The following scientific article was officially published in the journal *Physical & Occupational Therapy In Pediatrics*, published by Taylor & Francis (Informa Healthcare). This article's citation is as follows:

Carole Fortin, Debbie Ehrmann Feldman, Farida Cheriet & Hubert Labelle. "Differences in Standing and Sitting Postures of Youth with Idiopathic Scoliosis from Quantitative Analysis of Digital Photographs", Physical & Occupational Therapy in Pediatrics, Vol. 33, no. 3, (2013): pp. 313-326.

doi: 10.3109/01942638.2012.747582

The manuscript, in its initial version submitted by the authors to the journal *European Spine Journal* in 2010, 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:

Fortin, Carole. "Développement et validation d'un outil clinique pour l'analyse quantitative de la posture auprès de personnes atteintes d'une scoliose idiopathique." Ph.D., Université de Montréal, 2010.

Chapitre7 Étude comparative de la posture debout et assise

7.1 Article 4 : Differences in standing and sitting posture in persons with idiopathic scoliosis

Carole Fortin, Debbie Feldman, Farida Cheriet, Hubert Labelle

Article soumis le 30 janvier 2010 à la revue *European Spine Journal*

L'auteur principal confirme sa contribution majeure à l'élaboration du protocole expérimental, au financement du projet, à l'acquisition, au traitement et à l'interprétation des données ainsi qu'à la rédaction de cet article scientifique (90%). 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, à l'analyse des données et à la rédaction de l'article. Les Docteurs Cheriet et Labelle ont contribué à l'élaboration du protocole expérimental et à la rédaction de l'article.

Differences in standing and sitting posture in persons with idiopathic scoliosis

Carole Fortin[1,2], P.T., M.Sc., Debbie E. Feldman[3,4], P.T., Ph.D., Farida Cheriet[1,5], Ph.D., Hubert Labelle[1,2], M.D.

Affiliations:

[1]Centre de recherche, CHU Sainte-Justine

[2]Faculté de médecine, Université de Montréal

[3]École de réadaptation, Université de Montréal

[4]Groupe de Recherche Interdisciplinaire en Santé

[5]École Polytechnique, Université de Montréal

ACKNOWLEDGEMENTS

This project is supported by the Discovery Advancement Program of the Canadian Arthritis Network. C. Fortin is supported by a Ph.D. scholarship from the FRSQ, MENTOR, a strategic CIHR training program/REPAR and research Centre of Sainte-Justine University Hospital Center. Dr. Ehrmann Feldman is funded by the FRSQ. The authors acknowledge Ionut Alexandrescu, Christian Bellefleur, Philippe Debanné, Fabiana Dias Antunes and Philippe Labelle for their technical assistance, Frédérique Gauthier for data collection, Erin Grunstein for the recruitment of participants with IS and all participants.

ABSTRACT

Posture asymmetries are associated with muscle imbalance and can play an important role in scoliosis progression. Posture may differ in standing and sitting positions and require different therapeutic interventions. We explored if differences in standing and sitting posture indices could be detected using a quantitative clinical posture assessment tool and verified if these differences are influenced by type of scoliosis. Standing and sitting posture of 50 participants aged from 10 to 20 years old with thoracic and thoracolumbar or lumbar idiopathic scoliosis (Cobb angle: 15º to 60º) were assessed from digital photographs. Based on the XY coordinates of natural reference points and of markers placed on several anatomical landmarks, 13 angular and linear posture indices were calculated in both positions using a software program. Paired Student's t tests were used to compare values of standing and sitting posture indices. When all participants were analyzed together, significant differences between positions (paired t-tests, $p<0.05$) were found for head protraction, shoulder elevation, scapula asymmetry, trunk list, scoliosis angle, waist angles and frontal and sagittal pelvic tilts. When analysis were done according to the type of scoliosis, difference in head protraction was only observed in thoracic scoliosis whereas differences in scapula asymmetry, trunk list and frontal pelvic tilt were only detected in thoracolumbar or lumbar scoliosis. These findings support the usefulness of this quantitative clinical tool to document diferences in posture among persons with scoliosis. This tool may guide the clinician in the selection of appropriate exercises to improve posture.

Key words: standing posture, sitting posture, idiopathic scoliosis, global postural re-education

INTRODUCTION

Posture asymmetries are frequently observed among persons with idiopathic scoliosis (IS)[31, 46], are associated with muscle imbalance [19, 21, 35, 38, 41] and can play an important role in scoliosis progression [4, 17, 35, 41, 43]. This progression is attributable to biomechanical factors such as modified trunk alignment and body weight influences which create modifications in muscular moments acting on the spine especially during growth spurt [5, 17, 35, 43]. To restore good posture and to prevent scoliosis progression, physiotherapists work on muscle balance. Posture is usually assessed in the standing position. However, children and adolescents spend many hours a day in the sitting position at school or in leisure activities. Because assuming positions for long time periods may influence scoliosis progression, certain authors recommend that posture be assessed in both standing and sitting positions [15, 22, 41]. Moreover, asymmetries in posture indices, such as pelvic tilt, scoliosis or trunk list, could influence trunk kinematics and muscle activity differently in standing and sitting positions [1, 15, 33].

Pelvic frontal tilt in the standing position is frequently attributed to lower limb discrepancy in youths with thoracolumbar or lumbar scoliosis. However, according to Winter and Pinto [45], pelvic obliquity may also be caused by hip contractures, the scoliosis itself, or from a combination of these causes. Assessing differences between standing and sitting posture may help determine whether pelvic frontal tilt is associated with scoliosis or lower limb asymmetries or discrepancy [41] and be useful in terms of treatment approaches.

