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Functional knee control and the association with biomechanical factors and hip abductor strength

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Abstract

Higher injury rates for knee anterior cruciate ligament (ACL) have been found in female athletes compared with males. Established risk factors for ACL injury include anatomy, external, hormonal and biomechanical factors. Non-contact ACL injuries can occur at landings, change in directions or rapid deceleration with the knee joint extended and rotational forces causing high loads on the ACL. Preventive effects of training programs have been documented and a protocol to assess movement patterns as functional or not functional is developed. The Functional Movement Screen^{TM} (FMS^{TM}) detect weakness and instability in movement patterns. Low scoring points have been associated with increased risk of injury. Muscle strength is important for injury. In special, findings suggest that weakness in hip abductor muscles are associated with knee pain and increased knee valgus motions during jumping and side-cutting. Knee abduction moments have been associated prospectively with ACL injury and lack of strength in hip abductors might lead to compensatory activity in gluteal muscles, which alters biomechanics and increases ACL loading.

The purpose of this study was to investigate associations between an adapted FMS score, hip abduction strength and knee abduction moments. Thirty-one female handball players conducted baseline and post intervention testing where screening points, hip abduction strength and biomechanics of four different jump tasks was collected in a test laboratory. Participants were divided to intervention or control group. The intervention group conducted a training program (2 times/week for 8 weeks) focusing on hip abductor strength and neuromuscular control of knee and hip joints. Findings were moderate correlations between total FMS score and knee abduction moments in the take-off phase in a counter movement jump. Further, hip abduction strength was correlated with knee abduction moments at initial contact in an in-jump task and hip abduction strength was correlated with scoring points from a one-legged squat test. Analysis of change between baseline and post-test found weak and non-significant correlations between the three testing procedures. In conclusion, the adapted FMS score, hip abductor strength and biomechanical factors are moderately associated with each other. Moreover, these correlations were not found when analyzing change from baseline to post-test. The current results may indicate that screening for risk of ACL injury should include a comprehensive evaluation and different testing procedures.

Acknowledgement

With this, I would like to thank everyone who has contributed to this study and my master thesis. At first, all the participants and coaches of the teams recruited to this study have been extraordinary. Without the response and warm welcome from coaches and participants' willingness to share of their time, it would not have been possible to conduct a study like this.

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My fellow student, Are Grytdal who has worked alongside me since the start of the project have put down numerous hours together with me in the testing laboratory, on field with the training intervention and in analysis of the results. Thank you for all the laughs and help with the project!

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Eirik Nordgård Strupstad

List of content

Introduction

Physical activity is beneficial for human health and well-being. However, with increasing sports participation, the risk of musculoskeletal injuries increases (1, 2). Knee injuries are the most common reported injuries (2) and represent 15-50 % of all injuries in sports (3, 4). Concerns have been expressed regarding the high incidence of ACL injuries in adolescents and young adults (5). It has been estimated that 80.000 to 250.000 ACL injuries occur in the United States each year (2, 6, 7). Over 50 % of these injuries affect individuals between 15 and 25 years of age (6). A report from the National Collegiate Athletic Association found higher knee injury rates in female soccer players compared with their male counterparts (8). Male soccer players experienced half the risk of ACL injury compared to females (8).

Apart from gender, factors external to the body and internal factors like anatomy, hormonal and biomechanical differences have been established as risk factors for ACL injury (6, 8-12). Weather conditions, shoe-surface interaction, type of sport, practice versus match exposure and use of protective equipment are external risk factors (6, 9). These factors are often non-modifiable (9) and difficult to measure because of the influence from internal risk factors. However, there is a general agreement of more injuries during match exposure compared to training exposure (12). This increased risk can be as high as 24 times (4). Anatomical risk factors include, knee valgus, foot pronation, size of femoral notch, ACL geometry, body mass index and knee joint laxity (6, 9).

