protocole expérimental et à la rédaction de l'article.

Reliability of a quantitative clinical posture assessment tool among subjects with idiopathic scoliosis

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ABSTRACT

Objective: To determine overall, test-retest and inter-rater reliability of posture indices among persons with idiopathic scoliosis.

Design: A reliability study using two raters and two test sessions.

Setting: Primary care center.

Participants: Seventy participants aged from 10 to 20 years old with different types of idiopathic scoliosis (Cobb angle: 15º to 60º) were recruited from the scoliosis clinics.

Interventions: Not applicable.

Main Outcome Measures: Based on the XY coordinates of natural reference points (cf: eyes, etc.) as well as of markers placed on several anatomical landmarks, 32 angular and linear posture indices taken from digital photographs in the standing position were calculated from a specially developed software program. Generalizability theory served to estimate the reliability and standard error of measurement (SEM) for the overall, test-retest and inter-rater designs.

Results: When both factors (rater and test session) that could affect measurement reliability were considered randomly, 26 out of 32 of the posture indices had a good level of reliability ($\phi \geq 0.79$) and six had a moderate level of reliability (ϕ from 0.51 to 0.72). The most reproducible indices were Waist Angles, Knee Valgus and Varus and Trunk List. The least reliable were Tibio Calcaneus and Q Angles. The SEM values ranged from 0.86º to 4.26º and 2.08 to 8.51mm.

Conclusions: This clinical posture assessment tool is reproducible among persons with idiopathic scoliosis. It may serve to monitor treatment effectiveness or change in posture over time in these persons.

Key words: posture assessment, reliability, idiopathic scoliosis, generalizability theory

INTRODUCTION

Correction of posture is an important goal of physiotherapy interventions to prevent scoliosis progression in persons with idiopathic scoliosis (IS). Posture is defined as the alignment or orientation of body segments while maintaining an upright position [1]. Posture asymmetries are associated with the risk of progression in IS[2-4], can affect functional activities[5, 6] and limit participation in active life[7]. The Cobb Angle remains the gold standard to monitor change in scoliosis over time and is calculated from radiographs[8]. It gives information on vertebral alignment[9]. Physiotherapists and physicians commonly assess posture based on qualitative assessment[10-13]. Effectiveness of physiotherapy interventions has been criticized[14] in persons with IS and this may be due in part to the lack of adequate clinical quantitative measurement tools to monitor change on posture over time. Although there are sophisticated 3D posture analysis systems such as Optotrak, Vicon, Motion Analysis and surface topography systems these systems are not accessible for most clinicians.

A promising technique to assess posture clinically in a global fashion may be the calculation of body angles and distances on photographs[15-20]. This method is fast, easy to do and accessible for most clinicians. Although, photograph acquisition has demonstrated good intra-rater reliability for several posture indices in normal persons, these results cannot be generalized to persons having pathological conditions[21]. Also, current tools do not include posture indices representing all body segments or are not specific enough to characterize scoliosis[22-26]. Our team has developed a software based quantitative clinical posture assessment tool for the calculation of angles and distances using digital photographs. This tool has good concurrent validity with radiographs and a 3D surface topography system in persons with IS[27] but the reliability of these indices has not yet been established.

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The general objective of this research project was to assess the overall, test-retest and inter-rater reliability of selected indices of a new quantitative clinical posture assessment tool among persons with IS. The generalizability theory served as the statistical technique to determine the sources of variance (Generalizability study), the level of reliability and SEM expected for particular designs (Decision study)[28].

Methods

Selection of posture indices of the tool

We conducted a literature review to select posture indices to be included for the present global quantitative clinical assessment tool of posture. Forty-five indices taken from direct measures or from photographs were first identified[15]. From these, thirty-four indices (Appendix 1) were retained for the reliability study based on these criteria: 1) the clinical relevance and capacity to measure changes in posture in all body segments (Tyson and Desouza[26] content validity study) and 2) the utility to characterize IS such as trunk list[22-25], waist angles[29] and measurement of frontal and sagittal spinal curves[30-32].

Participants

We recruited 70 participants (60 females and 10 males) from the scoliosis clinic at the CHU Sainte-Justine in Montreal. Inclusion criteria were: ages 10 to 20 years old, idiopathic scoliosis diagnosis with a frontal deformity between 15º and 60º (Cobb angle) and pain-free at the time of evaluation. Mean age of participants was 15.7 ± 2.5 years and average weight and height were 51.9 ± 9.3 Kg and 1.61 ± 9.5 cm, respectively. Twenty-six participants had a right thoracic scoliosis (mean of 37.9º ± 11.4º), 22 a double major scoliosis (means for each curve of 34.8º ± 13.0º; 33.2º ±11.2º), 16 a thoraco-lumbar scoliosis (mean of 25.8º ± 7.2º) and six a lumbar scoliosis (mean of 26.7º ±13.3º). We excluded participants who had a leg length discrepancy greater than 1.5 centimetres as well as those who had had spine surgery. All participants and their parents signed informed consent forms and the project was approved by the ethics committee of CHU Sainte-Justine.