One posture evaluation and treatment approach used in physical therapy called Global Postural Re-education (GPR) has been proposed by Souchard [40, 41] to assess differences in posture asymmetries between standing and sitting positions. This technique aims to identify whether anterior or posterior muscles are responsible for the observed posture asymmetries and to determine the impact of the position (standing versus sitting) on the magnitude of these asymmetries and on the scoliosis. These observations guide the clinician in the selection of stretching postures and sensory integration exercises to correct posture in the standing and/or sitting positions [21, 29, 30, 38, 41].

The GPR method brings new knowledge in the understanding of muscular impact on scoliosis [41]. Nevertheless, the selection of appropriate postural re-education in standing and/or sitting positions is actually based on subjective impressions that are not quantified by reliable and valid clinical measurement tools. Our team has developed a software based quantitative clinical posture assessment tool (QCPAT) for the calculation of angles and distances using digital photographs. This tool has good psychometric properties for measurements taken in the standing position (test-retest and inter-rater reliability as well as concurrent validity with radiographs and a 3D surface topography system) in persons with IS [12, 13] but the ability to detect differences between standing and sitting posture indices has not yet been established.

Thus, the purpose of this project was to explore if the QCPAT could be used to detect differences in standing and sitting posture indices among persons with idiopathic scoliosis. A secondary objective was to verify if results were influenced according to the type of scoliosis.

Methods

Participants

Fifty participants (43 females and 7 males) were selected from our previous study on reliability and validity of this tool. They were recruited from the scoliosis clinic at the Sainte-Justine University Hospital Center (SJUHC) in Montreal. Inclusion criteria were: ages 10 to 20 years old, idiopathic scoliosis diagnosis with a primary single curve between 15º and 60º (Cobb angle) and pain-free at the time of evaluation. 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 SJUHC.

Procedure and instrumentation

Participants were assessed by a physiotherapist at our laboratory at SJUHC and a quantitative posture evaluation software was used to calculate posture indices of the head and trunk. The software has a user-friendly graphical interface and it allows calculation of postural indices from a set of markers selected interactively on the digital photographs (Figure 1). These markers (5 mm in diameter) were placed on the subject by the physiotherapist on the tragus, spinous processes (C2, C4 and C7 to S1), coracoid process, inferior angle of scapulae, ASIS and PSIS. To facilitate measurement of sagittal posture indices, hemispheric 10 mm reflective markers were added onto C4, C7, ASIS, and PSIS. Other anatomical reference points such as eyes, tips of the ears, upper end, lower end and center of waist also served for angle calculations.

Digital photographs were taken with two Panasonic Lumix cameras (DMC-FX01, 6.3 mega pixels) fixed on the bars of the 3D system (used for the validity study) 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 done with a carpenter's level. Placement instructions given to all participants concerning positioning for data collection were standardized. To limit the variability associated with subjects' standing positions, two reference frames for feet placement (triangles of 30º) were drawn on the floor for frontal and sagittal standing views [41, 44]. Subjects were asked to look straight ahead and stand in a normally comfortable position [23, 32, 44]. Supplementary sagittal photographs were taken with participants standing with flexed elbows if greater trochanter and ASIS were not otherwise visible [27].

For sitting position acquisitions, a table (75.5 cm height and 137.5 cm long) was placed at the same distance from the two cameras. Subjects were sitting in "long sitting": an erect position with legs as straight as possible on the table, and were asked to look straight ahead. Before the acquisition in the long "sitting position", palpation was done again and markers were re-positioned when necessary on the anatomical landmarks. The "long sitting" position was chosen because it has already been used in studies evaluating back and lower limb posterior muscle flexibility [2, 6, 36].

Quantitative posture indices from digital photographs were calculated with the custom software program allowing the operator to select a specific marker from the graphical interface and to put it directly on the corresponding anatomical landmark on a paticipant's photograph. Different sets of markers are available according to each view (anterior, posterior or lateral). Following the selection of the markers associated with the calculation of an angle, its value is automatically displayed (Fig 1). For angle calculation on photographs, the origin of the horizontal and vertical axes is located at the left bottom corner of the image. For calibration, a cube of 15 cm was used. The Appendix describes the methods for angle and distance calculation. All postural photos were digitalized by the same trained operator in standing and sitting positions. To obtain a better estimate of the participant's true score, the mean of two trials per each position was used for data analysis [7].

Data analysis

We used descriptive statistics (mean, standard deviation – SD, range) to characterize participants with scoliosis and the magnitude of posture indices from the clinical posture assessment tool in standing and sitting positions. We compared the average values of each posture index in the standing and sitting positions using paired t-tests. Certain indices could take on positive or negative values: for example, shoulder elevation could be positive if the left shoulder was higher or negative if the left shoulder was lower. To allow adequate comparisons between participants and positions for data implicating negative or positive signs, we have transformed the values to the same reference sign.

We used independent t-tests to compare the magnitude of the head, shoulder, scapula, trunk list and frontal pelvic tilt posture indices according to the type of scoliosis (thoracic scoliosis and thoracolumbar or lumbar scoliosis) in both positions. We did not include right and left waist angles and sagittal pelvic tilt since these indices are dependent on the side of the scoliosis and the number of participants was not sufficient to sub-divide the scoliosis types into right and left. Paired t tests were used to determine differences between positions among these two scoliosis categories for each posture index. For this analysis, participants were categorized according to their primary curve; three participants were excluded for the following reasons: X-rays could not be retrieved, X-rays were too old, and lack of clarity regarding the primary scoliosis. All calculations were done using SPSS statistical analysis software (version 17.0 for Windows).