ACL injuries occur through direct contact to the knee joint or a non-contact mechanism (13). Studies report that as many as 70 % of ACL injuries in athletes occur through non-contact mechanisms (14, 15). Typically, non-contact ACL injuries occur at landing from a jump, during cutting maneuvers (13) or through a rapid deceleration from high speed to complete stop (14). Video analysis reveals that in most non-contact ACL injuries the knee is close to full extension and rotational forces through tibia and femur affects the joint (14, 16, 17). Studies have documented positive effects of different preventive programs on ACL injury risk when comparing an intervention group with controls (18-25). However, to obtain a preventive effect it is crucial that compliance to the prevention program is high (20).

Earlier, no common protocol to assess movement patterns and sport specific skills as functional or not functional existed. The Functional Movement Screen $^{\text{TM}}$ (FMS$^{\text{TM}}$) was developed to fill an existing gap between pre-participation testing and performance testing, and identify athletes at risk of injury (26-29). The FMS$^{\text{TM}}$ places individuals in extreme positions to detect weakness and instability in fundamental movement patterns (28). For testers it is noticeable if the athlete does not master stability and mobility appropriately (28). Movements assessed with the FMS^{TM} are the deep squat, in-line lunge, hurdle step, shoulder mobility, active straight leg raise, trunk stability push-up and quadruped rotary stability (26-29). Each test is scored from zero to three, three being the best score. Zero points are given if the subject feels pain during the test (27). One point is given if a person is unable to complete the whole movement pattern. Two points are given if the movement is completed using compensatory movements or equipment. For three points, the movement must be performed correctly without any compensation (27). Points from each test create a composite score ranging from zero to 21 points (28, 29).

Ability of the FMS^{TM} to predict injuries in professional footballers (30), military officer candidates (31) and female collegiate athletes (32) have been studied. Kiesel and colleagues (2007) investigated the likelihood of injury and FMS^{TM} scores in 46 professional footballers. Through one competitive season, players with a score $\leq$ 14 points on the FMS^{TM} had an increased risk of injury of 11.7 times compared to players with >14 points (30). O’Connor and colleagues (2011) recruited 874 males at the Officer Candidate School training and assessed the predictive value of the FMS^{TM} through comparisons of FMS^{TM} scores and risk of injury. Participants with a score $\leq$ 14 points had a relative risk of 1.5 compared to those scoring > 14 points. The FMS^{TM} score was not associated with risk of overuse injuries (31). In 38 female collegiate athletes, the risk of injury was 3.9 times higher for players scoring $\leq$ 14 points compared to players scoring > 14 points on the FMS^{TM} (32). These results suggest that the FMS^{TM} can predict injuries in different populations and across genders.

Intra-rater reliability of the FMS^{TM} have been examined (33, 34). Gribble and colleagues (2013) recruited three persons to serve as models. They were videotaped in frontal and sagittal plane and performed all FMS^{TM} tests three times. Thirty-eight participants met for two test sessions to rate the FMS^{TM}. They were divided in three groups based on experience with the FMS^{TM}. Results revealed a moderate intra-rater reliability across all participants. Raters with most experience achieved high to excellent intra-rater reliability (33). Smith and colleagues (2013) found high intra-rater reliability between two testing sessions using four raters with different experience. The lowest reliability was calculated for the certified FMS^{TM} rater (34).

Muscle strength is a key component in motor performance (35) and injury prevention. One method to test muscle strength is by using hand-held dynamometers (35, 36). It is a portable measuring device, which is less expensive, easier to use and more applicable in research and clinical testing compared to isokinetic testing devices (37-39). Testing is performed during isometric contractions (37) by using the “make” or the “break” test technique (40). With the ”break” technique the examiner exerts a force with the hand-held dynamometer to the limb being tested which overcomes the maximal force output of the subject (40, 41). Conversely, with the “make” technique the examiner fixates the hand-held dynamometer to the limb being tested and the subject exerts a maximal force against the hand-held dynamometer through an isometric contraction (40, 41). The “break” technique reveals higher force output through eccentric activation of the muscles compared to isometric testing with the “make” technique. Therefore, these two techniques should not be used interchangeably when testing muscle strength in clinical practice or research (40).

