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Reliability of a quantitative clinical posture assessment tool among persons 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 Tertiary care paediatric centre.
Participants Seventy participants aged between 10 and 20 years with different types of idiopathic scoliosis (Cobb angle 15 to 60°) were recruited from the scoliosis clinic.
Main outcome measures Based on the XY co-ordinates of natural reference points (e.g. eyes) as well as 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. Generalisability theory served to estimate the reliability and standard error of measurement (SEM) for the overall, test–retest and inter-rater designs. Bland and Altman's method was also used to document agreement between sessions and raters.
Results In the random design, dependability coefficients demonstrated a moderate level of reliability for six posture indices ($\phi = 0.51$ to 0.72) and a good level of reliability for 26 posture indices out of 32 ($\phi \geq 0.79$). Error attributable to marker placement was negligible for most indices. Limits of agreement and SEM values were larger for shoulder protraction, trunk list, Q angle, cervical lordosis and scoliosis angles. The most reproducible indices were waist angles and knee valgus and varus.
Conclusions Posture can be assessed in a global fashion from photographs in persons with idiopathic scoliosis. Despite the good reliability of marker placement, other studies are needed to minimise measurement errors in order to provide a suitable tool for monitoring change in posture over time.

Keywords: Posture assessment; Reliability; Idiopathic scoliosis; Generalisability theory; Bland and Altman method

Introduction

Correction of posture is an important goal of physiotherapy interventions to prevent progression in persons with idiopathic scoliosis. 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 idiopathic scoliosis [2], and can affect functional activities [3,4] and limit participation in active life [5]. The Cobb angle remains the gold standard to monitor change in scoliosis over time, and is calculated from radiographs [6,7]. It provides information on vertebral alignment, and is formed by the intersection of lines drawn on the borders of the superior and inferior end-vertebra (more inclined vertebrae) and perpendiculars drawn to these lines. Physiotherapists and

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physicians commonly assess posture based on qualitative assessment [1,8]. The effectiveness of physiotherapy interventions has been criticised [9] in persons with idiopathic scoliosis, and this may be due, in part, to the lack of adequate clinical quantitative measurement tools to monitor change in posture over time. Although there are sophisticated three-dimensional (3D) posture analysis systems such as Optotrak (Northern Digital Inc., Waterloo, Canada), Vicon (Vicon Motion Systems, Oxford, UK), Motion Analysis (Motion Analysis Corporation, Santa Rosa, CA, USA) and surface topography systems, these systems are not accessible for most clinicians. The use of reliable and valid clinical tools to document impaired posture is recommended in the Guide to Physical Therapist Practice [10].

A promising technique to assess posture clinically in a global fashion may be the calculation of body angles and distances on photographs [11–17]. This method is fast, easy 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 generalised to persons with pathological conditions [18]. Also, current tools do not include posture indices representing all body segments or are not specific to characterise scoliosis [12,19–21]. The authors' team has developed a software-based 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 idiopathic scoliosis [22], but its reliability has not been established to date.

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 idiopathic scoliosis. The generalisability theory served as the statistical technique to determine the sources of variance, the level of reliability and the standard error of measurement (SEM) expected for particular designs [23].

Methods

Selection of posture indices of the tool

A literature review was conducted to select posture indices for inclusion in the present global quantitative clinical assessment tool of posture. Forty-five indices taken from direct measures or from photographs were first identified from studies of adult, children or adolescent populations [12]. Several posture indices had different names but were measured from the same anatomical landmarks, whereas others were calculated differently but were used to measure the same body segment alignment. In total, 34 posture indices that covered all body segments were selected in the global posture evaluation for the reliability study (Appendix 1). The selection of posture indices was based on: (1) their clinical relevance [1]; (2) their capacity to measure changes in posture in all body segments based on criteria from Tyson and DeSouza's content validity study [21] and on their intra-rater level of reliability (intra-class correlation coefficient > 0.70); and (3) their utility to characterise idiopathic scoliosis, such as trunk list, waist angles, and measurement of frontal and sagittal spinal curves [19,20,22,24].