Results

There were 50 participants in this study and 86% were female. Mean age was 15.4 ± 2.6 years and average weight and height were 51.8 ± 8.5 Kg and 161.6 ± 10.2 cm, respectively. Twenty-nine subjects had a primary right thoracic scoliosis (mean of 36º ± 12º), 14 a thoracolumbar scoliosis (mean of 27º ± 8º) and seven a lumbar scoliosis (mean of 29º ±10º). Twenty-six of participants had a compensatory curve.

Differences between standing and sitting positions

We found differences between standing and sitting positions for ten out of thirteen postural indices when all subjects were analyzed together (Table 1). At the head and neck body segment, only the Head protraction index showed a statistically significant difference between the standing and sitting posture. The angle of Head protraction was increased in the sitting position. Shoulder elevation and Scapula asymmetry were both significantly lower in the sitting position than in standing.

At the back level, left and right Waist angles, Trunk list and Scoliosis angle were significantly different in the two positions. For the pelvis, Pelvic frontal tilt was significantly lower in the sitting position and left and right Pelvic sagittal tilts were significantly tilted posteriorly in the sitting position.

Differences according to the type of scoliosis

Independent t-tests performed on posture indices reveal statistically significant differences according to the type of scoliosis only for the frontal pelvic tilt (p=0.01) and trunk list (p=0.02) in the standing position. Subjects with thoracolumbar or lumbar scoliosis had greater frontal pelvic tilt and trunk list than subjects with thoracic scoliosis (Figure 2).

When data are analyzed according to the type of scoliosis, subjects with thoracic scoliosis demonstrated significant differences between positions for six out of twelve indices whereas eight out of twelve indices where significantly different in thoracolumbar or lumbar scoliosis (Table 2). Significant differences were found for shoulder elevation, trunk list, waist angles (left and right) and the left and right sagittal pelvic tilts indices in both types of scoliosis. Differences in head protraction index was only observed in thoracic scoliosis whereas differences in scapula asymmetry and frontal pelvic tilt were only detected in thoracolumbar or lumbar scoliosis (Table 2). No significant difference could be found for the Scoliosis angle in both groups of scoliosis.

Discussion

The objectives of this study were to explore whether differences between standing and sitting positions could be detected with the QCPAT from digital photographs in persons with IS and to evaluate the association between type of scoliosis and these differences. Although differences between standing and sitting positions could be detected for ten out of thirteen posture indices when all participants were analyzed together, the differences were influenced by the type of scoliosis.

Our results are similar to those of Nault et al. [31] regarding the magnitude of head, shoulder and pelvis posture asymmetries in the standing position. In agreement with Gram and Hasan's [15] results, we found larger values in the standing position for trunk list in the thoracolumbar or lumbar scoliosis type. Thoracolumbar and lumbar scoliosis are more associated with pelvic and lower limb asymmetries which can increase the trunk list in the standing position [11, 14, 16].

Except for head position and waist angles, the mean values of posture indices were lower in the sitting position indicating less asymmetry. In the sitting position, the base of support is greater and the impact of lower limb discrepancy is eliminated creating more stability and less compensation, especially in thoracolumbar and lumbar scoliosis [3]. The position of the head in the frontal plane (Frontal eyes obliquity and Head Lateral Bending) was stable across positions and types of scoliosis, in agreement with previous reports [8, 31]. However, in the sagittal plane, head protraction was increased in sitting and was associated with thoracic scoliosis. Thoracic scoliosis is often characterized by a decrease in thoracic kyphosis which has been attributed to retraction of spinal muscles [28, 41]. The "long sitting" position places tension on the posterior muscles [2, 6, 36, 41]. It is possible that subjects with thoracic scoliosis are stiffer and need to compensate by bending their head to maintain balance. This hypothesis should be verified with a larger sample size.

Gram and Hasan [15] have already pointed out the importance of assessing the effect of standing and sitting postures on spinal curves in persons with IS. Using a 3D posture analysis system, they reported significant differences between standing and sitting postures for their 3D scoliosis angle (named 3D apex angle) but not for the trunk list (lateral lean) and the 2D scoliosis angle (named frontal apex angle) when all curve types were analyzed together. This discrepancy with our findings may be attributable to our larger sample size (n = 47 in our study and n= 19 in Gram and Hasan's study [15]). However, when our participants were divided into two scoliosis groups, our results were similar to those of Gram and Hasan [15]. According to our results and those reported by Gram and Hasan [15], it is possible that the position (standing versus sitting) does not affect the scoliosis angles in the same manner. Persons may compensate differently according to factors such as muscle stiffness, muscle activity (electromyography) and magnitude of the curve. Gram and Hasan [15] have reported an increase in muscle activity of all posterior back muscles in the erect sitting position which may help stabilise the spine in sitting.

Clinical Applications

Our data demonstrate that the QCPAT is able to detect change between standing and sitting positions for several posture indices among persons with IS. This tool may contribute to improvement in clinical practice by facilitating the analysis of differences in posture between positions, by assessing global sitting posture for ergonomic purposes or for non-ambulant persons and by quantifying the impact of posterior muscle flexibility (of the back and lower limbs) on sitting posture indices by means of angles and distances calculations.