Procedure and instrumentation

Two trained physiotherapists evaluated participants at the LAVIANI laboratory at CHU Sainte Justine and a quantitative posture evaluation software was used to calculate posture indices. The software has a user-friendly graphical interface and it

allows calculation of posture indices from a set of markers selected interactively on the digital photographs (Figure 1). The training consisted of two practical sessions (one hour duration) of palpation and marker placement on healthy persons (one female and one male) to assert that both physiotherapists were in agreement for the understanding of the method and procedure. Each physiotherapist completed palpation and marker placement for the anatomical landmarks on two test sessions (Appendix 1). Forty-nine [49] round adhesive 5 mm green markers were placed on the following anatomical landmarks (chosen according to their reliability already showed in previous studies[19, 33]): spinous process (C2, C4 and C7 to S1), right and left tragus, coracoid process, acromion, inferior angle of scapulae, ASIS, PSIS, greater trochanter, knee inter-articular joint line, midpole of patella, tibial tuberosity, internal femoral condyles, dome of talus, lateral and medial malleolus (Figure 1). Palpation and marker placement lasted on average 15 minutes. To facilitate measurement of sagittal posture indices, 13 hemispheric 10 mm reflective markers were added on C7, cervical apex, upper end, apex and lower end vertebrae of thoracic and lumbar spine, right and left acromion, ASIS, and PSIS. Anatomical reference points such as eyes, tip of the ears, upper end, lower end and center of waist and mid-calf also served for angle calculation.

Digital photographs were taken with two Panasonic Lumix cameras (DMC-FX01, 6.3 mega pixels) fixed on bars within the laboratory and adjusted vertically to capture the full height of participants. The cameras were placed at a distance of 1.59 m for anterior and right lateral views and 1.73 m for posterior and left lateral views at a height of 87.5 cm. Vertical and horizontal level adjustments of the cameras were made for each set of photographs in each test session using a carpenter's level. Placement and instructions given to all subjects concerning the positioning for data collection were standardized. To limit the variability associated with subject's position, two reference frames for feet placement (triangles of 30º) were drawn on the floor for frontal and sagittal views[34, 35]. Subjects were asked to look straight ahead and stand in a normally comfortable position[16-18, 20, 35]. Supplementary sagittal photographs were taken with participants standing with flexed elbows if greater trochanter and ASIS were not otherwise visible[17].

Data acquisition followed a specific sequence and lasted on average 20 to 25

minutes (including marker placement). First, digital photographs of front and back views were taken by the first rater (Trial 1). Subsequently, the subject was asked to walk around and re-positioned to take a second set of photographs in these views (Trial 2). Hemispheric markers were added onto anatomical landmarks (previously mentioned) and the subject was placed in the lateral position for acquisition of right and left lateral photographs (Trial 1). The person was asked again to move and re-positioned for the second set of photographs in these lateral views (Trial 2). Markers were removed and landmarks on skin were thoroughly cleaned before the second rater repeated the procedure. After the first session, participants were asked to come back 60 minutes later to repeat the assessment by the two raters (test-retest reliability). The physiotherapists completed the test sessions in random order. To avoid any bias in the selection of a trial and to obtain a better estimate of the raters' true score, the mean of two trials per each rater was used to determine the level of reliability[36].

Quantitative posture indices from digital photographs were calculated with the custom software program which can be installed with its components on any computer. This software uses interactive click-on markers with the computer mouse. The operator selects a specific marker from the graphic interface and places it directly on the corresponding marked anatomical landmark or anatomical reference point of a participant's photograph. The software automatically calculates and displays the angles or distances when markers corresponding to the calculation of this index are selected (Figure 1). For angle calculation, horizontal and vertical borders of the photograph served as references and for distance calculation, a cube of 15 cm (constant distance from the position of reference) was used as a calibration tool. Calculation of the 32 posture indices with the software program took about 20 minutes. Two indices (Thoracic kyphosis and Lumbar lordosis) were dropped due to not having enough data to calculate reliability. Appendix 1 describes the methods for angle and distance calculation. All posture photos were digitized by the same trained operator. Thus, the reliabilities evaluated in the present study are related to the consistency of marker placements and posture from one rater or test session to the other.

Data analysis

Descriptive statistics (mean, standard deviation – SD) are used to characterize participants with scoliosis and the posture indices from the clinical posture assessment tool.

Reliability of the posture indices was calculated according to the generalizability theory, an extension of the intra-class correlation coefficient [28]. There are two components of this type of analysis, the first being the generalizability study (G-study), the second, the decision study (D-study). In the present research, a two-factor crossed design was retained (factors were the test session and the rater). Accordingly, the G-study computes the magnitude of the variances attributed to the persons (P)**,** to the systematic errors related to test sessions (S) and raters (R), and to random errors associated with the interactions between raters and test sessions (RS), persons and test sessions (PS) and persons and raters (PR)**.** The residual error is the interaction between all sources of variance and included error coming from unknown factors (PRS). In order to facilitate the interpretation of the G-study results, the magnitude of each variance was expressed as a percentage of the total variance. The D-study (decision) uses the information of the G-study to determine the reliability of a particular protocol. To take into account the systematic effect of rater and test session, the coefficients of dependability (ϕ) were chosen. The reliability was calculated for D-studies involving one rater on one test session for three designs: 1) with both factors random, 2) with the factor rater fixed giving the test-retest reliability and 3) with the factor test session fixed giving the inter-rater reliability (formulas for each design are presented in Appendix 2). Like the intra-class coefficient (ICC), the dependability coefficient ranges between 0 and 1: 0 is absence of reliability and 1, perfect reliability. Interpretation of the coefficients is as follows: values above 0.75 will be considered as good reliability, those between 0.50 and 0.75 as moderate and those under 0.5 as poor [37]. To assess the errors in terms of the unit of measurement, the standard error of measurement (SEM), which is the square root of the sum of all error variances components, was also computed [28]. We used the GENOVA software program for these analyses[38].

RESULTS

Table 1 describes the means and standard deviations (SD) for each rater on both test sessions and the grand mean and SD for the two raters on both test sessions for all posture indices. Thoracic Kyphosis and Lumbar Lordosis indices could not be measured from the lateral views for most of the participants and thus were not included in the reliability study.

