

Musculoskeletal examination in young athletes and non-athletes: the Finnish Health Promoting Sports Club (FHPSC) study

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ABSTRACT

Objectives To determine the inter-rater repeatability of a musculoskeletal examination and to compare findings between adolescent athletes and non-athletes in Finland.

Methods In this cross-sectional study, a musculoskeletal examination assessing posture, mobility and movement control was carried out by a sports and exercise medicine physician on 399 athletes aged 14–17 years and 177 non-athletes. Within 2 weeks another sports and exercise medicine physician repeated the examination for 41 adolescents to test the inter-rater repeatability.

Results In total, 10 of the 11 tests performed had at least moderate inter-rater reliability ($\kappa \geq 0.4$ or percentage agreement $>80\%$). Athletes more often than non-athletes had one shoulder protruded (8.0% vs 4.0%, OR 2.81, 95% CI 1.16 to 6.81). Forty-six per cent of athletes had good knee control in the two-legged vertical drop jump test compared with 32% of non-athletes (OR 1.99, 95% CI 1.29 to 3.06). Athletes had better core muscle control with 86.3% being able to remain in the correct plank position for 30 s compared with 68.6% of non-athletes (OR 2.70, 95% CI 1.67 to 4.36). In the deep squat test, good lumbar spine control was maintained only by 35.8% of athletes and 38.4% of non-athletes.

Conclusion A basic musculoskeletal examination is sufficiently reliable to be performed by trained physicians as a part of a periodic health evaluation. Shortfalls in mobility, posture and movement control are common in both athletes and non-athletes. These deficits could have been caused by sedentary behaviour, monotonous training, or both.

BACKGROUND

Injury risk assessment through a musculoskeletal examination has been a long-standing goal for sports medicine practitioners. An athlete's periodic health evaluation (PHE) includes a comprehensive assessment of her/his current health status and is typically the entry point for the medical care of a young athlete.¹

Physical performance tests and their ability to determine a risk level for injuries

What are the new findings?

- Posture, mobility and movement control can be tested with adequate repeatability from adolescent athletes and non-athletes in a periodic health evaluation performed by a sports and exercise medicine physician.
- Participation in sports is associated with better shoulder and ankle mobility, knee control in the vertical drop jump test and better core muscle control.
- Fewer than 40% of athletes and non-athletes are able to maintain good lumbar spine control and heels on the floor in the deep squat test with dowel on raised straight arms.

have been in focus but most often they have not been able to predict lower extremity injuries.^{2–3} These types of tests have used quantifiable performance outcomes, and the results could have been affected by compensation movements.

On the other hand, musculoskeletal screening can also focus on movement quality. This involves identification and rating of functional compensations, asymmetries, impairments or efficiency of movement control through transitional (eg, squats, sit-to-stand, lunge) or dynamic movement (eg, hopping, walking, running, landing, cutting) tasks.⁴ Posture control is defined as maintaining, achieving or restoring a state of balance during any posture or activity.⁵ A previous study found that static and dynamic posture control appears to be unrelated in healthy adolescents and is not related to strength. Given that injuries primarily occur during dynamic conditions, assessment should also be carried out under dynamic conditions.⁶

Before proposing to use a series of tests in clinical practice, the reliability of the tests needs to be established. Tester experience



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increases the reliability of the test.⁷ The reliability of the functional movement screen (FMS) has previously been reviewed and found to vary between different substests.⁸ Previous studies have compared injury risk factors between college-aged athletes and the general population,⁹ and reviewed physical examination risk factors for lower extremity injuries in high-school-aged athletes.¹⁰ To our knowledge, posture, mobility and movement control have not previously been compared between adolescent athletes and non-athletes.

The aims of this study were to evaluate the inter-rater reliability of the musculoskeletal examination and to examine the posture, movement control and mobility of adolescent athletes and non-athletes. We believe that a combination of static, transitional and dynamic tests with both quantitative and qualitative measurements and evaluations is the most feasible way to examine the function of the musculoskeletal system of an individual.

