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Research article

Clinical Spino-Pelvic Parameters in Skiers and Non-Athletes

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Abstract

Background: Athletes that perform sports requiring repetitive sagittal spinal motion have been shown to develop increased spinal curvatures suggested as a result of postural adaptations from exercise loading. Alpine and Mogul skiing both requires variable levels of spinal and pelvic loading, placing athletes at risk of developing spinal malalignment and back pain. Therefore the purpose of this study is to compare the clinical spino-pelvic alignment between elite young skiers and age-matched non-athletes.

Methods: Sample group (*n*=102) consisted of elite skiers (Alpine and Mogul, *n*=75) mean age 18.3 (SD 1.1) and non-athletes (*n*=27) mean age 16.4 (SD 0.6). Examination with clinical methods using the Debrunner Kyphometer and Palpation meter were used to measure the spino-pelvic parameters in standing and sitting positions.

Results: Skiers mean age 18.3 (SD 1.1) and controls 16.4 (SD 0.6, p=0.001). Significant differences were shown for standing lumbar lordosis of the skiers -27.2° (SD 6.8) compared with controls -30.4° (SD 7.3, p=0.04), sitting lumbar lordosis of the skiers -2.5° (SD 9.5) compared with controls -7.4° (SD 9.9, p=0.027) and standing lumbar flexion of the skiers; 61.5° (SD 9.5) compared with controls; 67.6° (SD 7.4, p=0.004). Significant differences were shown in sitting pelvic neutral of the skier's -3.6° (SD 3.1) compared with controls; -1.8° (SD 2.8, p=0.007), and pelvic anteversion of the skiers 7.1° (SD 4.0) compared with controls; 11.8° (SD 3.0, p=0.001).

Conclusion: Clinical methods show elite skiers to have significantly less standing and sitting lumbar and pelvic values for spino-pelvic sagittal alignment compared to an age-matched non-sporting population. This is suggested to be due to adaptation from heavy loads on the spine, pelvis and hips from skiing and training activities.

Introduction

The human spine has several physiological curvatures that occur in the sagittal plane, a cranial and caudal lordotic curve that is separated by the kyphotic curve [1]. It has been suggested that the spinal curvatures act to assist with force distribution throughout the spinal column [1]. Variables such as growth, balance, posture and sporting activities are all associated with the development and changes within these curves [2]. Moreover, Todd et al. [3] have shown that changes to the sagittal alignment of spinal curvatures may influence pelvic parameters. An upright stable postural alignment is maintained by the pelvic parameters helping to balance the coupling of lumbar lordosis and hip joint extension [1]. Moreover, it has been suggested that for humans to maintain an upright balance, spino-pelvic rotation around the femoral heads must occur [1]. In squatting, the spino-pelvic values have been shown to be lower in the presence of hip joint hypomobility [4]. Therefore, it would appear reasonable to compare spino-pelvic values in both standing and sitting positions.

Previous studies have investigated spino-pelvic sagittal alignment and mobility with clinical methods [2, 5-11]. A review of clinical measuring devices by Barrett et al. [12] suggested the Debrunner Kyphometer to have a strong level of reliability for measuring spinal curvatures, in spite of criticisms from Agnvall et al. [6] such as inconsistent findings, conflicting levels of evidence and poor levels of validity. However, within a clinical environment clinicians must be capable of choosing a clinical method that suits their best judgment for performing examination procedures. Moreover, expense, duration, and convenience of using non-radiological methods are all important factors to consider; and therefore, exploring clinical methods may be a suitable alternative option [9]. Athletes that perform sports requiring repetitive sagittal spinal motion have been shown to develop increased spinal curvatures as a result of postural adaptations from exercise loading intensities [2, 5, 11]. Alpine and Mogul skiers both develop different skiing patterns. Mogul skiing is freestyle in nature, requires a more upright spinal posture, as Alpine skiing requires a greater level of spinal and hip joint flexion. Previous studies have shown with clinical methods an increased thoracic kyphosis to develop in adolescent elite cross-country skiers after five years of intensive training [5], whilst other studies have shown spinal asymmetries in adolescent female volleyball players [13]. Moreover, canoeists [14] and elite cyclists [15-17] have both been shown to develop an increased thoracic kyphosis in standing, which reduced when, re-measured in sitting. However, other sports have failed to show any change in spinal sagittal alignment such as tennis [18] swimmers, bodybuilders, sailors, soccer and rugby [2]. Moreover, Todd et al. [3] have shown with radiological methods that an increase in Type I spinal curvatures according to Roussouly et al. [1] to be more prevalent in young elite skiers compared to non-athletes of a similar age. It could be suggested that the development of sagittal spino-pelvic malalignment may be related to postures associated with specific sports and therefore, the influence of Alpine and Mogul skiing on spino-pelvic alignment and posture requires further investigation.