Regarding knee injuries, a review by Renstrom and colleagues (2008) provided evidence that hip abductor strength is of great importance for knee injury prevention (5). Another study found associations between low hip abductor strength and knee pain (42). Further, hip external rotators and abductors provide eccentric resistance to knee valgus motions (43). Weakness in these muscles can increase knee valgus motion during jumping and side-cutting and through this mechanism increase load on the ACL and risk of injury (43).

Testing with the hand-held dynamometer is reliable (38, 44). Thorborg and colleagues (2010) investigated test-retest measurement variation in hip abduction strength. Nine healthy individuals met for two testing sessions. One examiner tested hip abduction strength in two positions with a hand-held dynamometer. For the supine position using mean of the three best repetitions the researchers found excellent reliability. In side lying position, mean of the three best repetitions reached moderate to good reliability (38). Kelln and colleagues (2008) recruited nine men and eleven women for two test sessions with three testers. Hip abduction was tested in supine position and the researchers reported excellent intra-rater reliability (44).

Video analysis of female handball matches found that plant-and-cut movements and one-legged landings from jump shots were the two main situations leading to ACL injuries (17). The underlying mechanisms, seems to be a valgus collapse with the knee extended or near to full extension combined with internal or external rotation of tibia, relative to femur (16, 17). Knee abduction moments can be calculated from the magnitude of the ground reaction force and the moment arm in the frontal plane (45). The moment arm of the ground reaction force is stronger associated with knee abduction moments compared with the magnitude of ground reaction force (45). Reduction in one of these factors reduces overall knee abduction moment (46).

Hewett and colleagues (2005) investigated associations between biomechanical measurements during drop vertical jumps and ACL injury prospectively in 205 female athletes. Biomechanical measurements were obtained at baseline. Nine subjects suffered an ACL injury during 13 months of follow-up. All ACL injuries were classified as non-contact. Biomechanical measurements were significantly different between the injured and uninjured group (47). Knee abduction angles were 8.4° greater at initial contact in the injured group. Peak external knee abduction moment was significantly greater in the injured group compared with the uninjured group. Vertical ground reaction force was 20 % higher and side-to-side knee abduction moments difference was 6.4 times higher in the injured group (47). Key predictors for increased risk of ACL injury were the increased valgus motion and valgus moments of knee joint at impact (47). Another study, included 82 men and women, compared isometric hip external rotator and hip abductor strength with lower extremity kinematics and gluteal activity in a double-leg landing task (43). Individuals who differed in hip abductor and external rotation strength during landing were not different in frontal and transverse plane hip motion or frontal plane knee motion. However, higher gluteal activity was observed in individuals with low abductor and external rotator strength. This compensatory gluteal activation and lack of strength in hip abductors may contribute to altered biomechanics associated with increased ACL loading and injury risk (43).

In the literature there exists no studies which have investigated associations between all the three testing procedures mentioned above. Associations between the FMS^{TM} and risk of injuries have been found. Findings indicate that hip abductor weakness is related to increased knee abduction moments and strengthening of hip abductors can lead to decreased knee abduction moments in jump landings. Weak or malfunctioning hip abductors have also been associated with knee pain. Further, the International Olympic Committee have recommended research on associations between hip abductor strength and ACL injury rates (5). Therefore the main purpose of this study was to investigate associations between total FMS score, hip abduction strength and knee abduction moments. Hypotheses were that, i) there is a positive association between total FMS score and hip abductor strength, ii) there is a negative association between hip abductor strength and knee abduction moments, iii) there is a negative association between total FMS scores and knee abduction moments.

Methods

Participants

Thirty-three female handball players (age 21.5 ± 2.8 years, body mass 71.1 ± 8.2 kg, height 171.2 ±5.1 cm) volunteered to participate in the study. The study protocol was approved by the Regional Committee for Ethics in Medical Research (project no. 2014/1135). All participants signed an informed consent before enrollment. The study was carried out according to the Declaration of Helsinki.