Several authors [18-20, 34, 41] consider that muscles are organised into muscular chains and that one muscle's stiffness in the muscular chain will influence the others creating compensation in body posture. According to Souchard, the standing position puts tension onto anterior muscles whereas the "long sitting" position puts tension onto posterior muscles. Link et al. [26] showed that persons with short hip flexor muscles (anterior muscles) had greater lumbar lordosis in the standing position than persons with longer hip flexors. It also seems that short hamstring muscles have less of an effect on the pelvic tilt and lumbar lordosis in the standing position [25,26,42]. In the "long sitting" position, the hamstring muscles are stretched and because of their insertion on the ischial tuberosity, they tend to pull the pelvis into a posterior tilt. Our tool may thus serve to quantify the global repercussion of posterior muscle flexibility on posture and to determine which body segment is more influenced by muscle stiffness. This tool may therefore assist the physiotherapist in determining which muscles and positions should be targeted for treatment (as proposed in GPR) and may also serve to document the effectiveness of physical therapy interventions on anterior or posterior muscle flexibility. The development of other posture indices in the sitting position such as thoracic kyphosis, lumbar lordosis, sagittal trunk list and hip, knee and ankle joint angles will however be needed to have a complete analysis of the consequence of posterior muscle stiffness on posture. Future studies will also be necessary to assess its sensitivity to change over time and to correlate muscle stiffness with posture impairments.

The significant difference found between standing and sitting positions for the frontal pelvic tilt index indicates that this clinical tool may also serve as a screening tool to establish if pelvic obliquity is attributable to lower limb discrepancy or asymmetries (asymmetry of pelvic frontal tilt disappears in the sitting position) or spine deformity (pelvic frontal tilt remains the same in both standing and sitting position) [41, 45]. This tool may also assist the clinician in determining the degree (or amount) of lower limb correction needed to level the pelvis and its influence on other body segments. This tool may therefore help reduce the frequency of lower limb scannography.

Although we did not test persons with paralytic curves, this tool may possibly help in monitoring sitting posture among youths with paralytic scoliosis by detecting changes in posture indices, especially pelvic obliquity, which has been associated with higher incidence of surgery in this group [10, 24,39]. This tool can also provide measurements of standing and sitting heights (to determine growth localization and velocity) which is recommended in the follow-up of youths with different types of scoliosis [9, 16]. Growth spurt, growth velocity and growth localization (lower limbs versus trunk segment) are important risk factors for scoliosis progression [5, 9]. The good test-retest and inter-rater reliability found for marker placement in our previous study [12] combined with the results of this study support its clinical utility. Since photograph acquisitions and calculation of posture indices (angles and distances) are fast and non radiating (as opposed to x-rays), this tool can be used in repeated measurements of standing and sitting posture in persons with different types of scoliosis.

Conclusion

Our results show that it is possible to detect differences between standing and sitting positions for many posture indices among persons with IS from digital photographs using the QCPAT. The differences found in posture indices were influenced by the type of scoliosis. This new tool may contribute to improve physical therapy practice by facilitating the analysis of posture in different positions. As such, it can help guide the clinician in the selection of appropriate stretching postures and sensory integration exercises to restore good posture in the standing and/or sitting positions to prevent scoliosis progression. However, future studies with larger numbers of participants with different types of scoliosis and with other diseases (such as back pain, osteoarthritis or neurological impairments) are still needed to demonstrate if this tool’s posture indices are sensitive enough to detect change over time.

References

1. Al-Eisa E, Egan D, Deluzio K, Wassersug R (2006) Effects of pelvic asymmetry and low back pain on trunk kinematics during sitting: a comparison with standing. Spine 31:E135-143

2. Baltaci G, Un N, Tunay V, Besler A, Gerçeker S (2003) Comparisaon of three different sit and reach tests for measurement of hamstring flexibility in female university students. Br J Sports Med 37:59-61

3. Bennett BC, Abel MF, Granata KP (2004) Seated postural control in adolescents with idiopathic scoliosis. Spine 29:E449-E454

4. Burwell RG, Cole AA, Cook TA, Grivas TB, Kiel AW, Moulton A, Thirlwall AS, Upadhyay SS, Webb JK, Wemyss-Holden SA, Whitwell DJ, Wojcik AS, Wythers DJ (1992) Pathogenesis of idiopathic scoliosis: the Nottingham concept. Acta Orthop Belg 58:pp 33-58

5. Cheung J, Halbertsma JPK, Veldhuisen AG, Sluiter WJ, Maurits NM, Cool JC, van Horn JR (2004) The relation between electromyography and growth velocity of the spine in the evaluation of curve progression in idiopathic scoliosis. Spine 29:1011-1016

6. Cornbleet SL, Woolsey NB (1996) Assessment of hamstring muscle length in school-aged children using the sit-and-reach test and the inclinometer measure of hip joint angle. Phys Ther 76:850-855

7. Crocker L, Algina J (1986) Introduction to classical and modern test theory. Wadsworth Group, Thomson Learning, Belmont, CA.

8. De Mauroy JC (1996) La scoliose - Traitement orthopédique conservateur. Sauramps Médical, Montpellier.

9. Diméglio A (1996) La scoliose idiopathique. Massion, Paris.

10. Dubousset J (1997) Cotrel-Dubousset instrumentation for paralytic neuromuscular spinal deformities with emphasis on pelvic obliquity. In: Bridwell KL, DeWald RE, The textbook of Spinal Surgery, 2nd ed, Lippencott-Raven, Philadelphia. pp. 933- 947.