The purpose of the present study was to evaluate clinically the spino-pelvic alignment and mobility in standing and sitting positions between young elite skiers (Alpine and Mogul) and that of a non-athletic population of a similar age. The hypothesis of the present study is to show that the spino-pelvic sagittal alignment and mobility of young elite skiers is different to that of a non-athletic population. To our knowledge this is the first study that will carry out such an investigation.

Material and Methods

Study subjects

The sample group (*n*=102) consisted of young athletic elite Alpine and Mogul skiers (*n*= 75) and a non-athletic population (*n*=27). Inclusion criteria for the skiers group was training >11 hours per week and competing at elite level, High School grade 1-4, between 16-20 years of age and recruited from the Åre High School Ski Academy, Sweden. Inclusion criteria for the control group was first year High School pupils from a class at High Schools in Åre and Östersund, Sweden, that have not previously or at present participate in any organised sporting activities for more than 2 hours per week. All participants were invited to participate in this prospective study after a short presentation about the project by two of the authors. The testing was carried out at the elite Ski School in Åre and the hospital in Östersund, Sweden. Participants (skiers and controls) were excluded if they had a history of previous surgery to the lumbar spine, pelvis or hip joint or a history of systemic pathology including inflammatory arthritis or pelvic inflammatory disorders and pregnancy. Data collection encompassed clinical tests in standing and sitting positions for spinal alignment, and mobility, pelvic neutral, anteversion and retroversion. These were calculated and reported in degrees. A blinded examiner marked anatomical landmarks and placed measuring instruments, therefore, maintaining consistency and avoiding inter-operator reliability. An assistant recorded all measurements, with the aim of limiting investigation bias. The demographic characteristics of the full sample are presented in Table 1. The present study was approved by the Regional Ethical Review Board in Gothenburg at The Sahlgrenska Academy, Gothenburg University, Gothenburg, Sweden (ID number: 692-13).

Methods

Testing procedure

A non-invasive measurement of spinal sagittal mobility was carried out in the relaxed standing and sitting positions (Figure 1&4) using the modified Debrunner's Kyphometer (Protek AG, Bern, Switzerland). The Debrunner Kyphometer is essentially a protractor with two arms that are placed on specific bony landmarks [18]. The Debrunner Kyphometer is capable of providing measurement in a 1 degree-scale. The original Kyphometer design measured kyphosis angles up to 52° (Debrunner, 1972). Each arm is connected together by a block, large enough to span two spinous processes. Modifications increased the range to 70° and made it suitable for measuring lumbar flexion and extension [10]. Previous studies have shown validity measurements for comparing the Debrunner Kyphometer with a radiological standard, for thoracic kyphosis (ICC 0.67, 95% CI: 0.26 to 0.83, $p<0.001$) and lumbar lordosis (ICC 0.33, 95% CI: 0.13 to 0.50, $p=0.001$) respectively [6].

Standing spinal mobility measurements

Participants were instructed to look straight-forward and stand relaxed, not "at attention" barefooted with their feet together and arms hanging by their side [10]. The same examiner located and marked the bony landmark points by palpation. These were re-palpated and re-marked between each test due to skin drag from pelvic movement. Sagittal thoracic and lumbar spinal motion was measured separately. For the thoracic spine, marking of the anatomical landmarks was by palpation between the T2-3 spinous processes and between T11-12 spinous processes. The upper measuring point was located by palpating below the C7 vertebrae and lower measuring point by tracing around the lower ribs to the T11-12 segments.

Figure 1. Neutral zero position for measuring thoracic kyphosis.

In the lumbar spine anatomical landmarks were palpated and marked between T11-12 spinous processes and the lower point between the posterior superior iliac spine (PSIS) on the S1-2 segments. These were classified as the neutral position and measurements were recorded for thoracic kyphosis (TK) and lumbar lordosis (LL).