Reliability study

G-Study : Sources of variance

For all posture indices, the inter-person variance (P) was the major source of variance (51 to 99%). The variance component associated with rater (R) was low (0 to 5%), except for the Q and Tibio Calcaneu**s** Angles (7 to 19%). Variance components for test session (S) and interaction between raters and test sessions (RS) were less than 1.2%. The variance of the interaction between persons and test sessions (PS) was 0 to 8% while interactions between persons and raters (PR) determined variance magnitude between 0 to 12%. The interaction between persons, raters and test sessions (PRS) varied from 1 to 28% with higher values for the Frontal Thoracic Angle (23%), the Frontal Pelvic tilt (16%-17%), the Q Angle (17%-18%) and the Tibio Calcaneu**s** Angle (21%-28%).

D-Study

The dependability coefficients (ϕ) and SEMs for posture indices are presented in table 2. In the random design, 26 out of 32 posture indices have a good level of reliability ($\phi \geq 0.79$) and six out of 32 have a moderate level of reliability (ϕ from 0.51 to 0.72). The most reproducible indices in this design were Waist Angles (L and R; ϕ = 0.98), Trunk List (ϕ = 0.95) and Knee Valgus and Varus (ϕ = 0.99 and 0.95, respectively). The least reliable were Tibio Calcaneus Angles (L and R; ϕ = 0.51 and

0.53), Q Angles (L and R; $\phi = 0.64$ and 0.63, respectively) and the Frontal Lumbar Angle ($\phi = 0.67$) (see Table 2).

In the test-retest design, all posture indices, except for the Right Tibio Calcaneus Angle ($\phi = 0.73$), have good reliability ($\phi \geq 0.77$). In the inter-rater design, 29 posture indices out of 32 have good reliability ($\phi \geq 0.78$) and three posture indices have moderate level of reliability (ϕ from 0.67 to 0.72).

In the random design, the SEM values ranged from 0.86º to 4.26º for angular measurements and from 2.08 to 8.51mm for the linear one. As expected, the ranges were smaller for the test-retest and inter-rater designs with values from 0.45º to 2.95º and 1.20 to 5.77mm (Table 2). The higher angular SEMs were associated with Cervical Lordosis, Scoliosis 1 and Scoliosis 2 index. For linear index, the Shoulder Protraction has the highest SEM value.

DISCUSSION

The general objective of this study was to assess the reliability of a quantitative clinical posture assessment tool among persons with idiopathic scoliosis. Using the G-study results of generalizability theory, the overall, test-retest and inter-rater reliabilities were computed for D studies involving one rater on one test session because it is more adapted to the real clinical context.

Reliability was good or moderate for all posture indices irrespective of D-study designs. Nevertheless, the dependability coefficients for the random design were lower and SEMs were higher than those of test-retest and inter-rater designs. Using the formula provided in the appendix 2, one can observe that the random design takes into account all possible sources of error in the denominator whereas, in other designs, the variance attributable to the fixed factor (R or S) is eliminated in the denominator. Moreover, the interaction between the fixed factor and the inter-person variance (PR or PS) is included in the numerator. These two mathematical manipulations contribute to

the increase of the dependability coefficient for the test-retest and inter-rater designs[28, 36, 39, 40].

Generally, it is reported that inter-rater reliability is lower than the test-retest reliability for posture indices[18, 41, 42]. In our study, dependability coefficients and SEMs were similar for both test-retest and inter-rater reliability for several posture indices, possibly attributable to the consistency of marker placement between raters and between test sessions as well as to the stability of posture across trials[21, 40, 43]. Results from the G-Study corroborate this finding by the absence of any systematic effect due to test sessions (S) and raters (R - see Figure 2A) for most of the indices and low level of interaction associated with the two factors (PR, PS and SR < 4%)[40, 43]. Figure 2A is an example of well distributed values of an index (Trunk list) around the identity line (line with a 45° slope) where each point represents the average of the two test sessions for each rater. The closer the points are to the identity line, the greater is the agreement between raters. For this index, the absence of error attributable to raters and test sessions (variance R and S = 0%) means that reported SEM values come from participants and may be caused by oscillations which are higher in persons with IS[44, 45].

Lower coefficients found for Q Angles and Tibio calcaneus Angles were caused in part by a systematic effect at the rater level. As illustrated in figure 2B for the right Q angle, values computed for rater 2 are higher than those of rater 1.The same effect was observed for the left Q angle. Thus, it is suspected that rater 2 placed the tibial tuberosity marker more laterally than rater 1. For the Tibio Calcaneus Angles, the systematic effect for rater was not consistent between sides. Nevertheless, we had good test-retest reliability for both measures, in line with results in the literature[19, 41]. We suggest the use of the Frontal Knee Angle instead of the Q Angle, because the former demonstrated good reliability in the random design and is also used to assess frontal lower limb alignment. The planned development of a graphic interface with automatic marker placement might help to decrease these errors.