Participants

Seventy participants (60 females and 10 males) were recruited from the scoliosis clinic at the Sainte-Justine University Hospital Center in Montreal. Inclusion criteria were: age 10 to 20 years; diagnosis of idiopathic scoliosis with a frontal deformity between 15 and 60° (Cobb angle); and pain-free at the time of evaluation. The mean (standard deviation, SD) age of participants was 15.7 (2.5) years, and average weight and height were 51.9 (9.3) kg and 161 (9.5) cm, respectively. Twenty-six participants had a right thoracic scoliosis (mean 38°, SD 11°), 22 had a double major scoliosis (means for each curve: 35°, SD 13°; 33°, SD 11°), 16 had a thoracolumbar scoliosis (mean 26°, SD 7°) and six had a lumbar scoliosis (mean 27°, SD 13°). Participants with a leg length discrepancy of more than 1.5 cm and those who had spinal surgery were excluded. All participants and their parents signed informed consent forms, and the project was approved by the ethics committee of Sainte-Justine University Hospital Center.

Procedure and instrumentation

Two trained physiotherapists evaluated participants at the Laviani Laboratory at Sainte-Justine University Hospital Center. Each physiotherapist completed palpation and marker placement for the anatomical landmarks at two test sessions (Appendix 1). Quantitative posture evaluation software was used to calculate posture indices from a set of markers selected interactively on the digital photographs (Fig. 1). Forty-nine round, adhesive, 5-mm green markers were placed on the following anatomical landmarks (chosen according to their reliability in previous studies) [11,16,25]: spinous process (C2, C4 and C7 to S1), right and left tragus, coracoid process, acromion, inferior angle of scapulae, anterior superior iliac spine (ASIS), posterior superior iliac spine (PSIS), greater trochanter, knee interarticular joint line, mid-pole of patella, tibial tuberosity, internal femoral condyles, dome of talus, and lateral and medial malleolus (Fig. 1). 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 centre 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 – Matsushita Electric Industrial Co., Ltd., Osaka, Japan) fixed on bars within the laboratory and adjusted vertically to capture the full height of participants. The cameras were placed at a distance of

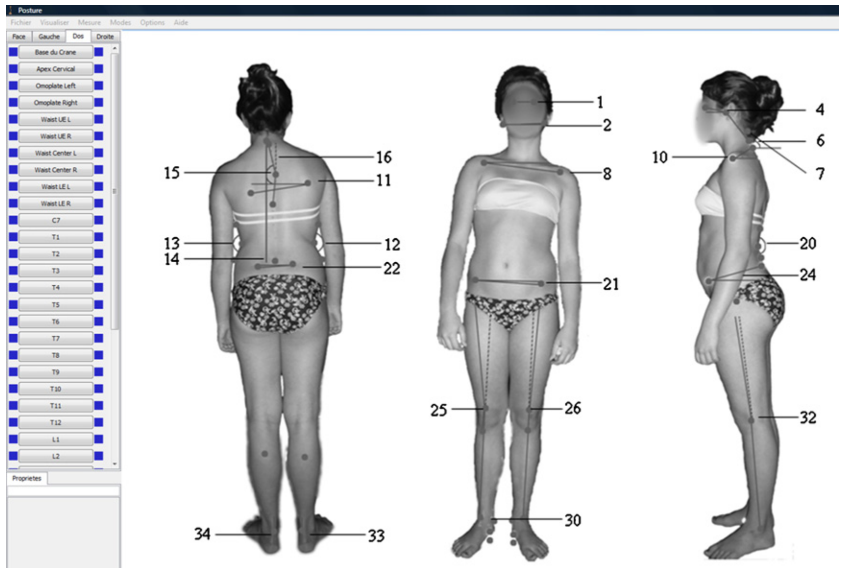

Fig. 1. Graphical interface with a reduced set of markers of the quantitative clinical posture assessment tool at the left; and back, anterior and lateral views of a participant demonstrating marker and anatomical reference point localisation and posture indices calculation for 23 out of 32 posture indices 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 insufficient data to determine reliability.

159 cm for anterior and right lateral views and 173 cm for posterior and left lateral views at a height of 88 cm. This set up of the cameras was imposed by the simultaneous use of a 3D system in a concomitant study. Vertical and horizontal level adjustments of the cameras were made for each set of photographs using a spirit level. Placement and instructions given to all subjects concerning the positioning were standardised. To limit the variability associated with participants' positions, two reference frames for feet placement (triangles of 30°) were drawn on the floor for frontal and sagittal views. Participants were asked to look straight ahead and stand in a normally comfortable position [13–15,17]. Supplementary sagittal photographs were taken with participants standing with flexed elbows if greater trochanter and ASIS were not otherwise visible [14].

Data acquisition followed a specific sequence and lasted for 20 to 25 minutes on average (including marker placement). First, digital photographs of front and back views were taken by the first rater (Trial 1). Subsequently, the participant was asked to walk around and repositioned to take a second set of photographs in these views (Trial 2). Hemispheric markers were added to anatomical landmarks (previously mentioned) and the participant was placed in the lateral position for two separate sets of photographs of right and left lateral views (Trials 1 and 2). Markers were removed and landmarks on skin were cleaned thoroughly before the second rater repeated the procedure. After the first session, participants were asked to return 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 for each rater was used to determine the level of reliability [26].