Inclusion criteria were no previous ACL injury or severe injuries to the lower extremities. Players were excluded if they had diagnosed flatfoot, experienced a spine prolapse during the last six months or participated regularly in training sessions aiming at improving neuromuscular function of knee and hip joint through the Norwegian Olympic Sports Center, Region Mid-Norway. An adapted screening procedure (for short, FMS) also functioned as exclusion criteria. Players with a total score of ≥ 9 points out of 12 points were excluded from the study. Results from the FMS were obtained on field at baseline. All of the other baseline and post intervention testing was conducted in a test laboratory. All participants were amateur handball players, as none of them have handball as their main income source.

Experimental design

Six eligible teams were visited on field. The purpose of this visit was to inform players and screen those who met all other inclusion criteria (see flowchart in figure 1). After baseline testing, two participants gave up playing handball and withdrew their consent for participation. This study was conducted as a single-blind controlled trial. Participants were assigned to either the intervention group or the control group. The control group was blinded to the intervention group training. The physiotherapist who screened the participants at baseline and post-test was unaware of the group assignment of the participants. The intervention group conducted two training sessions per week for eight weeks.

Testing procedure

All equipment was calibrated for each new test day. Body mass was measured at baseline and post-test using the Electronic Scale-9522WB (Weighing Apparatus Company Ltd., China) with one-decimal accuracy. Height was measured to the nearest half centimeter using a SECA 225, mobile measuring device (SECA, Germany). Dominant leg was determined by asking participants which leg they would use to kick a football as long as possible. For each participant, baseline and post-test was completed on the same day.

Screening

The FMS in this study included the deep squat, in-line lunge and the hurdle step test from the FMS^{TM} (27, 28) and the one legged squat test from the Nine-test screening battery (48) (see figure 2). A physiotherapist with experience in scoring the FMS^{TM} screened all of the participants at baseline and post-test. The in-line lunge, the hurdle step and the one-legged squat were assessed bilaterally, starting with the dominant limb. The lowest score on one leg was used as combined score for both legs. The score on each sub-test ranged from 0 to 3. The possible total score ranged from 0 to 12. Participants performed three repetitions on each sub-test before points were given. Criteria for scoring points of the FMS are listed in table 1. Additional equipment for the FMS^{TM} is a dowel, and a board with the measures of 5.08 cm X 10.16 cm (27, 28).