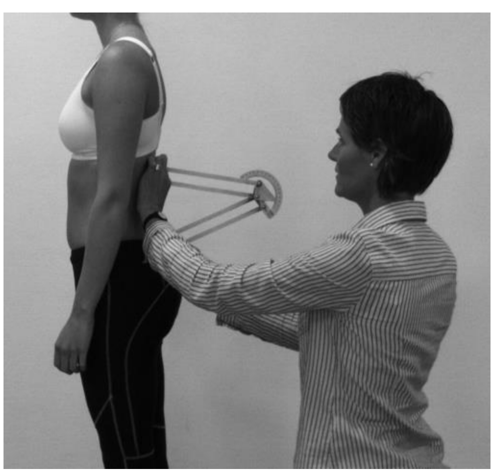

Figure 2. Neutral zero position for measuring lumbar lordosis.

Thoracic extension (TE) (Figure 2), participants were instructed to raise their chest without drawing the shoulders, and thereby reducing the paraspinal muscle activity that would interfere with the Debrunner Kyphometer and to arch their thoracic spine independently of their lumbar spine to minimize shoulder girdle retraction to their natural end-point without force. TE mobility was measured and recorded. Thoracic flexion (TF) (Figure 2), participants were instructed to drop their chin to their chest, roll forward to arch their thoracic spine “like a cat” independently of their lumbar spine to their natural end-point without force. TF mobility was measured and recorded. Lumbar extension (LE) (Figure 3), participants were instructed to arch their lumbar spine to their natural end-point without force and avoiding hip sway.

Figure 3. Measurement of active thoracic extension.

LE mobility was measured and recorded. Lumbar flexion (LF) (Figure 3), participants were instructed to “try to touch the floor with their hands without bending their knees” by rolling their lumbar spine forwards to their natural end-point without force. TF and LF measurements were determined by combining flexion and respective neutral position measurements. Likewise, TE and LE measurements were determined by subtracting the degree of extension from their respective neural position measurements. The combined total sagittal measurements for both thoracic and lumbar regions were also recorded.

Sitting spinal mobility measurements

Sitting on a specifically designed chair, (Figure 4) the participant was placed in a neutral position and instructed to sit tall with a straight, vertical line from their shoulder to hip. Location of bony landmarks, placing the clinical tool and measurements with the Debrunner Kyphometer for sitting neutral LL was similar to the standing protocol. Sitting lumbar extension (sLE), (Figure 5) participants were instructed to arch their lumbar spine and tilt their pelvis forwards as far as they could, increasing maximum sitting pelvic anteversion. sLE mobility

Figure 4. Measurement of active thoracic flexion.

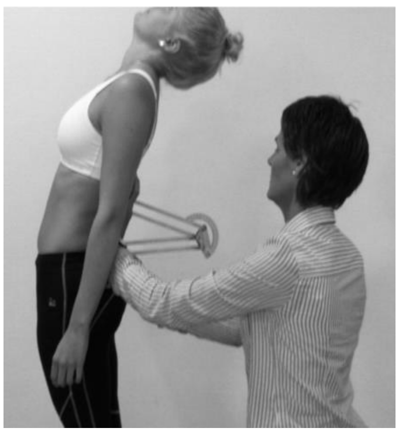

Figure 5. Measurement of active lumbar extension.

was measured, recorded and calculated similar to the standing protocol. Sitting lumbar flexion (sLF), (Figure 6) participants were instructed to slump their lumbar spine and tilt their pelvis backwards as far as they could, increasing maximum pelvic retroversion. sLF mobility was measured, recorded and calculated similar to the standing protocol. The sitting sagittal measurements for the lumbar regions were recorded.

Figure 6. Measurement of active lumbar flexion.

Sitting pelvic motion measurements

Measurement of pelvic motion (Figure 7) was carried out by Palpation meter (PALM, Performance Attainment, Associates, St Paul Minnesota, USA), the participant adopted a neutral sitting position in a specifically designed chair. The same examiner palpated and marked the anterior superior iliac spine (ASIS) and posterior iliac spine (PSIS). The Palpation meter has been shown to be reliable (ICC 0.97 and 0.98) and valid (ICC 0.79 and 0.78) instrument for measuring pelvic crest height differences compared with radiographic measurements [20].