Quantitative posture indices from digital photographs were calculated with the custom software program. 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 (Fig. 1). For angle calculation, horizontal and vertical borders of the photograph served as references. For distance calculation, a cube of 15 cm (constant distance from the position of reference) was used as a calibration tool. Two indices (thoracic kyphosis and lumbar lordosis) were dropped due to insufficient data to calculate reliability. Appendix 1 describes the methods for angle and distance calculation. All posture photos were digitised by the same trained operator who was not involved in the data collection process. 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, SD) are used to characterise participants with scoliosis and the posture indices from the clinical posture assessment tool.

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) (° or mm[a])	Rater 2 Mean (SD) (° or mm[a])	Rater 1 + Rater 2 Mean (SD) (° or mm[a])
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)[a]	60.4 (18.8)[a]	62.4 (18.2)[a]
Shoulder protraction L (50)	60.2 (18.1)[a]	64.1 (18.1)[a]	63.9 (17.7)[a]
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)[a]	8.7 (19.8)[a]	8.4 (19.5)[a]
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)[a]	12.7 (9.4)[a]	12.8 (9.4)
Knee valgus (58)	26.8 (24.9)[a]	26.5 (24.6)[a]	26.6 (24.7)[a]
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)
Tibiocalcaneal angle R (66)	7.3 (2.9)	5.1 (3.0)	6.2 (2.9)
Tibiocalcaneal angle L (65)	5.9 (3.3)	7.3 (2.9)	6.6 (2.9)

[a]Data in mm.

Reliability of the posture indices was calculated according to: (1) the generalisability theory, an extension of the intra-class correlation coefficient [23]; and (2) the Bland and Altman limits of agreement method [27].

There are two components of the generalisability theory analysis: the generalisability study (G study) and the decision study (D study). The advantage of this approach lies in the determination of potential sources of errors (variances) which can thereafter guide researchers/physiotherapists in strategies to be used to reduce these errors [18]. In the present research, a two-factor crossed design was retained (factors were test session and 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 interpretation of the G study results, the magnitude of each variance was expressed as a percentage of the total variance. The D study 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 coefficient of dependability (ϕ) was 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 rater fixed, giving test–retest reliability; and (3) with the test session fixed, giving inter-rater reliability (formulae for each design are presented in Appendix 2). Like the intra-class correlation coefficient, the dependability coefficient ranges between 0 and 1: 0 is absence of reliability and 1 is perfect reliability. Interpretation of the coefficients was as follows: values >0.75 were considered as good reliability, those between 0.50 and 0.75 as moderate reliability and those <0.5 as poor reliability [28]. To assess the errors in terms of the unit of measurement, the SEM, which is the square root of the sum of all error variances components, was also computed [23]. The GENOVA software program was used for these analyses [29].

The Bland and Altman method was also used to document between-session and between-rater agreement of measurements of posture indices [27]. The 95% limits of agreement represent 2 SD above and below the mean differ-

Table 2
Reliability: dependability coefficients (ϕ) and standard errors 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(° or mm[a])	ϕ_S	SEM_S (° or mm[a])	ϕ_R	SEM_R (° or mm[a])
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[a]	0.92	5.1[a]	0.90	5.8[a]
Shoulder protraction L (50)	0.85	7.3[a]	0.92	5.0[a]	0.95	4.1[a]
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[a]	0.98	2.9[a]	0.98	2.7[a]
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[a]	0.98	1.2[a]	0.97	1.6[a]
Knee valgus (58)	0.99	2.7[a]	0.995	1.7[a]	0.99	1.8[a]
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
Tibiocalcaneal angle R (66)	0.51	2.6	0.73	1.6	0.67	1.9
Tibiocalcaneal angle L (65)	0.53	2.4	0.77	1.5	0.70	1.7

[a] Data in mm.
Indices in bold can be selected for evaluation of global posture.

ence between sessions and between raters for each posture index.

Results

Table 1 describes the means and SDs 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 because of excessive trunk rotation or scapula protuberance, and thus were not included in the reliability study. All posture indices except the knee varus and valgus and scoliosis angles followed a normal or near-normal distribution.

