

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

Kerttu Toivo,^{1,2} Pekka Kannus,^{1,2} Sami Kokko,³ Lauri Alanko,⁴ Olli J Heinonen,⁵ Raija Korpelainen,^{6,7,8} Kai Savonen,^{9,10} Harri Selänne,¹¹ Tommi Vasankari,² Lasse Kannas,³ Urho M Kujala,³ Jari Villberg,³ Jari Parkkari^{1,2}

To cite: Toivo K, Kannus P, Kokko S, *et al.* Musculoskeletal examination in young athletes and non-athletes: the Finnish Health Promoting Sports Club (FHPSC) study. *BMJ Open Sport & Exercise Medicine* 2018;**4**:e000376. doi:10.1136/bmjsem-2018-000376

► Additional material is published online only. To view please visit the journal online (<http://dx.doi.org/10.1136/bmjsem-2018-000376>).

Accepted 4 April 2018

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



For numbered affiliations see end of article.

Correspondence to

Kerttu Toivo; kerttu.toivo@fimnet.fi

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 subtests.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.

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

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 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

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	61	0.45
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)	OR* (95% CI)	Athletes (n=201)	Non-athletes (n=114)	OR* (95% CI)	Athletes (n=399)	Non-athletes (n=177)	OR* (95% CI)
Shoulder mobility									
Good (%)	42.4	33.3	1.31 (0.70 to 2.45)	64.2	62.3	1.07 (0.63 to 1.81)	53.6	52.0	0.97 (0.66 to 1.43)
Satisfactory (%)	25.8	20.6	1.37 (0.68 to 2.76)	17.9	14.0	1.17 (0.61 to 2.36)	21.8	16.6	1.39 (0.86 to 2.24)
Poor (%)	30.3	46.0	0.54 (0.29 to 0.99)	16.9	23.7	0.78 (0.42 to 1.43)	23.6	31.6	0.75 (0.50 to 1.14)
Modified Thomas test									
Marked iliopsoas tightness on one side (%)	5.6	1.6	1.77 (0.42 to 7.41)	5.0	3.5	1.23 (0.44 to 3.44)	5.3	2.8	1.40 (0.62 to 3.19)
Marked iliopsoas tightness on both sides (%)	27.3	23.8	1.14 (0.55 to 2.37)	12.4	13.2	0.87 (0.41 to 1.84)	19.8	16.9	1.24 (0.75 to 2.05)
Generalised Joint laxity (%)	11.6	11.1	0.97 (0.37 to 2.57)	45.7	40.7	1.51 (0.91 to 2.51)	28.7	30.1	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)
Able to perform 30 s plank (%)	85.1	66.7	87.4	69.6	86.3	68.6
Deep squat						
Highest score (%)	36.4	39.7	35.3	37.7	35.8	38.4
Middle score (%)	42.9	25.4	40.3	21.1	41.6	22.6
Lowest score (%)	20.7	34.9	22.9	38.6	21.8	37.3
One-leg stance						
>2 cm side-to-side difference (%)	12.6	7.9	10.0	11.4	11.3	10.2
≥13 cm on one side (%)	5.6	0.0	5.5	3.5	5.5	2.3
≥13 cm on both sides (%)	6.6	3.2	7.5	13.2	7.0	9.6
Vertical drop jump						
Good control (%)	53.0	46.0	38.8	23.7	45.9	31.6
Impaired control (%)	40.4	36.5	41.8	43.9	41.1	41.2
Poor control (%)	5.6	15.9	18.4	31.6	12.0	26.0

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.