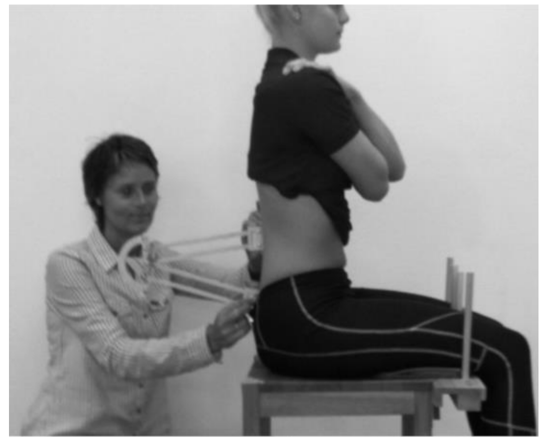

Figure 7. Seated Debrunner Kyphometer neutral position.

The ASIS was palpated anteriorly to the most superior prominent protrusion of the iliac crest. The PSIS was palpated posteriorly to the most prominent protrusion of the iliac crest. Caliper tips were placed on the ASIS and PSIS and firmly compressed as suggested by Gajdosik et al. [8] and the neutral angle of pelvic motion was measured and recorded in degrees. Pelvic anteversion was measured with the lumbar spine in maximal extension, participants were instructed to arch their lumbar spine and tilt their pelvis forward maximally. If pain was experienced in this position, it was recorded. Pelvic retroversion was measured with the lumbar spine in maximal flexion, participants were instructed to slump their lumbar spine and tilt their pelvis backwards maximally. If pain was experienced in this position, it was recorded. Pelvic motion was measured on both sides of the pelvis and the degree of pelvic motion was calculated and recorded in neutral, anteverted and retroverted sitting positions.

Statistical analysis

Data was analysed using IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY: IBM Corp. The description of data was expressed in terms of the mean and standard deviation (SD), median and range including frequencies and percentages were appropriate. An independent t-test was performed to compare variables, (skiers and controls). The statistical significance for all tests was set as $p<0.05$.

Figure 8. Seated extension with Debrunner Kyphometer.

Figure 9. Seated flexion Debrunner Kyphometer.

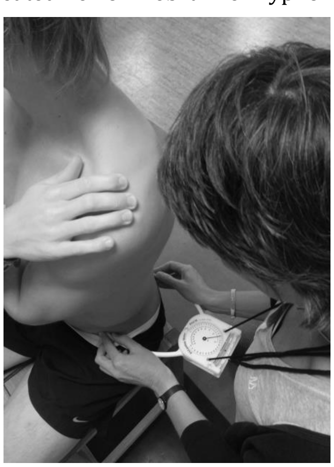

Figure 10. Seated pelvic inclinometer pelvic motion testing.

Results

Table 1 summarises the demographic characteristics of the whole population. The mean age enrolled population for both skiers and controls was 17.7 (±1.4) years (Skiers mean age 18.3 SD 1.1 and controls 16.4 SD 0.6, p=0.001). No participants had to withdraw from the study due to the exclusion criteria; however, failure to attend investigations and skiers travelling abroad, data from 98 participants was only available for the final analysis.

	All subjects (*n*=102)	Skiers (*n*=75)	Controls (*n*=27)	*p*-value
Age (years)	17.7 (1.4)	18.3 (1.1)	16.4 (0.6)	<0.001
Female sex, n (%)	53 (52%)	35 (47%)	18 (67%)	0.074
Height (cm)	173 (8.3)	174 (8.2)	172 (8.6)	0.19
Weight (kg)	69 (12.2)	70 (9.1)	67 (17.9)	0.39
Body mass index (kg/m^2)	22.9 (3.3)	22.9 (2.2)	22.7 (5.3)	0.81

Values are mean and (standard deviation; SD).

Table 1. Baseline characteristics for all subjects and stratified by group

The mean values for comparison of both groups using the Debrunner Kyphometer in standing are shown in Table 2. A significant difference was noted for the comparison of the skiers standing LL -27.2° (SD 6.8°) compared to the controls -30.4° (SD 7.3°, p=0.04).