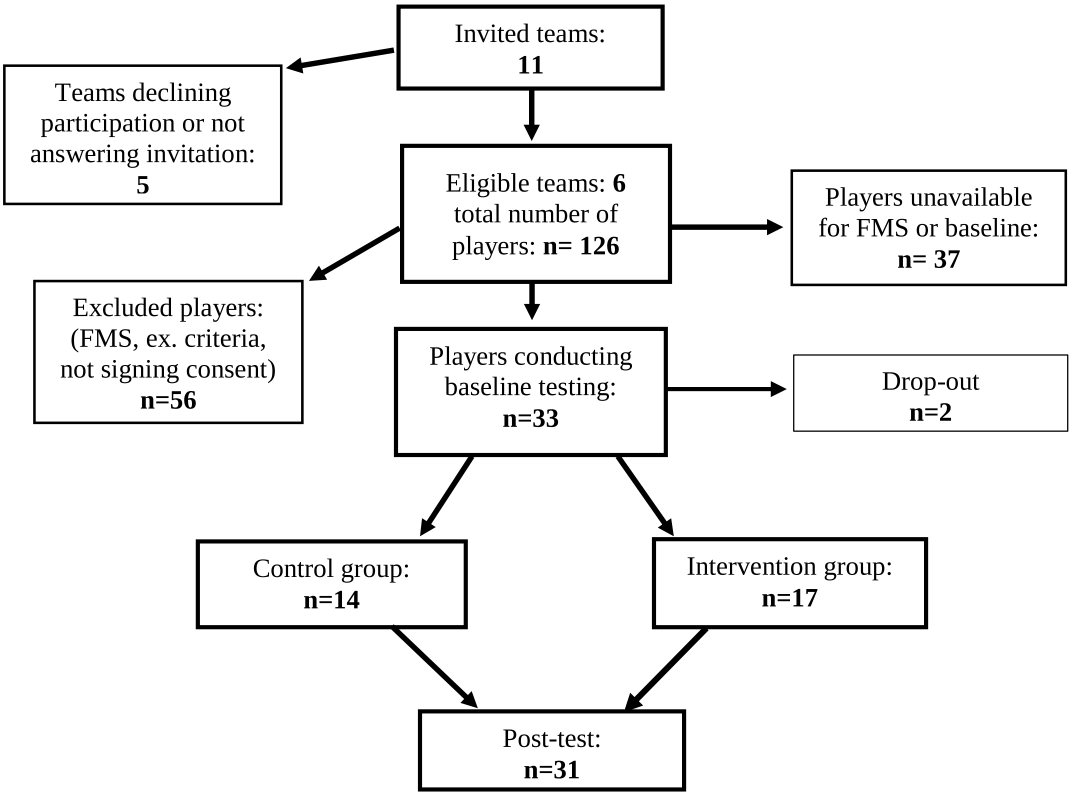

Figure 1. Flowchart of participants in this study.

In the deep squat, participants placed their feet, shoulder width apart and held a dowel overhead with a 90° angel in the elbow joint (27, 28). The dowel was moved upward by extending elbow joints. Instructions were to squat down as low as possible while keeping the torso in an upright position. Heels should not be lifted from the ground and the dowel should be held with arms extended in the squat position. This position should be held for about 1 sec before returning to an upraised position (27, 28).

The in-line lunge started with participants placing the heel of the front foot on a predetermined mark on the board (5.08 cm X 10.16 cm). Participants squatted down and made contact between the knee of the back foot and heel of the front foot. A mark was made were the toes of the back foot touched the block. Participants held the dowel behind the back with the opposite hand of the front foot at the cervical spine and the other hand on the dowel at the lumbar spine. The dowel should stay in contact with the head, thoracic spine and middle of buttocks throughout the test. Starting position was upright with feet flat on the block and toes pointing forward. Participants lowered their back knee and touched the block behind the heel of the front foot, before returning to starting position. The posture should be upright throughout the test (27).

Table 1. Scoring options for the adapted FMS (27, 48)

Points	Deep squat	In-line lunge	Hurdle step	One-legged squat
3	- Parallel upper torso with tibia or toward vertical - Femur below the horizontal line between knee joints - Hips aligned over knee and ankle - The dowel is aligned over feet	- The dowel is held with both hands at the cervical and lumbar area of the back and must be held in contact with the lumbar spine - No flexion of the lumbar spine - The dowel and feet are parallel in the sagittal plane - Contact between knee and board behind front foot heel	- Hips, knees and ankles in line - Minimal to no flexion or extension in lumbar spine - The dowel and the string is parallel	- Hip, knee and foot remain in line throughout the movement - Pelvis remain in horizontal alignment - Vertical upper body
2	- Additional board placed under heels* - Parallel upper torso with tibia or toward vertical - Femur below the horizontal line between knee joints - Hips aligned with knees and ankles - The dowel is aligned over feet	- Loss of contact between the dowel and the lumbar spine due to lumbar spine flexion - Flexion of lumbar spine or sideways flexion of torso during the test - Dowel and feet are not parallel in sagittal plane - Unable to make contact between knee and board behind front foot heel	- Hips, knees and ankles not in line - Flexion or extension movement of the lumbar spine - Dowel and string is not parallel	- Hip, knee and foot remain in line throughout the movement - Pelvis not horizontal aligned - Upper body is not vertical
1	- Additional board placed under heels - Tibia and upper torso are not parallel - Femur not below the horizontal line between knee joints - Hips, knees and ankles are not aligned - Lumbar flexion	- Loss of balance	- Contact between foot and the string - Loss of balance	-Hip, knee and foot is not in line through the movement (typically knee valgus or knee varus is noted)
0	-Participants reported pain during execution of the movement	-Participants reported pain during execution of the movement	-Participants reported pain during execution of the movement	-Participants reported pain during execution of the movement

**If criteria for three points were not achieved a board (5.08cm X 10.16cm) was placed under the heels of the participants*

In the hurdle step test, participants placed their feet touching the base of the hurdle with toes aligned (27). Height of the hurdle string was adjusted to the height of the tibial tuberosity of each participant. Participants held the dowel with both hands positioned behind the neck and across the shoulders while stepping over the string and touching the floor with the heel. An upright posture with the stance leg extended should be held until the moving leg returned to starting position (27)

In the one-legged squat test, hands were fixated at the hip. The passive leg was flexed throughout the test. The upper body should be in an upright position while squatting as deep as possible. The test should be performed as slow as possible. The deepest position was held for about 1 sec before returning to starting position (48).