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 4%), except for the Q and tibiocalcaneal angles (7 to 19%). Variance components for test session (S) and interaction between raters and test sessions (RS) were <1%. 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 and 12%. The interaction between persons, raters and test sessions (PRS) varied from 1 to 28%, with higher values for the frontal lumbar angle (23%), the frontal pelvic tilt (16 to 17%), the Q angle (17 to 18%) and the tibiocalcaneal angle (21 to 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 had a good level of reliability ($\phi \geq 0.79$) and six out of 32 had a moderate level of reliability ($\phi = 0.51$ to 0.72). The most reproducible indices in this design were waist angles (L and R; $\phi = 0.98$), trunk list ($\phi = 0.95$), and knee valgus and varus ($\phi = 0.99$ and 0.95, respectively). The

Table 3
Bland and Altman limits of agreement between sessions and raters.

Posture indices	Limits of agreement ±2SD			
	Sessions		Raters	
	Mean difference	LL to UL	Mean difference	LL to UL
Head lateral bending (°)	0.0	−1.9 to 1.9	0.1	−1.6 to 1.8
Gaze angle (°)	−0.4	−5.1 to 4.4	−0.7	−4.4 to 3.0
Head protraction (°)	0.0	−2.8 to 2.9	0.4	−2.4 to 3.2
Cervical lordosis (°)	−0.3	−5.4 to 4.8	1.4	−7.4 to 10.1
Shoulder elevation (°)	0.0	−2.2 to 2.2	−0.1	−1.8 to 1.7
Shoulder protraction (mm)	−0.6	−14.5 to 13.3	0.3	−14.0 to 14.6
Scapula asymmetry (°)	−0.2	−5.0 to 4.6	0.7	−3.9 to 5.2
Waist angle (°)	0.1	−2.5 to 2.6	0.2	−2.1 to 2.5
Trunk list (mm)	−0.5	−8.6 to 7.6	0.5	−8.2 to 9.3
Scoliosis 1 (°)	−0.1	−4.6 to 4.4	−3.0	−9.4 to 3.5
Scoliosis 2 (°)	−0.4	−8.4 to 7.6	0.1	−8.9 to 9.1
Frontal pelvic tilt (°)	−0.2	−2.7 to 2.3	0.4	−2.7 to 3.4
Sagittal pelvic tilt (°)	−0.4	−4.3 to 3.6	0.8	−2.6 to 4.1
Frontal knee angle (°)	0.0	−1.6 to 1.5	−0.7	−2.3 to 0.9
Q angle (°)	0.2	−4.4 to 4.8	−3.3	−8.8 to 2.2
Knee varus (mm)	−0.6	−3.7 to 2.6	−0.2	−3.3 to 3.0
Knee valgus (mm)	0.6	−5.1 to 4.3	−0.3	−6.0 to 5.4
Sagittal knee angle (°)	0.1	−3.0 to 3.1	0.3	−3.7 to 4.4
Tibiocalcaneal angle (°)	0.0	−4.1 to 4.0	−1.4	−6.0 to 3.2

SD, standard deviation; LL, lower limit; UL, upper limit.

least reliable were tibiocalcaneal angles (L and R; $\phi = 0.51$ and 0.53, respectively), 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 tibiocalcaneal angle ($\phi = 0.73$), had good reliability ($\phi \geq 0.77$). In the inter-rater design, 29 posture indices out of 32 had good reliability ($\phi \geq 0.78$) and three posture indices had moderate reliability ($\phi = 0.67$ to 0.72).

In the random design, the SEM values ranged from 0.9 to 4.3° for angular measurements and from 2.1 to 8.5 mm for linear measurements. As expected, the ranges were smaller for the test–retest and inter-rater designs with values from 0.5 to 3.0° and 1.2 to 5.8 mm (Table 2). The higher angular SEMs were associated with cervical lordosis, scoliosis 1 and scoliosis 2 indices. Among linear indices, shoulder protraction had the highest SEM value.

Bland and Altman limits of agreement

Bland and Altman limits of agreement analysis revealed small mean differences between sessions and raters, but the limits of agreement were large for several posture indices (Table 3). Larger between-rater mean differences and/or wider ranges of differences were found for shoulder protraction, trunk list, Q angle, cervical lordosis and scoliosis angles. Fig. 2(A and B) shows a representative index with no systematic effect between sessions and raters, and Fig. 2(C and D) shows no systematic effect between sessions but a systematic effect between raters for the Q angle. Plots of ±2 SD of the limits of agreement of two posture indices presenting high test–retest and inter-rater dependability coefficients are illustrated in Fig. 3. There is a similar range of differences between sessions and raters.