METHODS

This multi-institutional and multidisciplinary study was a part of the Finnish Health Promoting Sports Club (FHPSC) study and used a cross-sectional design. The study was conducted by the University of Jyväskylä in conjunction with six national Centres of Excellence in

Sports and Exercise Medicine and the UKK-institute. All youth participating in the study were aged 14–17 years and represented both genders. A clinical health examination was performed, and the health behaviour and health status of youth participating in sports clubs was compared with their non-participating peers¹¹; these groups are referred to as athletes and non-athletes in this article.

Data collection

A total of 240 youth sports clubs from 10 most popular sports disciplines in Finland were targeted to produce a nationally representative sample of the most popular team and individual youth sports. Sports that have their main competition season in the winter were basketball, cross-country skiing, floorball, ice hockey and skating. Summer sports were soccer, gymnastics, orienteering, swimming, and track and field. Of the invited sports clubs, 154 agreed to participate in the study.

The data collection started by surveys from January to May 2013 for winter sports and from August to December 2013 for summer sports. Comparison data for non-athletes were collected via schools (ninth grades) similarly in two stages within the same time frame. Complementary data, including athletes and non-athletes, were compiled

Table 1 Musculoskeletal tests in the Finnish Health Promoting Sports Club study

Test	Scoring
Posture	
Shoulder posture	Protrusion of one or both shoulders by inspection from the side scoliometer reading at acromioclavicular joint level.
Forward bend	Scoliometer reading from the level of sacrum, iliac crest and lower scapula.
Iliac crest height	Presence of asymmetry by palpation and inspection from the front.
Mobility	
Shoulder mobility	Dowel on raised straight arms, second dowel fits between head and arms. Highest score—with ease. Middle score—with mild resistance. Lowest score—compensates with cervical protrusion.
Modified Thomas test ⁴⁶	Presence of marked iliopsoas tightness on one or both sides.
Navicular drop ²⁹	≥10 mm on either or both sides, side difference ≥2 mm.
Beighton and Horan joint mobility index ⁴⁷	Generalised joint laxity ≥4 points.* ²²
Movement control	
30 s plank ⁴⁸	Ability to remain in correct position for 30 s.
Deep squat ⁴⁹	Highest score—lumbar spine remains in neutral zone and heels on the floor, dowel on raised straight arms. Middle score—lumbar spine control not assessed, heels remain on floor, hands behind neck. Lowest score—heels lifted from floor, hands behind neck.
Trendelenburg test ⁵⁰	20 cm stance, positive Trendelenburg sign—pelvis tilts toward raised leg.
One-leg stance ³⁹	20 cm stance, normal performance—lateral movement <13 cm, side difference ≤2 cm.
Vertical drop jump ⁵¹	First and second landing assessed, ⁵² rating: good–reduced–poor control. ⁵³

*Ability to put hands flat on the floor with knees straight, elbow and knee hyper extension >10°, ability to bend thumb onto the front of forearm, ability to bend little finger up at 90° to the back of hand.

in spring 2014. The clinical examination data were mainly collected between August 2013 and April 2014.

Musculoskeletal examinations

The protocol for assessing the inter-rater reliability consisted of two separate visits. A physical examination including the musculoskeletal examination was followed by a second visit in which the musculoskeletal examination was repeated for selected subjects.

To assess the differences between athletes and non-athletes, 576 clinical examinations were performed, out of which 399 were for athletes and 177 for non-athletes (261 boys and 315 girls).¹¹ The participation percentage of those asked to take part in the health examination was 37% for athletes and 34% for non-athletes. The examinations were carried out in the six national Centres of Excellence in Sports and Exercise Medicine located in different regions of Finland (Helsinki, Tampere, Turku, Jyväskylä, Kuopio and Oulu).

Sixty youth (the first 10 athletes from each of the six centres) were invited for the repeated examination. Forty-one re-examinations were completed by another sports and exercise medicine physician for 30 athletes and 11 non-athletes (20 boys and 21 girls). These were completed within 2 weeks from the first visit. In all, there were 12 physicians completing the examinations and re-examinations.