11. Fauvy L (1991) L'altération structurale asymétrique du socle ilio-lombaire. in La Scoliose Vingt années de recherche et d'expérimentation GKTS Sauramps Medical, Montpellier:53-60

12. Fortin C, Feldman DE, Cheriet F, Gravel D, Gauthier F, H. L (2008) Développement et validation d'un outil clinique pour l'analyse quantitative de la posture : Résultats préliminaires, Actes de colloque REPAR

13. Fortin C, Feldman DE, Cheriet F, Labelle H (2009) Validity of a quantitative clinical measurement tool of trunk posture in idiopathic scoliosis Spine in press

14. Giakas G, Baltzopoulos V, Dangerfield PH, Dorgan JC, Dalmira S (1996) Comparison of gait patterns between healthy and scoliotic patients using time and frequency domain analysis of ground reaction forces. Spine 21:2235-2242

15. Gram MC, Hasan Z (1999) The spinal curve in standing and sitting postures in children with idiopathic scoliosis. Spine 24:169-177

16. Guillaumat M., Lebard J.P., Khouri N., Tassin J.L (1991) Scoliose idiopathique en période de croissance. Éditions techniques- Encycl Méd Chir (Paris-France), Appareil locomoteur 15874 A10:18p

17. Haderspeck K, Schultz A (1981) Progression of idiopathic scoliosis: an analysis of muscle actions and body weight influences. Spine 6:447-455

18. Hamaoui A, Le Bozec S, Poupard L, Bouisset S (2007) Does postural chain muscular stiffness reduce postural steadiness in a sitting posture? Gait Posture 25:199-204

19. Janda V (1983) On the concept of postural muscles and posture in man. Aust J of Physiother 29:83-85

20. Kantor E, Poupard L, Le Bozec S, Bouisset S (2001) Does body stability depend on postural chain mobility or stability area. Neurosci Lett 308:128-132

21. Kendall Peterson F, McCreary Kendall E, Provance Geise P, McIntyre Rodgers, Romani WA, (2005) Muscles: Testing and Function, with posture and pain. Lippincott Williams & Wilkins, Baltimore, MD

22. Kuo Y-L, Tully EA, Galea MP (2009) Sagittal spinal posture after pilates-based exercice in healthy older adults. Spine 34:1046-1051

23. Lafond D, Descarreaux M, Normand MC, DE. H (2007) Postural development in school children : a cross-sectional study. .*Chiropr Osteopat* 15:1

24. Larson EL, Aaro S, Ahlinder P, Öberg B (1998) Preoperative evaluation of activity and function in patients with paralytic scoliosis. Eur Spine J 7:294-301

25. Li Y, McClure PW and Pratt N (1996). The effect of hamstring muscle stretching on standing posture and on lumbar and hip motions during forward bending.Phys Ther 76(8): 836-845.

26. Link CS, Nicholson GQ, Shaddeau SA, Birch R and Gossman MR (1993). Lumbar curvature in standing and sitting in two types of chairs: Relationship of hamstring and hip flexor muscle length. Phys Ther 70(10): 611-618.

27. McEvoy MP, Grimmer K (2005) Reliability of upright posture measurements in primary school children. BMC Musculoskel Disord 6:35

28. Miramand Y (1991) Principe et technique de rééducation tridimensionnelle de la scoliose idiopathique. La Scoliose Vingt années de recherche et d'expérimentation GKTS Sauramps Medical, Montpellier:69-85

29. Mollon G, Rodot JC (1986) Scolioses structurales mineures et kinésithérapie. Étude statistique comparative des résultats. Kinésithérapie Scientifique 244:47-56

30. Moreno MA, Catai AM, Teodori RM, Borges BLA, Cesar MC, da Silva E (2007) Effect of a muscle stretching program using the Global Postural Re-education method on respiratory muscle strength and thoracoabdominal mobility of sedentary young males. J Bras Pneumol 33:679-686

31. Nault M-L, Allard P, Hinse S, Leblanc R, Caron O, Labelle H, Sadeghi H (2002) Relations between standing stability and body posture parameters in adolescent idiopathic scoliosis. Spine 27:1911-1917

32. Normand MC, Descarreaux M, Harrison DD, Harrison DE, Perron DL, Ferrantelli JR, Janik TJ (2007) Three dimensional evaluation of posture in standing with the PosturePrint: an intra- and inter-examiner reliability study. Chiropr Osteopat 15:15

33. O'Sullivan P, Grahamslaw KM, Kendell M, Lapenskie SC, Möller NE, Richards KV (2002) The effect of different standing and sitting postures on trunk muscle activity in a pain-free population. Spine 27:1238-1244

34. Pilon F, Gravel D, Nadeau S, Arsenault B, Tremblay L (2004) Influence de la lordose thoraco-lombaire et d'un étirement statique sur la raideur articulaire de la cheville. Physio-Québec 29:16-17

35. Reuber M, Schultz A, McNeil T, Spencer D (1983) Trunk muscle myoelectric activities in idiopathic scoliosis. Spine 8:447-456

36. Rodriguez PL, Santonja FM, Lopez-Minarro PA, Sainz de Baranda P, Juste JL (2008) Effect of physical education training programme on seat-and-reach score in schoolchildren. Sciences & Sports 23:170-175

37. Roebroeck ME, Hariaar J, Lankhorst GJ. The application of generalizability theory to reliability assessment: an illustration using isometric force measurements. Phys Ther 1993;73(6, june):386-95.

38. Sahrmann SA (2001) Diagnosis and treatment of movement impairment syndromes. Mosby Inc, St.Louis, MO

39. Smith R, Emans JB (1992) Sitting balance in spinal deformity. Spine 17:1103-1109

40. Souchard PE (1981) Le champ clos. Maloine SA, Paris.

41. Souchard PE, Ollier M (2002) Les scolioses. Masson, Paris.

42. Toppenberg RM and Bullock MI (1986). The interrelation of spinal curves, pelvic tilt and muscle length in the adolescent female. Aust J Physiother 32(1): 6-12.