Discussion

The general objective of this study was to assess the reliability of a quantitative clinical posture assessment tool among persons with idiopathic scoliosis. The reliability was reported using two different approaches: the generalisability theory (dependability coefficients and SEM) and the Bland and Altman analysis. Using the G study results of generalisability theory, the overall, test–retest and inter-rater reliabilities were computed for D studies involving one rater on one test session because this is more adapted to the real clinical context.

According to the generalisability theory approach, reliability was good or moderate for all posture indices irrespective of D study design. 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 Appendix 2, one can observe that two mathematical manipulations contribute to the increase in the dependability coefficient for the test–retest and inter-rater designs: the variance attributable to the fixed factor (R or S) is eliminated in the denominator, and the interaction between the fixed factor and the inter-person variance (PR or PS) is included in the numerator [23,26,30].

Generally, it is reported that inter-rater reliability is lower than test–retest reliability for posture indices [12,15]. In this study, the results of the generalisability theory were similar for test–retest and inter-rater reliability for most posture indices, indicating consistency of marker placement between

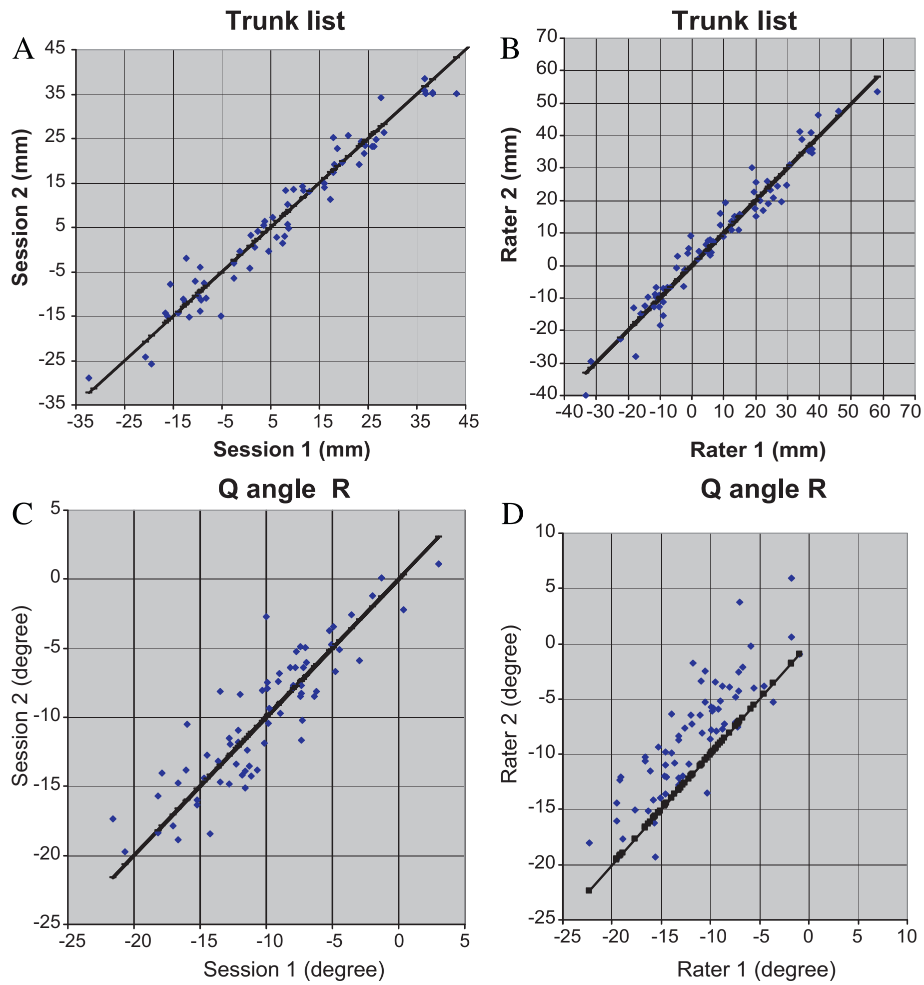

Fig. 2. Plots of between-session and between-rater data for trunk list and Q angle. Each point represents the average of the two raters for each test session (A and C) and the average of two test sessions for each rater (B and D). (A) and (B) show agreement (no systematic effect) between sessions and raters for the posture index trunk list because values are uniformly distributed around the identity line (line with a 45° slope). (C) shows more variation between sessions, and (D) demonstrates a systematic effect between raters for the posture index Q angle. The results of Rater 2 were systematically higher than those of Rater 1.

raters and test sessions [18,30]. Results from the G study corroborate this finding by the absence of any systematic effect due to test sessions (S) and raters [R, see Fig. 2(A and B)] for most of the indices, and a low level of interaction associated with the two factors (PR, PS and SR < 4%) [18,30]. Lower coefficients found for Q angles and tibiocalcaneal angles were caused, in part, by a systematic effect at the rater level. As illustrated in Fig. 2(D) 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 tibiocalcaneal angles, the systematic effect for rater was not consistent between sides.