During the first visit, height and weight were recorded. This was followed by a physical examination including a normal clinical investigation and also several previously well-documented static and dynamic posture, movement control and musculoskeletal balance tests (table 1). A scoliometer (OSI-scoliometer Orthopedic Systems) was used to measure height asymmetry at acromioclavicular joint level and angle of trunk rotation.

Outcomes

The main outcomes were the inter-rater reliability and the results of the musculoskeletal examination. The thresholds of acceptable reliability were defined at coefficient values ($\kappa \geq 0.4$) corresponding to moderate reliability as sufficient for observing human movement for screening purposes.⁸ Kappa 0.41–0.60 indicates moderate agreement, 0.61–0.80 substantial agreement and 0.81–1 almost perfect agreement.¹² The interpretation of κ also depends on the sample size.¹³ The results of the Trendelenburg test are not presented as there was a misunderstanding in how to record the results of the test.

Statistical method

Means were calculated for continuous variables. Dichotomous variables are shown as percentages of athletes and non-athletes separately for girls and boys. Comparisons were performed by using generalised linear mixed models. Two-level data structure was constructed, the subjects being level 1, and the Centre of Excellence in Sports and Exercise Medicine being level 2. Basically, the two-level modelling allows for the clustering of subjects' values within the centre in which they were tested. When comparing athletes and non-athletes, there are two options to fit to a given data set with two-level data structure: one data structure allowing the possible clustering of subjects' values and the other ignoring it. Additionally, for comparison between boys and girls the modelling allows for the difference between genders to possibly vary among clubs and school classes.

ORs are reported with 95% CIs. All statistical analyses were two-sided, and a p values of <0.05 was considered significant. When testing inter-rater repeatability, the percentage agreement and Cohen's κ value were calculated. The assumption of normal distribution was confirmed by visual inspection for each continuous variable. IBM SPSS (V.24.0) was used to carry out all analyses.

RESULTS

Characteristics of the participants

Athletes were taller than non-athletes and more often had normal body mass index (BMI). Girls who were athletes reached menarche at an older age than non-athletes (online supplementary file 1).

Inter-rater repeatability of the musculoskeletal tests

Posture and mobility

The inter-rater repeatability for evaluating iliac crest height asymmetry was almost perfect (κ 0.93), and the

Table 2 Inter-rater repeatability for posture and mobility tests in the Finnish Health Promoting Sports Club study

Test	Agreement (%)	κ values
Shoulder posture		
Shoulder protrusion on one or both sides	68	0.63
Scoliometer reading $\geq 3^\circ$ at AC-joint level (yes/no)	83	0.56
Forward bend		
Scoliometer reading $\geq 3^\circ$ at back	73	0.58
Scoliometer reading $\geq 7^\circ$ at back	81	0.09
Asymmetry in iliac crest height	97	0.93
Shoulder mobility		
Good	76	0.49
Satisfactory	81	0.22
Poor	81	0.47
Modified Thomas test		
Marked iliopsoas tightness on one side	93	0.36
Marked iliopsoas tightness on both sides	90	0.66
Navicular drop		
Side-to-side difference ≥ 2 mm	66	0.30
≥ 10 mm	71	0.15
Generalised joint laxity	81	0.47

Table 3 Posture tests among athletes and non-athletes in the Finnish Health Promoting Sports Club study

Test	Boys (n=261)		Girls (n=315)		Total (n=576)	
	Athletes (n=198)	Non-athletes (n=63)	Athletes (n=201)	Non-athletes (n=114)	Athletes (n=399)	Non-athletes (n=177)
Shoulder posture						
One shoulder protruded (%)	7.6	1.6	8.5	5.3	8.0	4.0
Both shoulders protruded (%)	32.3	28.6	21.4	14.9	26.8	19.8
Scoliometer reading $\geq 3^\circ$ at AC- joint level (%)	16.7	20.6	13.9	12.3	15.3	15.3
Forward bend						
Scoliometer reading $\geq 3^\circ$ at back (%)	41.4	49.2	41.8	41.2	41.6	44.1
Scoliometer reading $\geq 7^\circ$ at back (%)	4.0	6.3	5.0	4.4	4.5	5.1
Asymmetry in iliac crest height (%)	14.9	31.1	14.1	9.3	14.5	17.2
					OR (95% CI)	OR (95% CI)
					1.94 (0.69 to 5.46)	2.81 (1.16 to 6.81)
					1.33 (0.69 to 2.57)	1.34 (0.85 to 2.12)
					1.15 (0.58 to 2.29)	1.00 (0.61 to 1.64)
					1.23 (0.75 to 2.02)	0.97 (-0.67 to 1.40)
					1.10 (0.40 to 2.93)	0.93 (0.44 to 1.96)
					1.68 (0.74 to 3.82)	0.90 (0.53 to 1.53)