Some studies have reported the reliability of posture indices taken from photographs[17-19, 35, 46-48]. The ICCs for intra-rater reliability (intra-day and test-retest) varied from 0.71 to 0.99 when measurements were done between body segments[17, 35, 48] and varied from 0.13 to 0.69 if measurements were obtained from a vertical reference line[47]. Our test-retest reliability results are in agreement with studies using measurements among body segments for posture indices representing head and shoulder, trunk, pelvis and lower limb body segments. For most of our participants, it was not possible to measure thoracic and lumbar sagittal angles from hemispheric markers because of their morphological modifications associated with scoliosis. In contrast with Dunk et al[46, 47], in our study, test-retest reliability for Cervical Lordosis and frontal spinal angles was good to near perfect. In the Dunk et al.[47] study, angle measurements were calculated as deviation from the vertical reference line whereas relative measurements between body segments were used in ours. The lower repeatability of their measurement technique may be due to body sway in the sagittal and lateral planes. Possibly, a change in ankle joint angle due to body sway may modify spine position[44, 49]. With respect to inter-rater reliability, our SEM results are comparable to those described by Normand et al.[18] on healthy persons. They reported SEM values ranging from 0.50 to 1.5º and from 1.7 to 2.7mm for head, thorax and pelvis indices. However, when the rater and test session factors were both random, our coefficients were higher (ϕ : 0.72 to 0.95) than those of Normand et al.[18] ($ICC_{2,1}$: 0.56 to 0.72). Because the SEM values are in same order for the two studies, the higher coefficients in our research may be related to the greater inter-person variability which is expected with the different types and levels of severity of scoliosis included in this project.

This study is the first to report reliability for posture indices characterizing scoliosis from digital photographs (Waist Angles, Trunk list, Scoliosis 1 and 2, Frontal Thoracic and Lumbar Angles). The Frontal Lumbar Angle was less reproducible than the others. This index is calculated from two lumbar markers on the lower part of the curve. This part of the spine may be more affected by body sway and pelvic frontal asymmetry than the upper part[50, 51]. The SEM values obtained in our study for scoliosis angles and trunk list are similar to those found respectively by Cheung et

al.[52] from radiographs and McLean et al.[23] from a plumb line. In a previous study, we found a good relationship between Waist angles, Trunk list and Scoliosis 1 indices of this tool and measurements obtained from a 3D surface topography system and X-rays[27]. The good reliability and validity of these clinical indices taken from photographs may sustain their use for scoliosis screening, for the reduction of radiographs for the monitoring of scoliosis progression and for documenting cosmetic changes after conservative or surgical treatment. However, future studies will tell if the SEM values reported in this project are sensitive enough to detect scoliosis progression or treatment effectiveness.

As mentioned above, generalizability theory serves to identify sources of error in measurements. The residual or unknown error may include such factors as the temperature in the room and error due to the digitization process of photographs. Some of the evaluations took place during winter and on some particularly cold days, the temperature in the room was cool which may have caused more variability in participant's posture due to shivering. The error attributed to digitization process is presently unknown and should be investigated in the future. In the present study, to reduce possible errors, the same trained operator performed all measurements.

Clinical Applications

The quantitative clinical posture assessment tool proposed in this study has been developed to assess global posture among persons with IS who often present posture asymmetries in several body segments. We have selected from the medical literature 34 posture indices (and 32 were verified as reliable) as they represent the different body segments and characterise scoliosis. We acknowledge that this is a large number of indices to be measured in a clinical setting. The clinician can select various indices to assess global posture rather than do them all because some indices give duplicate information. For example, Frontal eyes obliquity and Head Lateral Bending or Frontal Knee Angle and Q Angle or back and front Pelvic lateral tilt were used in different studies to measure the same body segment alignment [18, 19, 44, 48, 53]. Based on our reliability study, the clinician can select either Frontal eyes obliquity or Head Lateral

Bending to assess the frontal head alignment. For the assessment of sagittal head alignment, right or left Gaze Angle or right or left Head Protraction can be selected to assess respectively Head tilt or Head protraction. It is preferable to use Frontal Knee Angle and back Pelvic lateral tilt to assess respectively frontal leg alignment and frontal pelvic obliquity especially if different evaluators perform the assessments. From this tool, 24 posture indices can be selected for a complete evaluation of posture (see Table 2, indices in bold). Also, based on clinical judgement, the clinician can select, from these indices, the most appropriate ones for a particular person or goal. For example, if indices are used for the follow-up of a person with IS, indices such as Trunk list, Waist angles and Scoliosis angles might be sufficient to determine change in the person's condition whereas a more complete posture assessment may include indices representing all affected body segments to indicate changes attributable to treatment effectiveness.

SEM values are more useful than reliability coefficients for the clinician in terms of decision making since they describe the error in the same unit of measurement and serve to calculate the smallest detectable difference between two measurements [21]. For example, in the random design, SEM values were 4.3º for the Scoliosis 2 angle and 1.0º for Frontal eyes obliquity. According to Roebroeck et al. [21], the 95% confident interval smallest detectable difference ($\pm 1.96 \times SEM \times \sqrt{2}$) expected between two sessions would be ±11.9º and ±2.8º respectively. These values indicate that change in measurement have to be greater than these threshold values to document real change in these PI if different raters perform the evaluation.

The tool that we have developed should be easy to use in a clinical setting as the material (digital cameras and software) is accessible, the training time for physiotherapists is minimal (two hours were allocated in our study for marker placement), the graphical interface of the software is user-friendly and the time required to complete an evaluation is about 30 minutes for a complete evaluation. The low variance attributable to test sessions and raters found for the majority of indices in our study (< 5%) suggests that a training of only a few hours (like in this study) may be enough to ensure agreement between physiotherapists for marker placement. In our study, the mean of two trials was used to assess the level of reliability but in practice, one trial could be used (which would save time) since trials had no effect on the test-

retest and inter-rater reliability [54-58]. Photograph acquisition is fast and calculation of posture indices can be delayed until later, which is useful for assessing persons with pain or balance disorders, who would not be able to tolerate long evaluations in standing. Future studies will be needed to verify the use of this tool in these populations.