Parameter	Skiers	Controls	P value
Thoracic kyphosis°	30.5 (6.5)	32.9 (6.4)	0.109
Lumbar lordosis°	-27.2 (6.8)	-30.4 (7.3)	0.040

Values are mean, median and (standard deviation; SD) unless specified otherwise

Table 2. Standing spinal sagittal alignment stratified by group

However, no significant differences were shown for the measurement of standing TK of the skier's 30.5° (SD 6.5°) compared with the controls 32.9° (SD 6.4°, p=0.109).

Table 3 shows the mean clinical values for standing spinal sagittal mobility between groups. A significant difference was shown for the skiers LF 61.5° (SD 9.5°) compared with the controls 67.6° (SD 7.4°, p=0.004), however, no significant differences were shown for comparison of skiers LE 28.5° (SD 10.6°) compared with the controls 27.2° (SD 8.8°, p=0.57), and for the skiers TF 24.9° (SD 6.5°) compared with the controls 24.6°(SD 7.9°, p=0.82), which, was similar for the skiers TE 22.2° (SD 7.7°) compared with the controls 21.2° (SD 8.4°, p=0.56).

Parameter	Skiers	Controls	*p*-value
Combined lumbar standing sagittal mobility°	89.9 (13.8)	94.7 (12.6)	0.12
Combined thoracic standing sagittal mobility°	47.1 (9.2)	45.8 (8.9)	0.49

Values are mean and (standard deviation; SD).

Table 3. Standing spinal sagittal mobility stratified by group

Table 4 shows the clinical values for combined sagittal lumbar mobility in standing stratified by group. A difference was shown for the combined lumbar mobility of the skiers 89.9° (SD 13.8°) compared with the controls 94.7° (SD 12.6°, p=0.12), whilst similar values were reported for the combined thoracic mobility of the skier's 47.1° (SD 9.2°) compared with the controls 45.8° (SD 8.9°, p=0.49).

Parameter	Skiers	Controls	*p*-value
Combined lumbar standing sagittal mobility°	89.9 (13.8)	94.7 (12.6)	0.12
Combined thoracic standing sagittal mobility°	47.1 (9.2)	45.8 (8.9)	0.49

Values are mean and (standard deviation; SD).

Table 4. Combined standing sagittal spinal mobility stratified by group

Table 5 shows the clinical values for sitting neutral LL, sitting LF, LE combined sitting lumbar mobility stratified by group. A significant difference was shown for the skiers sitting neutral LL -2.5° (SD 9.5°) compared with the controls -7.4° (SD 9.9°, p=0.027). Similar values were shown for sitting LF of the skiers 24.1° (SD 10.8°) compared with the controls 27.9° (SD 13.4°, p=0.15), as was sitting LE of the skiers 29.2° (SD 10.7°) compared with the controls 27.3° (SD 12°, p=0.47). There were no significant differences shown for the combined sitting lumbar mobility range of the skiers' 53.3°(SD 12.8°) compared with the control group 55.1° (SD 14.9°, p=0.56).

Parameter	Skiers	Controls	*p*-value
Sitting neutral lumbar lordosis°	-2.5 (9.5)	-7.4 (9.9)	0.027
Sitting lumbar flexion°	24.1 (10.8)	27.9 (13.4)	0.15
Sitting lumbar extension°	29.2 (10.7)	27.3 (12.0)	0.47
Combined sitting lumbar mobility°	53.3 (12.8)	55.1 (14.9)	0.56

Values are mean, median and (standard deviation; SD).

Table 5. Sitting neutral lumbar lordosis, lumbar flexion/extension and combined lumbar mobility stratified by group

Values for sitting pelvic neutral, anteversion and retroversion between groups are presented in Table 6. A significant difference was shown for sitting pelvic neutral between groups, with the mean values for the skier's pelvic neutral -3.6° (SD 3.1°) compared with the control group -1.8° (SD 2.8°, p=0.007). A significant difference was also shown in sitting for pelvic anteversion between both groups.

	Skiers	Controls	*p*-value
Pelvic neutral°			
Right	-3.6 (3.1)	-1.8 (2.8)	**0.007**
Left	-3.6 (3.1)	-1.9 (2.8)	**0.012**
Pelvic anteversion°			
Right	7.1 (4.0)	11.8 (3.0)	**<0.001**
Left	7.2 (4.3)	11.8 (3.3)	**<0.001**
Pelvic retroversion°			
Right	-13.6 (4.7)	-12.7 (6.2)	0.42
Left	-14.0 (4.5)	-13.0 (6.2)	0.35

Values are mean, median and (standard deviation; SD).