43. Veldhuizen AG, Wever DJ, Webb PJ (2000) The aetiology of idiopathic scoliosis: biomechanical and neuromuscular factors. Eur Spine J 9:178-184

44. Watson AWS, Mac Donncha C (2000) A reliable technique for the assessment of posture: assessment criteria for aspects of posture. J Sports Med Phys Fitness 40:260-270

45. Winter RB, Pinto WC (1986) Pelvic obliquity. Its causes and its treatment. Spine 11:225-234

46. Zabjek KF, Leroux MA, Coillard C, Rivard CH, Prince F (2005) Evaluation of segmental postural characteristics during quiet standing in control and idiopathic scoliosis patients. Clin Biomech 20:483-490

Figure legends

Figure 1

Graphical interface with a reduced set of markers of the quantitative posture assessment tool at the left and two numerical photographs of a participant in standing and sitting position at the right. The green circles can be individually displaced by the operator for the calculation of 2D posture indices. The six figures represent the scapula asymmetry (6), the scoliosis angle (10), the right and left waist angles (7, 8), the trunk list distance (9) and the pelvic frontal tilt (11).

Figure 2

Graphs of two indices: mean (SD) in standing and sitting positions for all participants, for the thoracic scoliosis group and for the thoracolumbar or lumbar scoliosis group. A) trunk list and B) pelvic frontal tilt.

APPENDIX

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. Head protraction	The angle formed by a line drawn between the tragus of the ear and C7 and a horizontal line through C7.
	4. Cervical lordosis	The angle formed by lines drawn through C2 and C4, and through C4 and C7.
Shoulder and scapula	5. 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.
	6. Scapula Asymmetry	The angle formed by a line drawn from the left and right inferior angle of scapula and the horizontal.
Trunk	7. Waist Angle R 8. 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.
	9. Trunk List	Distance between a line from C7 to S1.
	10. Scoliosis angle	The angle formed by lines drawn through the upper end-vertebra of the curve to the apex of the thoracic, thoracolumbar or lumbar scoliosis and the apex through the lower end-vertebra of the curve.
Pelvis	11. Pelvic Frontal tilt (back)	The angle formed by the horizontal and by the line joining the two PSIS.
	12. Pelvic Sagittal tilt R 13. Pelvic sagittal tilt L	The angle formed by the horizontal and by the line joining the PSIS and ASIS.

Table 1. Differences in posture indices in the standing and sitting positions.

Posture indices	**Standing** Mean (SD) [Range]	**Sitting** Mean (SD) [Range]	**Difference** Mean (SD) [CI 95%]	**P-value (paired t-test)**
Frontal eyes obliquity (º)	2.3 (1.8) [0.1 , 8.2]	2.0 (2.4) [-4.6 , 7.9]	0.3 (1.7) [-0.2 , 0.7]	0.27
Head Lateral Bending (º)	2.2 (1.7) [0.03 , 7.2]	2.0 (2.5) [-5.7, 6.6]	0.3 (1.8) [-0.28 , 0.8]	0.36
Head protraction (º)	127.8 (4.2) [119.5 ,139.0]	129.5 (5.1) [121.7 ,140.7]	-1.7 (3.3) [-3.0 , -0.3]	0.02*
Cervical lordosis (º)	162.8 (6.4) [155.3 , 184.3]	161.8 (7.1) [146.7 , 174.0]	1.2 (6.6) [-1.2 , 3.7]	0.31
Shoulder elevation (º)	3.5 (2.2) [-8.8 , -0.3]	2.5 (2.0) [-7.4 , 1.1]	1.1 (1.8) [-1.6 , -0.6]	0.000*
Scapula asymmetry (º)	7.2 (5.4) [-20.0 , -0.2]	6.0 (5) [-17.4 , 5.5]	1.2 (2.7) [-2.0 , -0.4]	0.003*
Trunk list (mm)	16.7 (12.9) [-62.0 , -1.1]	12.9 (13.7) [-40.0 , 17.0]	3.8 (12.3) [-7.3 , -0.3]	0.03*
Left Waist angle (º)	154.3 (10.2) [132.9 ,177.0]	156.8 (8.9) [138.8 , 174.7]	-2.6 (5.8) [-4.2 , -0.9]	0.003*
Right Waist angle (º)	155.1 (9.0) [131.5 , 173.1]	159.1 (8.6) [137.3 , 173.8]	-3.9 (6.6) [-5.8 , -2.1]	0.000*
Scoliosis angle (º)	163.6 (9.1) [187.4 , 144.7]	164.9 (9.0) [180.0 , 143.1]	-1.2 (4.2) [0.0 , 2.5]	0.046*
Pelvic frontal tilt (back) (º)	2.9 (2.5) [-10.6 , -0.1]	1.9 (2.9) [-11.7 , 3.1]	1.0 (2.8) [-1.8 , -0.2]	0.01*
Pelvic sagittal tilt (left) (º)	11.1 (4.8) [-1.0 , 20.3]	-27.2 (7.2) [-45.4 , -11.8]	38.2 (6.4) [36.1 , 40.3]	0.000*
Pelvic sagittal tilt (right) (º)	10.9 (5.5) [1.3 , 24.2]	-29.2 (7.8) [-46.0 , -11.6]	40.1 (6.9) [37.8 , 42.4]	0.000*

Legend: *: statistically significant $p<0.05$.

Positive sign in differences indicate a larger mean in the standing position.

Negative sign in differences indicate a lower mean in the standing position.

Table 2. Differences (Diff) in posture indices according to type of scoliosis (thoracic scoliosis vs thoracolumbar and lumbar scoliosis) in standing (Stand) and sitting (Sit) positions.