Conclusion

Our results show that it is possible to assess posture in a global fashion from photographs in persons with IS. The generalizability theory demonstrates that our results can be generalized to the "universe" of raters and test sessions**.** This posture evaluation tool is reproducible and should be easy to administer in a clinical setting. This new tool will improve physiotherapy practice by facilitating the analysis of posture abnormalities. It may serve to monitor treatment effectiveness or change in posture over time and to characterize posture asymmetries associated with different types of scoliosis (classification). This will need to be verified in future longitudinal studies.

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Figure legends

Figure 1

Graphical interface with a reduced set of markers of the quantitative clinical posture assessment tool at the left and, back, anterior and lateral views of a participant demonstrating marker and anatomical reference point localization and posture indices calculation for 23 out of 32 posture indices at the right**:** 1) Frontal Eyes Obliquity; 2) Head Lateral Bending; 4) Gaze Angle L; 6) Head Protraction L; 7) Cervical lordosis; 8) Shoulder Elevation; 10) Shoulder Protraction L; 11) Scapula Asymmetry; 12) Waist Angle R; 13) Waist Angle L; 14) Trunk List; 15) Scoliosis 1; 16) Frontal Thoracic Angle; 20) Lumbar Lordosis; 21) Frontal Pelvic tilt (front); 22) Frontal Pelvic tilt (back); 24) Sagittal Pelvic tilt L; 25) Frontal Knee Angle R; 26) Frontal Knee Angle L; 30) Knee Valgus; 32) Sagittal Knee Angle L; 33) Tibio Calcaneus Angle R; 34) Tibio Calcaneus Angle L (see Appendix 1 for the description of all indices). Note that the Lumbar Lordosis could be measured in this participant but not the Thoracic Kyphosis. These two indices were dropped due to not having enough data to determine reliability.

Figure 2

A) This graph shows no systematic effect between raters for the posture index Trunk list because values are uniformly distributed around the identity line (Line with a 45° slope). Each point represents the average of the two test sessions for each rater.
B) This graph shows a systematic effect between raters for the posture index Q Angle: Rater 2 results were systematically higher than those of Rater 1.

APPENDIX 1

Posture indices of the tool and methods of angle and distance calculation

Body segment	Posture indices	Body angle calculation
Head and neck	1. Frontal eyes obliquity	The angle formed by a line drawn between the left and right eye, and the angle of this line to the horizontal.
	2. Head Lateral Bending	The angle formed by a line drawn between the inferior tip of the left and right ear, and the angle of this line to the horizontal.
	3. Gaze Angle R 4. Gaze Angle L	The angle formed by a line drawn from the canthus of the eye and tragus of the ear and a horizontal line through the tragus.
	5. Head protraction R 6. Head Protraction L	The angle formed by a line drawn between the tragus of the ear and C7 and a horizontal line through C7.
	7. Cervical lordosis	The angle formed by lines drawn through C2 and C4, and through C4 and C7.
Shoulders and scapula	8. Shoulder Elevation	The angle formed by a line drawn between the left and right coracoid process markers, and the angle of this line to the horizontal.
	9. Shoulder Protraction R 10. Shoulder Protraction L	The distance from C7 to the acromion
	11. Scapula Asymmetry	The angle formed by a line drawn from the left and right inferior angle of scapula and the horizontal.
Thoracic	12. Waist Angle R 13. Waist Angle L	The angle formed by lines drawn through the upper end of waist to the center of waist and the center of waist through the lower end of waist.
	14. Trunk List	Distance between a line from C7 to S1.
	15. Scoliosis 1	The angle formed by lines drawn through the upper end-vertebra of the curve to the apex of the thoracic scoliosis and the apex through the lower end-vertebra of the curve.
	16. Frontal Thoracic Angle	The angle formed by a line drawn from the upper end-vertebra of the curve to the apex of the thoracic scoliosis and the vertical line passing through the apex.
	17. Kyphosis	The angle formed by lines drawn through the upper end-vertebra of the curve to the apex of the

		kyphosis and the apex through the lower end-vertebra of the curve.
Lumbar	18. Scoliosis 2	The angle formed by lines drawn through the upper end-vertebra of the curve to the apex of the thoraco-lumbar or lumbar scoliosis and the apex through the lower end-vertebra of the curve.
	19. Frontal Lumbar Angle	The angle formed by a line drawn from the apex of the curve to the lower end-vertebra of the thoraco-lumbar or lumbar scoliosis and the vertical line passing through the apex.
	20. Lordosis	The angle formed by lines drawn through the upper end-vertebra of the curve to the apex of the lordosis and the apex through L5.
Pelvis	21. Frontal Pelvic tilt (front)	The angle formed by the horizontal and by the line joining the two ASIS.
	22. Frontal Pelvic tilt (back)	The angle formed by the horizontal and by the line joining the two PSIS.
	23. Sagittal Pelvic tilt R 24. Sagittal Pelvic tilt L	The angle formed by the horizontal and by the line joining the PSIS and ASIS.
Knee	25. Frontal Knee Angle R 26. Frontal Knee Angle L	The angle of intersection from a line drawn between the ASIS and the midpole of the patella, and a second line drawn between midpole of the patella and talus.
	27. Q Angle R 28. Q Angle L	The angle formed from a line drawn between the ASIS and the midpole of the patella, and a second line drawn between the midpole of the patella and the tibial tuberosity.
	29. Knee Varus 30. Knee Valgus	Varus: distance between internal femoral condyles. Valgus: distance between internal malleolus.
	31. Sagittal Knee Angle R 32. Sagittal Knee Angle L	The angle formed from a line drawn between the great trochanter and the axis of rotation of the knee (aligned with the lateral joint line) and a line between this axis and external malleolus.
Foot	33. Tibio Calcaneus Angle R 34. Tibio Calcaneus Angle L	The angle formed from a line drawn between the center of the calcaneus and the Achilles tendon and a second line drawn from the Achilles tendon and the mid calf.