Table 6. Sitting pelvic neutral, anteversion and retroversion stratified by group

Mean values in sitting for the skiers pelvic anteversion 7.1° (SD

4.0°) compared with the control group 11.8° (SD 3.0°, p=0.001). However, no significant differences were reported between groups in sitting for pelvic retroversion (p=0.42).

Discussion

The most important findings with this study show that significant differences were noted for clinical values of the skiers neutral LL in standing and sitting and for standing LF mobility compared with the controls. A significant difference was also shown for comparison in sitting of pelvic neutral and pelvic anteversion for the skiers compared with the control group. Therefore, the conclusion of the present findings is that alterations in spino-pelvic alignment and mobility may occur more frequently with skiers and these may be a result of many variables such as hip joint growth disturbances, [21], spinal pathologies [22], in elite skiers or from adaptations due to increased spino-pelvic sagittal loading from an early sporting participation [2, 5, 11]. In the present study, there was a significant difference noted for the comparison of LL between both groups in standing and sitting. Mean values for standing LL of the skiers (-27.2°) was shown to be 3.2o less and significantly different compared with the controls (-30.4°). This was similar for the mean values for sitting LL of the skiers (-2.5°), which, were also shown to be 4.9° less, and significantly different compared to the controls (-7.4°). Comparison of standing spinal sagittal mobility between groups showed a significant difference for the mean value of LF for the skiers (61.5°) compared with the controls (67.6°). Therefore the skiers were unable to flex their lumbar spine 6.1° less than the controls. It could be hypothesized that hamstring flexibility [16-17] and hip joint growth disturbances [21] may have decreased LL and LF values for the skiers. Moreover, spinal pathologies [22], early sporting participation and development of hip joint muscle dominance and stiffness from adaptation to exercise loading [2, 5, 11] may have reduced the LL values in standing and sitting and LF mobility in the skiers compared with the control group.

There were no differences noted for the comparison of TK between groups with the mean values being shown for the skiers (30.5°) and controls (32.9°), to be similar to those reported in previous studies [9-10]. These conflict with previous studies that have shown sports such as canoeing, cycling, cross-country skiing, freestyle and Greco-Roman wrestling all to increase the curvature of thoracic kyphosis [5, 11, 14-18]. Similar values were also shown for the LE of the skiers (28.5°) and controls (27.2°) the TF of the skiers (24.9°) and controls (24.6°), and TE of the skiers (22.2°) and controls (21.2°). Moreover, these values appeared similar to those previously reported within an asymptomatic population [10]. There were no differences shown for the combined standing sagittal spinal mobility between groups. In the present study, the skiers were shown to have significantly less values in sitting for the measurement of pelvic neutral compared with the controls. The mean values in sitting for pelvic neutral of the skiers (-3.6°) were shown to be 1.8° less compared with the control group (-1.8°). This was similar for the values in sitting for pelvic anteversion of the skiers (7.1°), which, were shown to be 4.7° less compared to the controls (11.8°). No significant differences were noted for the values in sitting for pelvic retroversion between groups. Therefore, this suggests that in sitting, elite skiers show reduced values for both pelvic neutral and pelvic anteversion compared to non-athletes. Moreover, one reason why the skiers' values for pelvic anteversion were less may be related to them having a lower pelvic neutral value compared to the non-athletes. These differences may be due to the skier's finding it more difficult to sit in pelvic neutral and anteversion, perhaps adapting a more comfortable sitting pelvic retroversion and lumbar kyphosis position. Therefore, the present study hypothesizes that such differences in pelvic values may be related to other factors such as hamstring flexibility [16-17], hip joint growth disturbances [21], pathology in the lumbar spine [22], and muscular development from skiing in forward flexed postures, sustained loading [2, 5, 11] and sports specific adaptations affecting the spino-pelvic parameters [3].