Posture Indices	**Thoracic scoliosis** Mean (SD)				**Thoracolumbar or lumbar scoliosis** Mean (SD)			
	Stand	Sit	Diff	p	Stand	Sit	Diff	p
Frontal eyes obliquity (º)	2.0 (1.5)	1.7 (2.2)	0.3 (1.8)	0.40	2.5 (1.8)	2.1 (2.5)	0.3 (1.7)	0.38
Head Lateral Bending (º)	1.9 (1.2)	1.5 (2.2)	0.4 (1.8)	0.23	2.6 (1.9)	2.5 (2.6)	0.1 (1.8)	0.87
Head protraction (º)†	128.5 (4.3)	131.1 (5.3)	-2.5 (3.4)	0.01*	126.6 (3.9)	126.7 (3.5)	-0.1 (2.5)	0.87
Shoulder elevation (º)	3.4 (2.0)	2.3 (2.4)	0.9 (1.7)	0.008*	3.9 (2.4)	2.4 (1.7)	1.5 (2.0)	0.004*
Scapula asymmetry (º)	8.0 (5.7)	7.0 (5.5)	1.0 (3.1)	0.11	6.7 (5.2)	4.9 (4.4)	1.8 (2.1)	0.001*
Trunk list (mm)	12.5 (8.3)	11.1(13.9)	1.4 (12.6)	0.58	22.2 (16.3)	14.7 (14.2)	7 .5 (12.1)	0.01*
Left Waist angle (º)	152.1 (9.3)	154.5 (8.7)	-2.4 (5.7)	0.04*	158.0 (11.8)	161.3 (7.8)	-3.3 (6.1)	0.03*
Right Waist angle (º)	156.6 (6.9)	160.6 (7.1)	-3.9 (5.5)	0.001*	152.4 (11.4)	157.1 (10.4)	-4.6 (7.6)	0.01*
Scoliosis angle (º)	157.9 (6.5)	159.2 (6.6)	-1.3 (4.4)	0.06	170.7 (6.5)	171.9 (6.3)	-1.1 (5.0)	0.31
Pelvic frontal tilt (back) (º)	2.0 (2.1)	1.9 (3.1)	0.1 (2.5)	0.88	3.9 (3.1)	1.9 (3.0)	2.0 (2.9)	0.006*
Pelvic sagittal tilt (L) (º)	12.6 (4.0)	-24.9 (7.8)	37.5 (7.2)	0.000*	10.0 (4.7)	-30.0 (6.0)	40.0 (4.9)	0.000*
Pelvic sagittal tilt (R) (º)	13.8 (5.1)	-26.3 (9.0)	40.1 (7.6)	0.000*	8.0 (4.1)	-32.9 (8.0)	40.9 (6.0)	0.000*

Legend: *: statistically significant $p<0.05$.

†: Number of subjects was only 16 for thoracic scoliosis and 9 for thoracolumbar or lumbar scoliosis.

Positive sign in differences indicate a larger mean in the standing position.

Negative sign in differences indicate a lower mean in the standing position.