Legend: The numbers in the middle column correspond to numbers in Figure 1.

APPENDIX 2

Dependability coefficient (ϕ) and standard error of measurement (SEM) for random design

$$\phi = \frac{\sigma^2_P}{\sigma^2_P + \underbrace{\frac{\sigma^2_R}{n_R} + \frac{\sigma^2_S}{n_S} + \frac{\sigma^2_{PR}}{n_R} + \frac{\sigma^2_{PS}}{n_S} + \frac{\sigma^2_{RS}}{n_R n_S} + \frac{\sigma^2_{PRS}}{n_R n_S}}_{\text{Absolute error variance}}}$$

$$SEM = \sqrt{\frac{\sigma^2_R}{n_R} + \frac{\sigma^2_S}{n_S} + \frac{\sigma^2_{PR}}{n_R} + \frac{\sigma^2_{PS}}{n_S} + \frac{\sigma^2_{RS}}{n_R n_S} + \frac{\sigma^2_{PRS}}{n_R n_S}}$$

Dependability coefficient (ϕ_S) and standard error of measurement (SEM_S) for test-retest design (with rater fixed)

$$\phi_S = \frac{\sigma^2_P + \frac{\sigma^2_{PR}}{n_R}}{\sigma^2_P + \frac{\sigma^2_{PR}}{n_R} + \underbrace{\frac{\sigma^2_S}{n_S} + \frac{\sigma^2_{PS}}{n_S} + \frac{\sigma^2_{RS}}{n_R n_S} + \frac{\sigma^2_{PRS}}{n_R n_S}}_{\text{Absolute error variance}}}$$

$$SEM_S = \sqrt{\frac{\sigma^2_S}{n_S} + \frac{\sigma^2_{PS}}{n_S} + \frac{\sigma^2_{RS}}{n_R n_S} + \frac{\sigma^2_{PRS}}{n_R n_S}}$$

Dependability coefficient (ϕ_R) and standard error of measurement (SEM_R) for inter-rater design (with test session fixed)

$$\phi_R = \frac{\sigma^2_P + \frac{\sigma^2_{PS}}{n_S}}{\sigma^2_P + \frac{\sigma^2_{PS}}{n_S} + \underbrace{\frac{\sigma^2_R}{n_R} + \frac{\sigma^2_{PR}}{n_R} + \frac{\sigma^2_{RS}}{n_R n_S} + \frac{\sigma^2_{PRS}}{n_R n_S}}_{\text{Absolute error variance}}}$$

$$SEM_R = \sqrt{\frac{\sigma^2_R}{n_R} + \frac{\sigma^2_{PR}}{n_R} + \frac{\sigma^2_{RS}}{n_R n_S} + \frac{\sigma^2_{PRS}}{n_R n_S}}$$

Where:

σ^2_P = inter-persons variance

σ^2_R = Variance component for raters

σ^2_S = Variance component for test sessions

σ^2_{PR} = Variance component for interaction between persons and raters

σ^2_{PS} = Variance component for interaction between persons and test sessions

σ^2_{RS} = Variance component for interaction between raters and test sessions

σ^2_{PRS} = Residual error or variance component for interaction between persons, raters and test sessions

In this study, all coefficients were computed with n_R and n_S =1.

Table 1. Means and standard deviations (SD) for each rater on both test sessions and the grand mean (R1 + R2) and SD for the two raters on both test sessions for each posture index.