Statistically significant results are indicated in bold. Comparisons were performed by using generalised linear mixed models, the centre of sports medicine in which the examination was completed being level 2 in the analysis.

inter-rater repeatability for shoulder protrusion was substantial (κ 0.63). The following posture tests had moderate inter-rater agreement: scoliometer reading of $\geq 3^\circ$ at acromioclavicular-joint level (κ 0.56), scoliometer reading of $\geq 3^\circ$ at back (0.58). The percentage of agreement for scoliosis $\geq 7^\circ$ at back was 81% (κ 0.09) (table 2).

The interrater repeatability was substantial for marked iliopsoas tightness on both sides (κ 0.66). The following mobility tests had moderate interrater repeatability: shoulder mobility test (κ 0.42), Beighton and Horan mobility index (κ 0.47), and heels lifted from floor in the deep squat test (κ 0.55) (tables 2 and 3). The Kappa value for the navicular drop test was <0.4 and percentage of agreement $<80\%$ (table 2).

Movement control

The deep squat test as a whole had substantial inter-rater repeatability (κ 0.66), and the repeatability was best for receiving the highest score (κ 0.81). The vertical drop jump test as a whole had moderate inter-rater repeatability (κ 0.45), and the repeatability was substantial for poor control (κ 0.66). The one-leg stance test had moderate inter-rater repeatability (κ 0.48–0.60). A κ value of ≥ 0.4 was not obtained in the 30 s plank test; however, the percentage of agreement was $>80\%$ (table 4).

Musculoskeletal tests between athletes and non-athletes

Posture

Having one shoulder protruded (8.0% vs 4.0%, OR 2.81, 95% CI 1.16 to 6.81) was more common in athletes than non-athletes. Having iliac crests at different levels was less common in boys who were athletes (14.9% vs 31.1%) (OR 0.43, 95% CI 0.21 to 0.89) (table 3).

Mobility

Poor shoulder mobility was less common in boys who were athletes compared with non-athletes (30.3% vs 46.0%, OR 0.54, 95% CI 0.29 to 0.99) (table 5). Limited

Table 4 Inter-rater repeatability for movement control tests in the Finnish Health Promoting Sports Club study

Test	Agreement (%)	κ values
30 s plank	85	0.32
Deep squat	81	0.66
Highest score	93	0.81
Middle score	81	0.60
Lowest score	88	0.55
Trendelenburg sign positive	63	-0.13
One-leg stance		
>2 cm side-to-side difference	83	0.48
≥ 13 cm	83	0.60
Vertical drop jump		
Good control	71	0.35
Impaired control	71	0.41
Poor control	90	0.66

Table 5 Mobility tests among athletes and non-athletes in the Finnish Health Promoting Sports Club study

Test	Boys (n=261)		Girls (n=315)		Total (n=576)	
	Athletes (n=198)	Non-athletes (n=63)	Athletes (n=201)	Non-athletes (n=114)	Athletes (n=399)	Non-athletes (n=177)
Shoulder mobility						
Good (%)	42.4	33.3	64.2	62.3	53.6	52.0
Satisfactory (%)	25.8	20.6	17.9	14.0	21.8	16.6
Poor (%)	30.3	46.0	16.9	23.7	23.6	31.6
Modified Thomas test						
Marked iliopsoas tightness on one side (%)	5.6	1.6	5.0	3.5	5.3	2.8
Marked iliopsoas tightness on both sides (%)	27.3	23.8	12.4	13.2	19.8	16.9
Generalised Joint laxity (%)	11.6	11.1	45.7	40.7	28.7	30.1
					OR* (95% CI)	OR* (95% CI)
					1.31 (0.70 to 2.45)	1.07 (0.63 to 1.81)
					1.37 (0.68 to 2.76)	1.17 (0.61 to 2.36)
					0.54 (0.29 to 0.99)	0.78 (0.42 to 1.43)
					1.77 (0.42 to 7.41)	1.23 (0.44 to 3.44)
					1.14 (0.55 to 2.37)	0.87 (0.41 to 1.84)
					0.97 (0.37 to 2.57)	1.51 (0.91 to 2.51)
						1.40 (0.62 to 3.19)
						1.24 (0.75 to 2.05)
						0.99 (0.66 to 1.50)