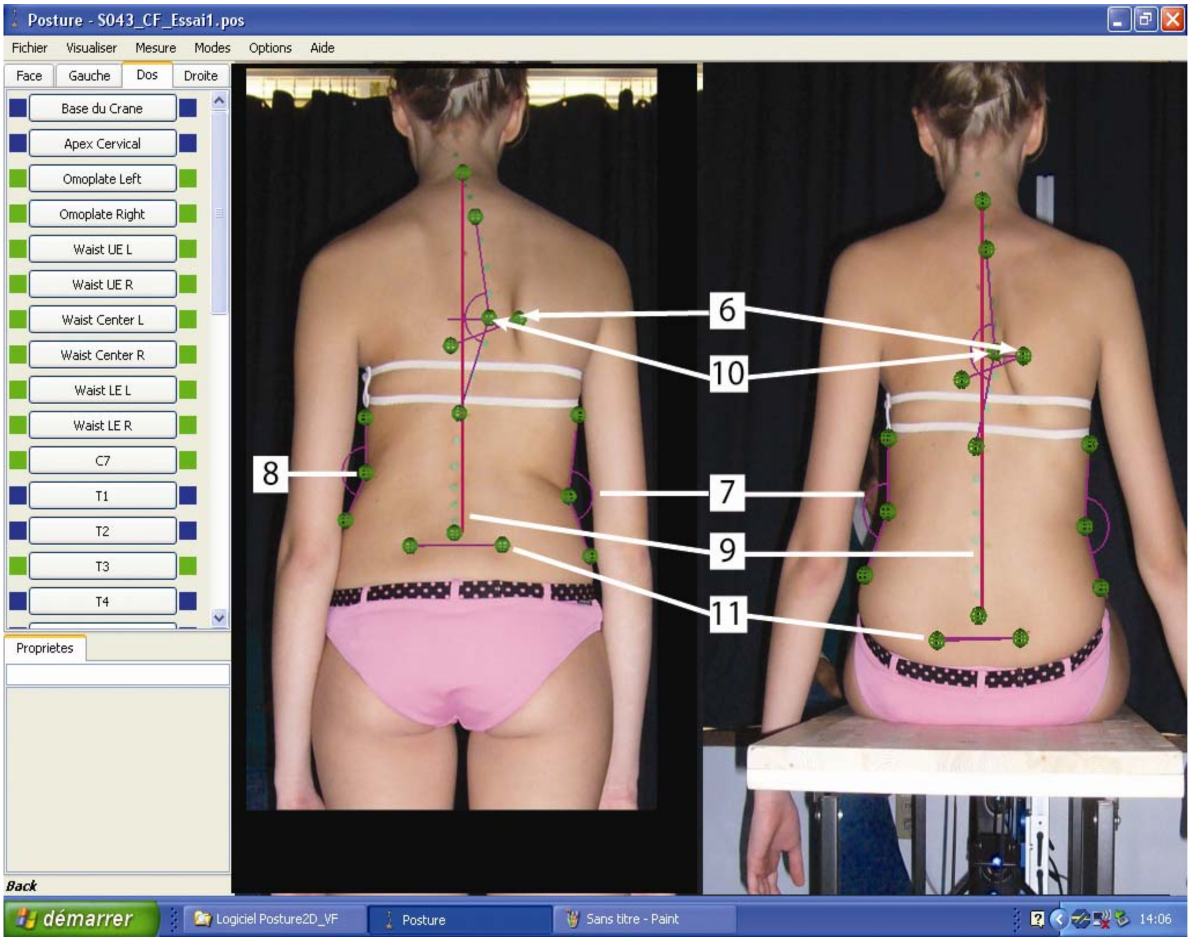
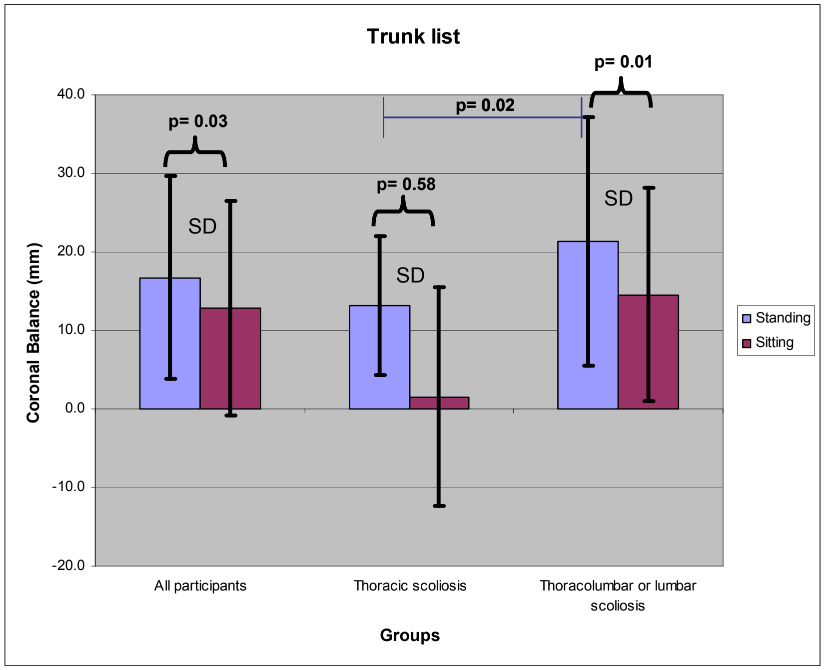
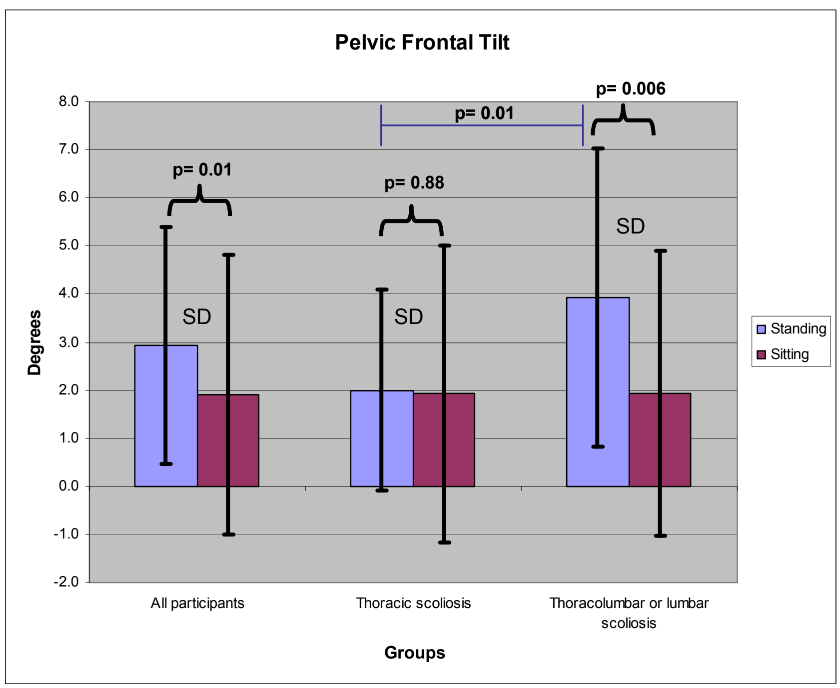

Posture - S043_CF_Essai1.pos
Fichier
Visualiser
Mesure
Modes
Options
Aide
Face
Gauche
Dos
Droite
Base du Crane
Apex Cervical
Omoplate Left
Omoplate Right
Waist UE L
Waist UE R
Waist Center L
Waist Center R
Waist LE L
Waist LE R
C7
T1
T2
T3
T4
Proprietes
Back
6
10
8
7
9
11
démarrer
Logiciel Posture2D_VF
Posture
Sans titre - Paint
14:06

Figure 1


Trunk list
p= 0.01
p= 0.02
p= 0.03
p= 0.58
SD
SD
SD
40.0
30.0
20.0
10.0
0.0
-10.0
-20.0
Coronal Balance (mm)
Standing
Sitting
All participants
Thoracic scoliosis
Thoracolumbar or lumbar scoliosis
Groups

A)


Pelvic Frontal Tilt
p= 0.006
p= 0.01
p= 0.01
p= 0.88
SD
SD
SD
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
Degrees
Standing
Sitting
All participants
Thoracic scoliosis
Thoracolumbar or lumbar scoliosis
Groups

B)

Figure 2