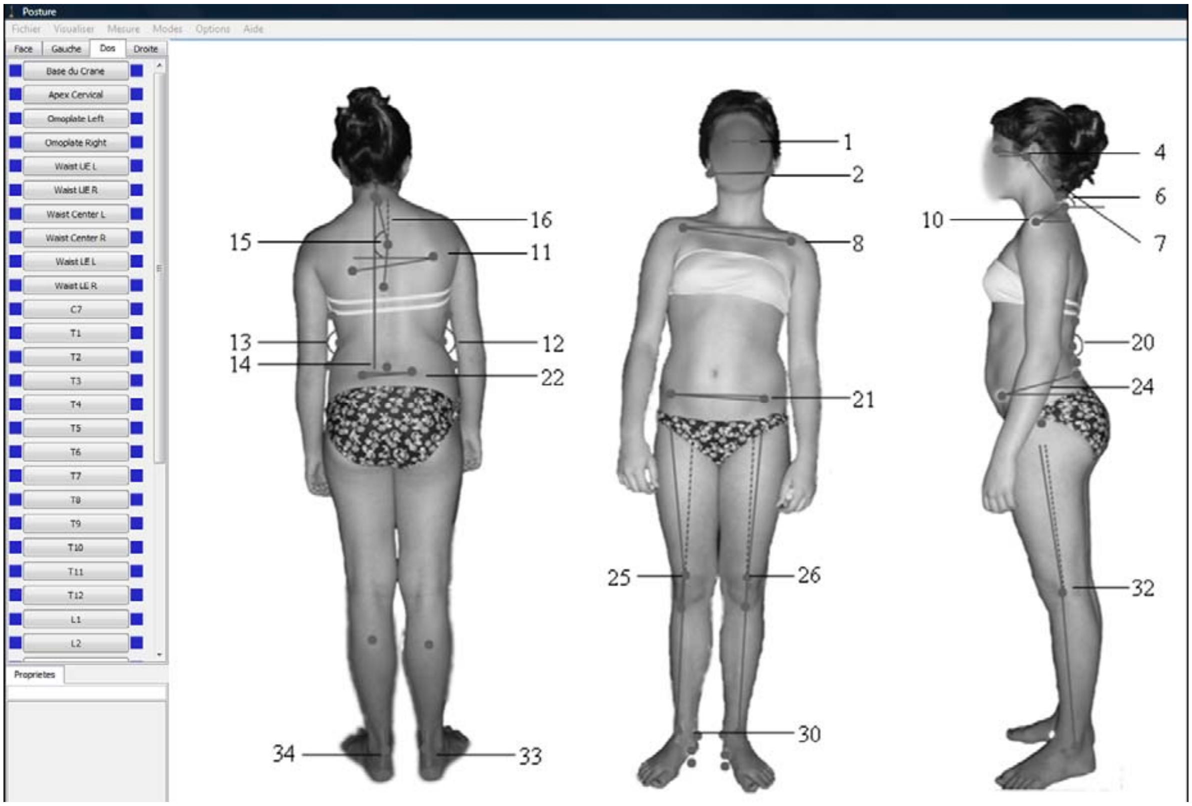
Posture Indices (N)	**Rater 1** Mean (SD) (º or mm*)	**Rater 2** Mean (SD) (º or mm*)	**Rater 1 + Rater 2** Mean (SD) (º or mm*)
Frontal eyes obliquity (70)	0.4 (3.0)	0.3 (3.0)	0.4 (2.9)
Head Lateral Bending (70)	0.3 (2.9)	0.2 (2.8)	0.3 (2.8)
Gaze Angle R (64)	5.8 (5.2)	6.5 (5.1)	6.2 (5.1)
Gaze Angle L (64)	5.9 (5.6)	5.9 (5.7)	5.9 (5.5)
Head protraction R (50)	52.9 (5.2)	52.6 (5.1)	52.8 (5.1)
Head Protraction L (56)	126.9 (4.4)	127.1(4.2)	127.0 (4.3)
Cervical lordosis (59)	162.9 (8.5)	161.5 (8.8)	162.2 (8.3)
Shoulder elevation (69)	-2.1 (3.8)	-2.0 (3.6)	-2.0 (3.7)
Shoulder Protraction R (33)	64.4 (18.7)*	60.4 (18.8)*	62.4 (18.2)*
Shoulder Protraction L (50)	60.2 (18.1)*	64.1 (18.1)*	63.9 (17.7)*
Scapula Asymmetry (69)	-4.9 (7.1)	-5.5 (6.7)	-5.2 (6.8)
Waist Angle R (69)	152.9 (9.8)	152.7 (9.9)	152.8 (9.9)
Waist Angle L (69)	154.9 (9.8)	155.1 (9.8)	155.0 (9.8)
Trunk List (69)	8.2 (19.4)*	8.7 (19.8)*	8.4 (19.5)*
Scoliosis 1 (60)	192.7 (14.3)	189.7 (12.3)	191.2 (13.2)
Frontal Thoracic Angle (57)	9.7 (5.0)	8.7 (4.6)	9.2 (4.8)
Scoliosis 2 (52)	185.6 (10.1)	185.8 (10.0)	185.7 (9.8)
Frontal Lumbar Angle (50)	7.4 (4.9)	6.9 (4.1)	7.1 (4.2)
Frontal Pelvic tilt (front) (70)	-1.6 (2.0)	-1.0 (1.9)	-1.3 (1.9)
Frontal Pelvic tilt (back) (69)	-1.8 (3.4)	-2.1 (3.3)	-1.9 (3.2)
Sagittal Pelvic tilt R (55)	12.1 (5.5)	12.2 (5.7)	12.1 (5.5)
Sagittal Pelvic tilt L (61)	11.2 (4.8)	10.5 (4.9)	10.9 (4.8)
Frontal Knee Angle R (69)	-5.3 (3.0)	-4.6 (3.1)	-4.9 (3.0)
Frontal Knee Angle L (69)	-4.1 (3.2)	-4.2 (3.0)	-4.1 (3.1)
Q Angle R (69)	-11.8 (4.6)	-8.4 (5.3)	-10.1 (4.8)
Q Angle L (69)	-12.3 (5.0)	-10.0 (5.1)	-11.2 (4.8)
Knee Varus (32)	12.9 (9.5)*	12.7 (9.4)*	12.8 (9.4)
Knee Valgus (58)	26.8 (24.9)*	26.5 (24.6)*	26.6 (24.7)*
Sagittal Knee Angle R (69)	1.7 (5.3)	1.3 (4.9)	1.5 (5.0)
Sagittal Knee Angle L (67)	0.6 (5.3)	0.2 (4.8)	0.4 (5.0)
Tibio Calcaneum Angle R (66)	7.3 (2.9)	5.1 (3.0)	6.2 (2.9)
Tibio Calcaneum Angle L (65)	5.9 (3.3)	7.3 (2.9)	6.6 (2.9)

Legend: *data in mm

Table 2. Reliability: Dependability coefficients (ϕ) and standard error of measurement (SEMs) for the posture indices for Random design, Test-retest design (Rater fixed) and Inter-rater design (Test session fixed)