The 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 minimal detectable difference between two measurements [18]. Although the study participants have greater posture asymmetries (expressed by larger SD) because of different types and magnitudes of scoliosis, the SEM values reported in this study are similar or lower than those reported previously in studies on posture among persons with no scoliosis or posture impairment [11,15,17,31].

Despite these results, the Bland and Altman analysis revealed wide limits of agreement between sessions and raters for several posture indices, suggesting a low level of reproducibility. The limits of agreement found in this study for the posture indices are similar to the minimal detectable difference calculated from the SEM values. For example, in the test–retest design, SEM values were 2.9 mm for the trunk list and 0.8° for shoulder elevation. According to Roebroeck *et al.* [18], the 95% confidence interval for the minimal detectable difference ($\pm 1.96 \times \text{SEM} \times \sqrt{2}$) expected between two sessions would be ±8 mm and ±2°, respectively. Limits of agreement between sessions reported for these indices are between −9 and +8 mm for the trunk list and between −2 and +2° for the shoulder elevation. This means that on 95% of occasions, measurements of trunk list and shoulder elevation taken at a second measurement session will be between 9 mm smaller or 8 mm larger, and 2° smaller and 2° larger,

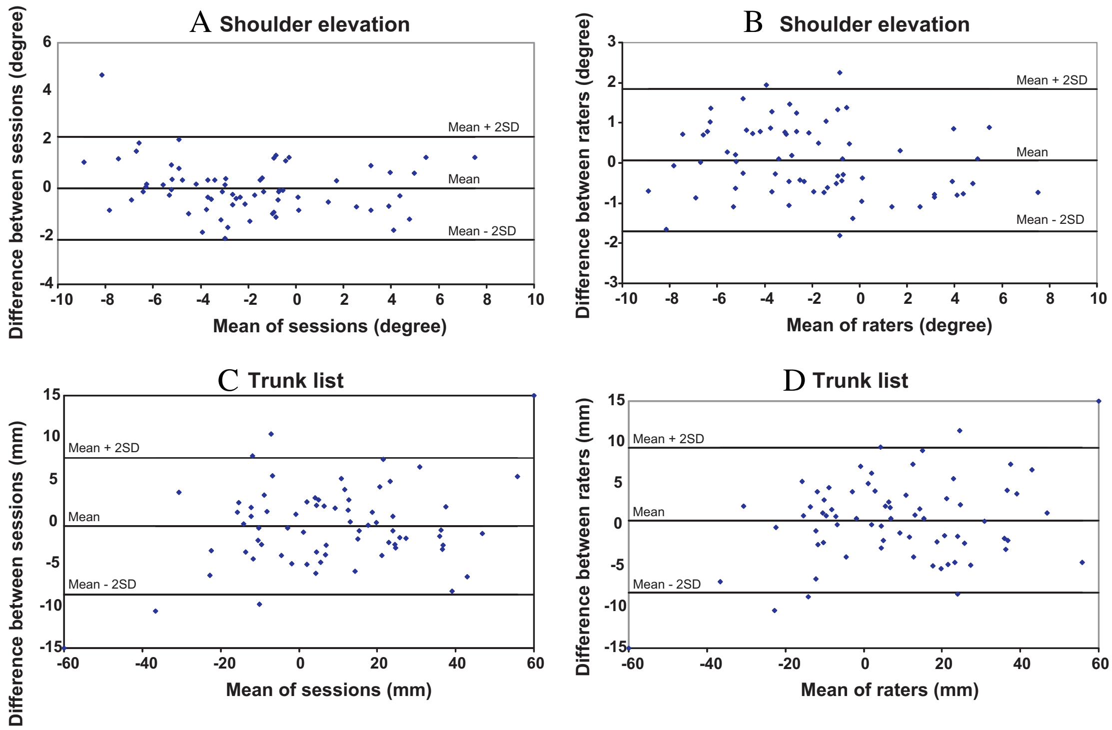

Fig. 3. Bland and Altman plots showing the average of two test sessions against differences between sessions (A and C) and the average of two raters against differences between raters (B and D) of two representative posture indices with high dependability coefficients.

respectively, than the measurements taken at the first session. Thus, in order to document real change in these posture indices, change scores would have to be greater than these threshold values. Normand *et al.* [15] reported similar SEM values and larger between-session and between-rater differences for head, trunk and pelvis posture indices taken from digital photographs. These authors concluded that their posture system was highly reliable and can be used to provide a normative database or to document posture asymmetries on patients. The Bland and Altman limits of agreement and minimal detectable differences calculated from SEM values reported in the present study, as well as in Normand *et al.*'s study [15], suggest a large amount of error. Thus, detection of small changes in some posture indices may not be possible.