Author affiliations

¹Tampere Research Center of Sports Medicine, Tampere, Finland

²UKK Institute for Health Promotion Research, Tampere, Finland

³Faculty of Sport and Health Sciences, University of Jyväskylä, Jyväskylä, Finland

⁴Clinic for Sports and Exercise Medicine, Helsinki, Finland

⁵Paavo Nurmi Centre & Unit of Health and Physical Activity, University of Turku, Turku, Finland

⁶Department of Sports and Exercise Clinic, Oulu Deaconess Institute, Oulu, Finland

⁷Center for Life Course Health Research, University of Oulu, Oulu, Finland

⁸Medical Research Center, University of Oulu and University Hospital of Oulu, Oulu, Finland

⁹Kuopio Research Institute of Exercise Medicine, Kuopio, Finland

¹⁰Department of Clinical Physiology and Nuclear Medicine, Kuopio University Hospital, Kuopio, Finland

¹¹Department of Psychology, University of Jyväskylä, Jyväskylä, Finland

Acknowledgements The authors thank all the participating sports clubs and their officials and coaches. The authors also thank the participating schools for their assistance in the surveys. Without all the adolescents who participated in the study, especially those who took part in preparticipation screening, this research would not have been possible. The authors want to express their gratitude to these youth.

Contributors All authors contributed to study conception and design. SK and JP coordinated and managed all parts of the study. KT carried out the literature search. SK and JV conducted data collection and performed preliminary data preparations. KT and JV conducted data analyses, and all the authors contributed to the interpretation of data. KT, PK and JP wrote the first draft of the paper, and all authors provided substantive feedback on the paper and contributed to the final manuscript. All authors have approved the submitted version of the manuscript. JP is the guarantor.

Funding This study was financially supported by the Finnish Ministry of Education and Culture (major, grant number: 6/091/2011) and Ministry of Social Affairs and Health (minor, grant number: 152/THL/TE/2012).

Competing interests None declared.

Patient consent Not required.

Ethics approval The study was carried out in conformance with the Declaration of Helsinki. A positive statement from the Ethics Committee of Health Care District of Central Finland was received (record number 23U/2012).

Provenance and peer review Not commissioned; internally peer reviewed.

Open Access This is an Open Access article distributed in accordance with the Creative Commons Attribution Non Commercial (CC BY-NC 4.0) license, which permits others to distribute, remix, adapt, build upon this work non-commercially, and license their derivative works on different terms, provided the original work is properly cited and the use is non-commercial. See: <http://creativecommons.org/licenses/by-nc/4.0/>

© Article author(s) (or their employer(s) unless otherwise stated in the text of the article) 2018. All rights reserved. No commercial use is permitted unless otherwise expressly granted.

REFERENCES

- Ljungqvist A, Jenoure PJ, Engebretsen L, et al. The International Olympic Committee (IOC) consensus statement on periodic health evaluation of elite athletes, March 2009. *Clin J Sport Med* 2009;19:347–65.
- Hegedus EJ, McDonough S, Bleakley C, et al. Clinician-friendly lower extremity physical performance measures in athletes: a systematic review of measurement properties and correlation with injury, part 1. The tests for knee function including the hop tests. *Br J Sports Med* 2015;49:642–8.
- Hegedus EJ, McDonough SM, Bleakley C, et al. Clinician-friendly lower extremity physical performance tests in athletes: a systematic review of measurement properties and correlation with injury. Part 2—the tests for the hip, thigh, foot and ankle including the star excursion balance test. *Br J Sports Med* 2015;49:649–56.
- Whittaker JL, Booyesen N, de la Motte S, et al. Predicting sport and occupational lower extremity injury risk through movement quality screening: a systematic review. *Br J Sports Med* 2017;51:580–5.
- Pollock AS, Durward BR, Rowe PJ, et al. What is balance? *Clin Rehabil* 2000;14:402–6.
- Granacher U, Gollhofer A. Is there an association between variables of postural control and strength in adolescents? *J Strength Cond Res* 2011;25:1718–25.
- Räsänen A, Pasanen K, Krosshaug T, et al. Single-Leg Squat as a Tool to Evaluate Young Athletes' Frontal Plane Knee Control. *Clin J Sport Med* 2016;26:478–82.
- Moran RW, Schneiders AG, Major KM, et al. How reliable are Functional Movement Screening scores? A systematic review of rater reliability. *Br J Sports Med* 2016;50:527–36.
- Engquist KD, Smith CA, Chimera NJ, et al. Performance comparison of student-athletes and general college students on the functional movement screen and the Y balance test. *J Strength Cond Res* 2015;29:2296–303.
- Onate JA, Everhart JS, Clifton DR, et al. Physical exam risk factors for lower extremity injury in high school athletes: a systematic review. *Clin J Sport Med* 2016;26:435–44.
- Kokko S, Selänne H, Alanko L, et al. Health promotion activities of sports clubs and coaches, and health and health behaviours in youth participating in sports clubs: the Health Promoting Sports Club study. *BMJ Open Sport Exerc Med* 2015;1:e000034.
- Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics* 1977;33:159–74.
- Sim J, Wright CC. The kappa statistic in reliability studies: use, interpretation, and sample size requirements. *Phys Ther* 2005;85:257–68.
- Kokko S, Kannas L, Villberg J. The health promoting sports club in Finland—a challenge for the settings-based approach. *Health Promot Int* 2006;21:219–29.
- Suni JH, Taanila H, Mattila VM, et al. Neuromuscular exercise and counseling decrease absenteeism due to low back pain in young conscripts: a randomized, population-based primary prevention study. *Spine* 2013;38:375–84.
- Parkkari J, Taanila H, Suni J, et al. Neuromuscular training with injury prevention counselling to decrease the risk of acute musculoskeletal injury in young men during military service: a population-based, randomised study. *BMC Med* 2011;9:35.
- Paszkevicz JR, McCarty CW, Van Lunen BL. Comparison of functional and static evaluation tools among adolescent athletes. *J Strength Cond Res* 2013;27:2842–50.