Statistically significant results are indicated in bold.

*Comparisons were performed by using generalised linear mixed models (GLMM), the centre of sports medicine in which the examination was completed being level two in the analysis.

ankle mobility in the deep squat test was less common in athletes than non-athletes; 21.8% of athletes compared with 37.3% of non-athletes were not able to perform the deep squat test with heels remaining on the floor (OR 0.48, 95% CI 0.32 to 0.71) (table 6).

Movement control

Athletes had better core muscle control with 86.3% being able to remain in the correct plank position for 30 s compared with 68.6% of non-athletes (OR 2.70, 95% CI 1.67 to 4.36). In the deep squat test, good lumbar spine control was maintained similarly in both groups (by 35.8% of athletes and 38.4% of non-athletes). Out of athletes, 41.6% and 22.6% of non-athletes were able to perform the deep squat test with heels remaining on the floor when lumbar spine control was not assessed (OR 2.52, 95% CI 1.65 to 3.86) (table 6).

In the one-leg stance test, girls who were athletes showed better lateral control of the trunk, 7.5% had lateral movement of <13 cm compared with 13.2% of non-athlete girls (OR 0.38, 95% CI 0.15 to 0.94). Good knee control was more common in athletes than non-athletes (45.9% vs 31.6% respectively, OR 1.99, 95% CI 1.29 to 3.06). Twelve per cent of athletes had poor knee control in the two-legged vertical drop jump test compared with 26% of non-athletes (OR 0.36, 95% CI 0.22 to 0.58) (table 6).

DISCUSSION

This study showed that 10 of the 11 musculoskeletal screening tests had at least moderate inter-rater reliability. These tests are reliable for trained physicians to evaluate the posture, mobility and movement control of adolescents as a part of a PHE.

This study also showed that athletes more often had normal BMI, better shoulder and ankle mobility, and better knee control in the vertical drop jump test compared with non-athletes. Core muscle control was better in athletes than non-athletes as was lateral control of the trunk in the one-leg stance test for girls. We found no difference between athletes and non-athletes in the deep squat test. Shortfalls in mobility, posture and movement control were common in both athletes and non-athletes. These deficits, such as shoulder protrusion, marked iliopsoas tightness and poor lumbar spine control, are speculated to be associated with sedentary behaviour, monotonous training, or both.

The strengths of this study were that the adolescents formed a representative sample from different regions of Finland and the sports club sample comprised the 10 most popular sports in Finland. Summer and winter sports and individual and team sports were equally represented.¹⁴ The number of athletes in the study was greater than the amount of non-athletes because we wanted to include participants of the most popular sports in Finland, and include both summer and winter sports and individual and team sports. In general, it is unlikely that subjects developed their skills in the tests or underwent posture changes due to growth during the 2-week

Table 6 Movement control tests among athletes and non-athletes in the Finnish Health Promoting Sports Club study