There are limitations to the present study. These include the effectiveness of the measuring device, accuracy of palpation and errors in clinical measurement [23]. Poor levels of agreement regarding validity with plain radiographs have previously been shown as reasons for not using this clinical instrument [6, 12], in spite of the Debrunner Kyphometer showing good reliability [6, 9-10] and strong levels of evidence with comparison of more technical methods such as rastersterography, 3D ultrasound and sterovideography [12]. Verbal instructions, participant positioning and fatigue from repeated measuring [24] have also been reported. In the present study, measurement of sagittal spino-pelvic alignment and mobility was recorded in the "upright standing" and "sitting" positions. These were chosen as they both reflect postures associated with Alpine and Mogul skiing patterns. However, skiing encompasses triplanar motion, with trunk flexion and extension movements occurring around the long axis of the spine [16].

In the present study, a difference in age was shown between the skiers (18.3) and controls (16.4) and moreover, was statistically significant. However, the intentions of the present study were to have aged matched groups. One of the reasons was that the skiers were from grade 1-4 and the controls from the first grade at High School. All participants within the study were shown to have a closed spinal physis on plain radiographs and thereby, limiting the possibility of growth-related spurts [25] between groups. It could be hypothesized that variability between skiing disciplines may have affected results. In the present study, Alpine and Mogul skiers were combined in the same group. However, these disciplines develop different skiing patterns, which increase variable degrees of knee and hip joint flexion to absorb the effect of ground reaction forces [26]. Therefore, it may be possible this could reduce the mechanical loading upon the spine and may have affected values for spino-pelvic alignment and mobility. Previous studies have shown athletes to develop an increase in spinal curvature due to specific load demands and sports-related biomechanics [2, 6, 11, 14-15]. However, sports such as tennis, volleyball and soccer have shown no increase in spinal curvatures [18, 27]. Moreover, these studies hypothesised that triplanar spinal motion occurred more frequently with these sports and therefore, specific spinal curvatures were less likely to develop. This was similar to the present study, were no increase in spinal curvatures was shown between groups for the measurement of TK of the skiers (30.5°) and controls (32.9°). However, in the present study a significant difference was shown for the LL of the skiers (-27.2°) compared with the controls (-30.4°) and it may be possible that such a difference may be related to the specific sports biomechanics of the skiers [2, 5, 11, 15].

Lower limb flexibility may have biased the study outcome, even though some studies have reported no association between hamstring flexibility and spinal posture in standing [28-29]. Hamstring extensibility has been shown to influence spinal and pelvic posture when trunk flexion is performed [16-17]. Moreover, in the present study, hamstring flexibility may have affected both the lumbar and pelvic posture in sitting. Pelvic posture has previously been shown to be affected by hamstring shortening in highly trained canoeists [17]. The hamstring muscles take their origin from the ischial tuberosity, therefore in the present study, skiers may have developed excessive tension in the hamstring muscles from training that may have influenced both standing and sitting lumbar and pelvic values. Other postural variances and biomechanical lower limb asymmetries such as hip joint Femoroacetabular impingement (FAI) have been shown to occur in young athletes [30]. Lamontagne et al. [4] has shown limited sagittal spino-pelvic mobility to occur in the presence of hip joint FAI. This is similar to the present study where the skiers showed reduced values for sitting in sagittal pelvic neutral and pelvic anteversion compared with the control group. Moreover, this was also reflected with the values for standing and sitting LL and for standing LF mobility. However, the present study's inclusion criteria did not consider hip joint FAI within its methodology. Moreover, the methodology of the present study selected only a young healthy population however; this may have limited the ability to distinguish variations in spino-pelvic alignment and mobility between these groups.

The present study was able to show that there are differences with measuring spino-pelvic alignment and mobility with clinical methods in young elite skiers compared to controls. A significant difference was shown for the mean values of the skiers standing and sitting neutral LL, standing LF mobility and for sitting pelvic neutral and pelvic anteversion. Therefore, the present study supports the hypothesis that, spino-pelvic values are different between elite skiers to that of a non-athletic population of a similar age. Moreover, the clinical relevance of the present study may assist researchers and clinicians to use non-radiological clinical methods for interpreting the spino-pelvic values of a young sporting and non-sporting population.

Conclusion

The conclusion of the present study shows that with clinical methods, elite skiers are shown to have significantly less standing and sitting lumbar and pelvic values for spino-pelvic sagittal alignment and mobility compared to a healthy non-sporting population of a similar age. This is suggested to be due to adaptation from heavy loads on the spine, pelvis and hips from skiing and training activities.

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