18. Ruivo RM, Pezarat-Correia P, Carita AI. Intrarater and interrater reliability of photographic measurement of upper-body standing posture of adolescents. *J Manipulative Physiol Ther* 2015;38:74–80.
19. Jung SI, Lee NK, Kang KW, et al. The effect of smartphone usage time on posture and respiratory function. *J Phys Ther Sci* 2016;28:186–9.
20. Bennell KL, Malcolm SA, Thomas SA, et al. Risk factors for stress fractures in track and field athletes. A twelve-month prospective study. *Am J Sports Med* 1996;24:810–8.
21. McCaw ST, Bates BT. Biomechanical implications of mild leg length inequality. *Br J Sports Med* 1991;25:10–13.
22. Clinch J, Deere K, Sayers A, et al. Epidemiology of generalized joint laxity (hypermobility) in fourteen-year-old children from the UK: a population-based evaluation. *Arthritis Rheum* 2011;63:2819–27.
23. Ostenberg A, Roos H. Injury risk factors in female European football. A prospective study of 123 players during one season. *Scand J Med Sci Sports* 2000;10:279–85.
24. Konopinski M, Graham I, Johnson MI, et al. The effect of hypermobility on the incidence of injury in professional football: a multi-site cohort study. *Phys Ther Sport* 2016;21:7–13.
25. Sohrbeck-Nøhr O, Kristensen JH, Boyle E, et al. Generalized joint hypermobility in childhood is a possible risk for the development of joint pain in adolescence: a cohort study. *BMC Pediatr* 2014;14:302.
26. Duval K, Lam T, Sanderson D. The mechanical relationship between the rearfoot, pelvis and low-back. *Gait Posture* 2010;32:637–40.
27. Pinto RZ, Souza TR, Trede RG, et al. Bilateral and unilateral increases in calcaneal eversion affect pelvic alignment in standing position. *Man Ther* 2008;13:513–9.
28. Schache AG, Blanch PD, Murphy AT. Relation of anterior pelvic tilt during running to clinical and kinematic measures of hip extension. *Br J Sports Med* 2000;34:279–83.
29. Shultz SJ, Carcia CR, Gansneder BM, et al. The independent and interactive effects of navicular drop and quadriceps angle on neuromuscular responses to a weight-bearing perturbation. *J Athl Train* 2006;41:251–9.
30. Verrelst R, De Clercq D, Vanrenterghem J, et al. The role of proximal dynamic joint stability in the development of exertional medial tibial pain: a prospective study. *Br J Sports Med* 2014;48:388–93.
31. Hewett TE, Myer GD, Ford KR, et al. Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: a prospective study. *Am J Sports Med* 2005;33:492–501.
32. Leppänen M, Pasanen K, Kujala UM, et al. Stiff Landings Are Associated With Increased ACL Injury Risk in Young Female Basketball and Floorball Players. *Am J Sports Med* 2017;45:386–93.
33. Renstrom P, Ljungqvist A, Arendt E, et al. Non-contact ACL injuries in female athletes: an International Olympic Committee current concepts statement. *Br J Sports Med* 2008;42:394–412.
34. Wild CY, Steele JR, Munro BJ. Why do girls sustain more anterior cruciate ligament injuries than boys?: a review of the changes in estrogen and musculoskeletal structure and function during puberty. *Sports Med* 2012;42:733–49.