Test	Boys (n=261)		Girls (n=315)		Total (n=576)				
	Athletes (n=198)	Non-athletes (n=63)	Athletes (n=201)	Non-athletes (n=114)	Athletes (n=399)	Non-athletes (n=177)			
		OR* (95% CI)		OR* (95% CI)		OR* (95% CI)			
Able to perform 30 s plank (%)	85.1	66.7	2.84 (1.36 to 5.93)	87.4	69.6	2.60 (1.36 to 4.95)	86.3	68.6	2.70 (1.67–4.36)
Deep squat									
Highest score (%)	36.4	39.7	0.87 (0.47–1.61)	35.3	37.7	0.91 (0.53–1.56)	35.8	38.4	0.87 (0.58–1.29)
Middle score (%)	42.9	25.4	2.42 (1.24–4.73)	40.3	21.1	2.39 (1.36–4.20)	41.6	22.6	2.52 (1.65–3.86)
Lowest score (%)	20.7	34.9	0.46 (0.24–0.88)	22.9	38.6	0.49 (0.30–0.83)	21.8	37.3	0.48 (0.32–0.71)
One-leg stance									
>2 cm side-to-side difference (%)	12.6	7.9	1.68 (0.60–4.70)	10.0	11.4	0.89 (0.43–1.84)	11.3	10.2	1.16 (0.66–2.06)
≥13 cm on one side (%)	5.6	0.0	NA	5.5	3.5	1.62 (0.49–5.41)	5.5	2.3	2.38 (0.79–7.17)
≥13 cm on both sides (%)	6.6	3.2	1.38 (0.28–6.84)	7.5	13.2	0.38 (0.15–0.94)	7.0	9.6	0.53 (0.26–1.09)
Vertical drop jump									
Good control (%)	53.0	46.0	1.17 (0.84–3.37)	38.8	23.7	1.99 (1.11–3.56)	45.9	31.6	1.99 (1.29–3.06)
Impaired control (%)	40.4	36.5	1.09 (0.55–2.16)	41.8	43.9	1.02 (0.63–1.65)	41.1	41.2	1.07 (0.73–1.58)
Poor control (%)	5.6	15.9	0.28 (0.11–0.73)	18.4	31.6	0.47 (0.27–0.83)	12.0	26.0	0.36 (0.22–0.58)

Statistically significant results are indicated in bold.

*Comparisons were performed by using generalised linear mixed models (GLMM), the centre of sports medicine in which the examination was completed being level two in the analysis.

period of time between the musculoskeletal examination and the re-examination. However, it is possible that the subject had day-to-day variation in alertness and this may have affected the performance. Further, performing a movement in an office setting may not reflect actual movement patterns during training or competition. The office setting is, however, valuable in adding awareness of these factors. There is evidence that programmes aimed at improving core muscle control and neuromuscular function are effective in reducing the risk of low back pain and acute injuries in young athletes and conscripts.^{15 16}

The tests or subtests that did not reach moderate inter-rater reliability ($\kappa \geq 0.4$) were such in which one finding was significantly less prevalent than the other. For example, scoliosis of 7° or more or marked iliopsoas tightness on one side only was present in approximately 5% of the subjects. However, in these tests the percentage of agreement reached $>80\%$. Thus we did not consider this to affect the repeatability of the Thomas test or forward bend test as a whole. Also, the 30 s plank test did not reach moderate repeatability based on the κ value; however, the percentage of agreement was 85%. In the re-examination, only 7% were not able to complete this test which may explain the low κ value for this test together with the small sample size ($n=41$). The navicular drop test was not found to have acceptable repeatability, thus we do not recommend using this test in a musculoskeletal examination.

More than 90% of the male subjects had reached puberty, and the girls who were athletes had reached menarche at an older age. In a previous study among adolescents aged 8–14 years, the FMS scores were found to be higher after puberty than before or during it. This suggests that after puberty there is an increase in muscular strength, proprioception and coordination. No significant differences in asymmetries were found across pubertal groups.¹⁷

Clinical findings

Protrusion of the shoulders is a common posture finding in adolescents.¹⁸ In our study, having one shoulder protruded was more common in athletes than non-athletes and may be explained by sport specific postures and muscle tightness as well as training habits. Smart phone usage time may also have an effect on shoulder posture.¹⁹

Differences in iliac crest height may be due to leg length discrepancy, bony asymmetry in pelvic bones or muscle imbalance. Leg length discrepancy, which may lead to asymmetric gait and posture changes with compensatory imbalances in muscle strength and flexibility, may be predictive of stress fractures in select populations.²⁰ Leg length discrepancy can be reliably assessed using radiologic techniques,²¹ but radiographs are not used in general screening.