As mentioned, except for the Q and tibiocalcaneal angles, the generalisability theory demonstrates that the variance component associated with sessions and raters was negligible (variance R and S = 0 to 3%). This means that error in measurement is not attributable to difference in marker placement between sessions and raters. Larger SEM values and wider limits of agreement may thus be attributable to other factors inherent to the participants, to the experimental conditions or to error due to the digitisation process of photographs. Persons with idiopathic scoliosis show greater oscillations in the sagittal and frontal planes [32,33]. This factor combined with the foot position (feet together with a 30° angle) may explain higher intra-person variability and may thus affect posture stability. The residual or unknown error may also include such factors as temperature in the room, error due to the digitisation process of photographs or perspective error. Some of the evaluations took place during winter and, on some particularly cold days, the temperature in the room was cool; this may have caused more variability in participants' posture due to shivering, especially at the shoulder girdle level. The error attributed to the digitisation process is presently unknown but is under investigation. In the present study, to reduce possible errors, the same trained operator performed all measurements. The greater distance between the feet and the centre of the camera and the feet position (triangles of 30°) may have caused distortion and introduced perspective errors [34]. These factors will need to be documented in future studies to determine their impact on measurement errors.

Clinical applications and future studies

Posture evaluation is commonly undertaken in physiotherapy practice. Several authors have recommended photograph acquisitions to assess global posture in a clinical setting [11–17]. The present authors selected 34 posture indices from the medical literature as they represent the different body segments and characterise scoliosis. It is acknowledged that this is a large number of indices to be measured in a clinical setting. The clinician can select specific indices to assess posture rather than measure them all, since some indices may 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 alignment of the same body segment [11,12,15,32,35,36]. Based on the present generalisability theory results, 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 head tilt or head protraction, respectively. It is preferable to use frontal knee angle and back pelvic lateral tilt to assess frontal leg alignment and frontal pelvic obliquity, respectively, especially if different evaluators perform the assessments. Thus, one can reduce the number of indices to 24 for a complete evaluation of posture (see Table 2, indices in bold).

This quantitative posture assessment tool may also be useful to document physical appearance among youths with idiopathic scoliosis. To the authors' knowledge, this tool is the first to present quantitative measurement of waist angles, trunk list and scoliosis angles from photographs. Measurement errors reported in this study for scoliosis angles are similar to measurement errors usually reported for Cobb angle measurement on radiographs. [37,38] Although a longitudinal study is needed to confirm this, the good level of reliability for marker placement may also be useful for trunk and lower limb growth monitoring of youths with idiopathic scoliosis.

This tool should be easy to use in a clinical setting as the material (digital cameras and software) is accessible, the training of therapists is minimal (2 hours were allocated in this study), the graphical interface of the software is user-friendly, and the time required for a global evaluation is <30 minutes. As photograph acquisition is fast and calculation of posture indices can be delayed, this tool may also be used among persons with pain or balance disorders. However, the use of both the generalisability theory and Bland and Altman method highlights the importance of minimising each potential source of measurement error to be able to accurately detect change in posture over time or scoliosis progression. As such, these results suggest that 2 hours of training was sufficient for between-session and between-rater consistency in marker placement. Nevertheless, the SEM values and the wide limits of agreement associated with several posture indices also suggest that strategies must be undertaken to better control other factors such as participants' oscillations, room temperature and acquisition set-up. Studies on the impact of the foot position (feet together vs feet apart) on the trunk list measurement as well as on the digitising process with the software are under investigation by the authors' team. A future study will use a postural stability platform to synchronise photograph acquisition with postural stabilisation to better control oscillations by the participant.

Conclusion

The results show that it is possible to assess posture in a global fashion from photographs in persons with idiopathic scoliosis. The generalisability theory demonstrates that marker placement for photographic acquisition is reproducible between sessions and raters. This new tool may improve physiotherapy practice by facilitating the analysis of posture abnormalities. It may also serve to monitor treatment effectiveness or change in posture over time, and to characterise posture asymmetries associated with different types of scoliosis (classification). However, the wide limits of agreement found for several posture indices indicate that other studies are needed to document factors that can affect the reliability of the posture measurements, so that measurement errors may be reduced.