35. Glaviano NR, Kew M, Hart JM, et al. Demographic and epidemiological trends in patellofemoral pain. *Int J Sports Phys Ther* 2015;10:281–90.
36. Holden S, Boreham C, Doherty C, et al. Two-dimensional knee valgus displacement as a predictor of patellofemoral pain in adolescent females. *Scand J Med Sci Sports* 2017;27:188–94.
37. Jeffries LJ, Milanese SF, Grimmer-Somers KA. Epidemiology of adolescent spinal pain: a systematic overview of the research literature. *Spine* 2007;32:2630–7.
38. Leppänen M, Pasanen K, Kannus P, et al. Epidemiology of overuse injuries in youth team sports: a 3-year prospective study. *Int J Sports Med* 2017;38:847–56.
39. Luomajoki H, Kool J, de Bruin ED, et al. Reliability of movement control tests in the lumbar spine. *BMC Musculoskelet Disord* 2007;8:90.
40. Suni J, Rinne M, Natri A, et al. Control of the lumbar neutral zone decreases low back pain and improves self-evaluated work ability: a 12-month randomized controlled study. *Spine* 2006;31:E611–20.
41. Hill JJ, Keating JL. Daily exercises and education for preventing low back pain in children: cluster randomized controlled trial. *Phys Ther* 2015;95:507–16.
42. Carlsson H, Rasmussen-Barr E. Clinical screening tests for assessing movement control in non-specific low-back pain. A systematic review of intra- and inter-observer reliability studies. *Man Ther* 2013;18:103–10.
43. Bahr R. Why screening tests to predict injury do not work-and probably never will...: a critical review. *Br J Sports Med* 2016.
44. Fourchet F, Horobeanu C, Loepelt H, et al. Foot, ankle, and lower leg injuries in young male track and field athletes. *Int J Athl Ther Train* 2011;16:19–23.
45. McHugh MP, Tyler TF, Tetro DT, et al. Risk factors for noncontact ankle sprains in high school athletes: the role of hip strength and balance ability. *Am J Sports Med* 2006;34:464–70.
46. Harvey D. Assessment of the flexibility of elite athletes using the modified Thomas test. *Br J Sports Med* 1998;32:68–70.
47. Beighton P, Solomon L, Soskolne CL. Articular mobility in an African population. *Ann Rheum Dis* 1973;32:413–8.
48. Strand SL, Hjelm J, Shoepe TC, et al. Norms for an isometric muscle endurance test. *J Hum Kinet* 2014;40:93–102.
49. Cook G, Burton L, Hoogenboom BJ, et al. Functional movement screening: the use of fundamental movements as an assessment of function - part 1. *Int J Sports Phys Ther* 2014;9:396–409.
50. Hardcastle P, Nade S. The significance of the Trendelenburg test. *J Bone Joint Surg Br* 1985;67:741–6.
51. Ford KR, Myer GD, Hewett TE. Valgus knee motion during landing in high school female and male basketball players. *Med Sci Sports Exerc* 2003;35:1745–50.
52. Bates NA, Ford KR, Myer GD, et al. Kinetic and kinematic differences between first and second landings of a drop vertical jump task: implications for injury risk assessments. *Clin Biomech* 2013;28:459–66.
53. Nilstad A, Andersen TE, Kristianslund E, et al. Physiotherapists can identify female football players with high knee valgus angles during vertical drop jumps using real-time observational screening. *J Orthop Sports Phys Ther* 2014;44:358–65.