Generalised joint laxity (GJL) has been suggested to be positively associated with physical activity in girls.²² However, in this study we did not find a difference between athlete and non-athlete girls in the prevalence of GJL. In

previous studies, GJL has been associated with a higher injury incidence in male and female athletes.^{23 24} There is also a possible link between generalised joint hypermobility and developing joint pain in adolescence.²⁵

In our study, we assessed core muscle function, knee joint alignment in the vertical drop jump and navicular drop. Poor core muscle control may be associated with anterior pelvic tilt and internal rotation of the femur along with valgus alignment of the knee and foot.^{26 27} Tight iliopsoas and rectus femoris muscles may also be associated with anterior pelvic tilt; however, this may not apply to findings during running.²⁸ It is important to consider the entire lower extremity posture rather than single-alignment characteristics since it has been found that navicular drop and quadriceps angle have independent and interactive effects on neuromuscular responses to a weightbearing, rotational perturbation.²⁹ Furthermore, the impaired ability to maintain dynamic joint stability has been found to contribute to the development of exertional medial tibial pain in women.³⁰

Knee joint malalignment is associated with increased loading of the joints, ligaments and tendons.³¹ Previous studies have shown that excessive knee valgus³¹ and stiff landings³² during the vertical drop jump (VDJ) test are associated with increased risk of ACL injury in young female athletes. Furthermore, ACL injuries are more common among female athletes than their male counterparts³³ and that girls display an increase in valgus alignment during puberty.³⁴ Patellofemoral knee pain is more often experienced by females than males and is highly prevalent in all age groups.³⁵ Knee valgus displacement in a vertical drop jump test has been shown to predict patellofemoral pain in adolescent females.³⁶

The prevalence of adolescent back pain increases with age,³⁷ and low back and pelvic pain have been found to be a common type of overuse injury in young athletes.³⁸ Patients with reduced control of active movements may form an important subgroup in patients with non-specific low back pain³⁹ and maintaining good lumbar spine position can also help reduce and prevent low back pain.^{15 40 41} We found that $<40\%$ of adolescents were able to perform the deep squat while maintaining good lumbar spine control and heels on the floor, and there was no difference between athletes and non-athletes. In a previous study comparing college-aged athletes and non-athletes, the female athletes scored higher in the deep squat test compared with non-athletes, whereas no difference was observed in men.⁹

From the one-leg stance position, the lateral shift of the pelvis relative to the trunk can be measured with moderate reliability in adults.^{39 42} In our study, we found that non-athlete girls more frequently had poor lateral control of the pelvis than athletes, and that there was no difference between athletes and non-athletes in asymmetric lateral control of the pelvis. Furthermore, nearly one-fifth of the adolescents in both groups had a side difference on ≥ 2 cm or lateral shift ≥ 13 cm on both sides indicating asymmetric or poor lateral control of the pelvis.

Although a number of markers in musculoskeletal screening tests are associated with an increased risk of sports injury, there is yet no final evidence to support screening of athletes' injury risk. In sports injury prevention studies, one challenge is to find the cut point at which athletes are determined to be at a higher risk.⁴³ An important goal of the PHE is to evaluate risk factors for developing acute and overuse injuries and musculoskeletal pain and to address those before the onset of problems. Importantly, risk factors also include later maturity, higher BMI and previous injury.^{44 45}

CONCLUSIONS

When using the level of at least moderate inter-rater reliability as a criterion, trained physicians may use musculoskeletal tests to assess adolescents' posture, mobility and movement control in a PHE.

The posture tests we recommend are shoulder posture, scoliosis in forward bend and iliac crest height asymmetry. For testing mobility, we recommend the shoulder mobility test, Thomas test and the Beighton and Horan mobility index. Finally, for testing movement control, we recommend the deep squat test, the one-legged stance test, the vertical drop jump test and the 30 s plank test.

Future studies are needed to see how the findings in these musculoskeletal tests and their different cut points predict and are associated with musculoskeletal symptoms and injury risk. Test properties need to be validated in different populations using appropriate statistical methods.

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