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Appendix A.

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	The angle formed by a line drawn from the canthus of the eye and the tragus of the ear, and a horizontal line through the tragus
	4. Gaze angle L	
	5. Head protraction R	The angle formed by a line drawn between the tragus of the ear and C7, and a horizontal line through C7
	6. Head protraction L	
	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	The distance from C7 to the acromion
	10. Shoulder protraction L	
	11. Scapula asymmetry	The angle formed by a line drawn from the left and right inferior angle of the scapula and the horizontal
Thoracic	12. Waist angle R	The angle formed by lines drawn through the upper end of the waist to the centre of the waist, and the centre of the waist through the lower end of the waist
	13. Waist angle L	
	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 thoracolumbar 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 thoracolumbar 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	The angle formed by the horizontal and by the line joining the PSIS and ASIS
	24. Sagittal pelvic tilt L	
Knee	25 Frontal knee angle R	The angle of intersection from a line drawn between the ASIS and the mid-pole of the patella, and a second line drawn between the mid-pole of the patella and the talus
	26. Frontal knee angle L	
	27. Q angle R	The angle formed from a line drawn between the ASIS and the mid-pole of the patella, and a second line drawn between the mid-pole of the patella and the tibial tuberosity
	28. Q angle L	
	29. Knee varus	Varus: distance between the internal femoral condyles
	30. Knee valgus	Valgus: distance between the internal malleoli
	31. Sagittal knee angle R	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 the external malleolus
	32. Sagittal knee angle L	

Foot	33. Tibiocalcaneal angle R	The angle formed from a line drawn between the centre of the calcaneus and the Achilles tendon, and a second line drawn from the Achilles tendon and the mid-calf
	34. Tibiocalcaneal angle L	

ASIS, anterior superior iliac spine; PSIS, posterior superior iliac spine.

Appendix B.

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

$$\phi = \frac{\sigma_P^2}{\underbrace{\sigma_P^2 + (\sigma_R^2/n_R) + (\sigma_S^2/n_S) + (\sigma_{PR}^2/n_R) + (\sigma_{PS}^2/n_S) + (\sigma_{RS}^2/n_R n_S) + (\sigma_{PRS}^2/n_R n_S)}_{\text{Absolute error variance}}}$$

$$\mathrm{SEM} = \sqrt{\frac{\sigma_R^2}{n_R} + \frac{\sigma_S^2}{n_S} + \frac{\sigma_{PR}^2}{n_R} + \frac{\sigma_{PS}^2}{n_S} + \frac{\sigma_{RS}^2}{n_R n_S} + \frac{\sigma_{PRS}^2}{n_R n_S}}$$

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

$$\phi_S = \frac{\sigma_P^2 + (\sigma_{PR}^2/n_R)}{\underbrace{\sigma_P^2 + (\sigma_{PR}^2/n_R) + (\sigma_S^2/n_S) + (\sigma_{PS}^2/n_S) + (\sigma_{RS}^2/n_R n_S) + (\sigma^2/n_R n_S)}_{\text{Absolute error variance}}}$$

$$\mathrm{SEM}_S = \sqrt{\frac{\sigma_R^2}{n_S} + \frac{\sigma_{PS}^2}{n_S} + \frac{\sigma_{RS}^2}{n_R n_S} + \frac{\sigma_{PRS}^2}{n_R n_S}}$$

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

$$\phi_R = \frac{\sigma_P^2 + (\sigma_{PS}^2/n_S)}{\underbrace{\sigma_P^2 + (\sigma_{PS}^2/n_S) + (\sigma_R^2/n_R) + (\sigma_{PR}^2/n_R) + (\sigma_{RS}^2/n_R n_S) + (\sigma_{PRS}^2/n_R n_S)}_{\text{Absolute error variance}}}$$

where $\sigma^2{}_P$ = inter-person variance, $\sigma^2{}_R$ = variance component for raters, $\sigma^2{}_S$ = variance component for test sessions, $\sigma^2{}_{PR}$ = variance component for interaction between persons and raters, $\sigma^2{}_{PS}$ = variance component for interaction between persons and test sessions, $\sigma^2{}_{RS}$ = variance component for interaction between raters and test sessions, and $\sigma^2{}_{PRS}$ = residual error or variance component for interaction between persons, raters and test sessions.

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

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