Posture Indices (N)	**Reliability**					
	Random Factors		**Test-retest (Rater fixed)**		**Inter-rater (Test session fixed)**	
	ϕ	SEM (º or mm*)	ϕ_S	SEM_S (º or mm*)	ϕ_R	SEM_R (º or mm*)
Frontal eyes obliquity (70)	0.90	1.0	0.94	0.7	0.97	0.5
Head Lateral Bending (70)	0.90	0.9	0.94	0.7	0.97	0.5
Gaze Angle R (64)	0.83	2.3	0.89	1.7	0.95	1.1
Gaze Angle L (64)	0.89	1.9	0.94	1.3	0.96	1.1
Head protraction R (50)	0.93	1.4	0.96	1.0	0.97	0.8
Head Protraction L (56)	0.92	1.3	0.95	1.0	0.98	0.6
Cervical lordosis (59)	0.79	4.2	0.91	2.6	0.90	2.8
Shoulder elevation (69)	0.93	1.0	0.95	0.8	0.98	0.5
Shoulder Protraction R (33)	0.81	8.5*	0.92	5.1*	0.90	5.8*
Shoulder Protraction L (50)	0.85	7.3*	0.92	5.0*	0.95	4.1*
Scapula Asymmetry (69)	0.88	2.4	0.94	1.7	0.96	1.4
Waist Angle R (69)	0.98	1.2	0.99	0.9	0.996	0.6
Waist Angle L (69)	0.98	1.3	0.99	1.0	0.995	0.7
Trunk List (69)	0.95	4.3*	0.98	2.9*	0.98	2. 7*
Scoliosis 1 (60)	0.93	3.5	0.98	1.7	0.95	2.9
Frontal Thoracic Angle (57)	0.88	1.8	0.94	1.2	0.95	1.1
Scoliosis 2 (52)	0.83	4.3	0.92	3.0	0.94	2.5
Frontal Lumbar Angle (50)	0.67	2.7	0.86	1.6	0.81	1.9
Frontal Pelvic tilt (front) (70)	0.72	1.1	0.88	0.7	0.84	0.8
Frontal Pelvic tilt (back) (69)	0.81	1.5	0.90	1.0	0.93	0.9
Sagittal Pelvic tilt R (55)	0.87	2.1	0.93	1.5	0.96	1.1
Sagittal Pelvic tilt L (61)	0.85	2.0	0.91	1.5	0.95	1.1
Frontal Knee Angle R (69)	0.91	0.9	0.97	0.5	0.95	0.7
Frontal Knee Angle L (69)	0.93	0.9	0.96	0.6	0.98	0.5
Q Angle R (69)	0.63	3.5	0.88	1.7	0.72	2.8
Q Angle L (69)	0.64	3.3	0.84	2.0	0.78	2.4
Knee Varus (32)	0.95	2.1*	0.98	1.2*	0.97	1.6*
Knee Valgus (58)	0.99	2.7*	0.995	1.7*	0.99	1.8*
Sagittal Knee Angle R (69)	0.87	1.9	0.95	1.1	0.94	1.3
Sagittal Knee Angle L (67)	0.86	1.9	0.94	1.2	0.94	1.2
Tibio Calcaneum Angle R (66)	0.51	2.6	0.73	1.6	0.67	1.9
Tibio Calcaneum Angle L (65)	0.53	2.4	0.77	1.5	0.70	1.7

Legend: *data in mm, indices in boldface font represent the 24 selected PI for evaluation of global posture.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Face Gauche Dos Droite
Base du Crane
Apex Cervical
Omoplate Left
Omoplate Right
Waist UE L
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Waist Center L
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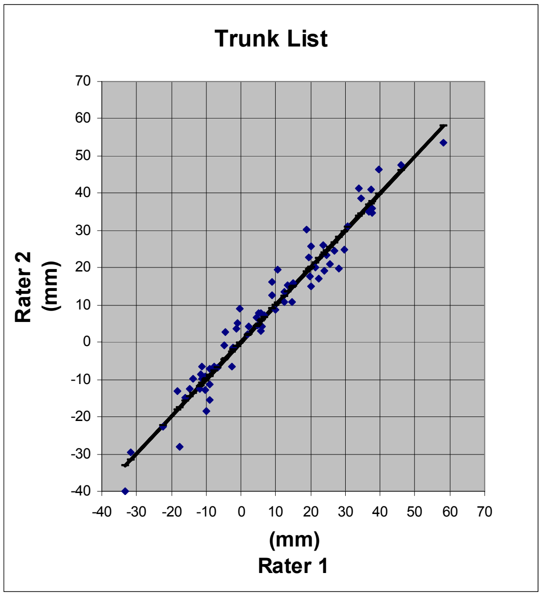
Figure 1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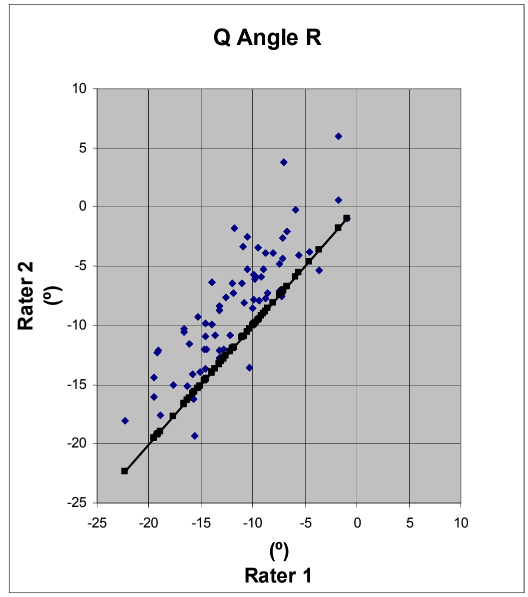
Rater 1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Rater 1

A)

B)

Figure 2