Hip abductor strength

Prior to baseline testing a pilot study was conducted, to ensure that isometric hip abductor strength measurements were reliable using the hand-held dynamometer (Lafayette Manual Muscle Testing System; Lafayette Instrument Company, Lafayette, IN, USA).

Participants performed two warm-up exercises preceding hip abductor strength testing. Warm-up was performed in upright position. First, they conducted 10 cycles of flexion and abduction of the hip joint on left and right side. The second exercise was 10 full range of motion hip abduction and adduction movements on both sides with a controlled pace.

The hand-held dynamometer technique used in this study was the “make” test technique (figure 3). Testing was conducted with participants in side-lying position on a bench with their back placed against a wall. The opposite arm of the tested leg was positioned under the head. The tester stabilized the participants’ hip during testing to minimize rotation of the hip and femur. The hand-held dynamometer was placed 2 cm proximal to the lateral epicondyle of femur. Participants were tested bilaterally with the leg extended and with knee and hip joint flexed at 90°. Two familiarization tests with a submaximal effort (~80 % of perceived maximal strength) were performed prior to the registration of isometric maximal voluntary contraction (MVC) force output of the hip abductors. All participants performed three MVC repetitions for each position. Each MVC lasted ~3 sec, with a resting period of 30 sec between each repetition. The order of the test position and side was randomized. A protractor was used to control the knee and hip joints angle. The highest obtained value was considered as the MVC. When the third measurement was the highest, a fourth test was required. During testing the participants received verbal encouragement to optimize performance.

Biomechanical assessment

Six Oqus 1 cameras (Qualisys, Sweden) were set up to record kinematics. Two Kistler force plates type 9286BA (Kistler Instrument Corporation, NY, USA) were used to record kinetics. Force plates were placed on the floor. Fifteen reflexive markers (Qualisys, Sweden) with a diameter of 19 mm were placed bilaterally on anatomical bony landmarks i.e. the medial and lateral ankle malleoli, lateral and medial femur epicondyles, trochanter major, iliac crest, acromion and on the sacrum using self-adhesive tape. Prior to the biomechanical assessment, participants conducted a warm-up procedure consisting of two sets with ten deep squats and three sets of squat jumps. The first two sets of squat jumps was three repetitions with submaximal effort. The third set was two squat jumps with maximal effort. During the biomechanical assessment, participants restrained their arms by holding them in hip position to minimize concealing of markers (figure 4). After landing from a jump, instructions were to stand on the force plates for 3 sec until data collection were stopped. The order of the four different jump tasks was randomized for each participant.

In the counter movement jump, participants were instructed to stand still on the force plates for 1 sec before initiating the jumping movement. Participants squatted to a freely chosen knee angle before accelerating their body upwards and landing on the force plate. They were instructed to jump as high as possible.

A line was marked 1 meter from the force plate to indicate starting position for the in-jump task. When performing the in-jump task, participants squatted down to a freely chosen knee angle and jumped forward aiming to land at the center of the force plates. Participants were instructed to jump as high as possible.

The one-legged jump landing started with participants standing on a box, 30 cm higher than the force plate. Participants kept their passive leg bent backwards to avoid compensation during landing on force plate with the passive leg. The passive leg was set to ground after data collection stopped. All participants performed the landing bilaterally.

Functional strength training program

The functional strength-training program consisted of four exercises directed to strengthen hip abductor muscles and improve neuromuscular control of knee and hip joints. Exercises were side lying and supine hip abduction, squat jumps, Bulgarian squat (figure 5 and 6). Ankle weights (1 kg) were used as resistance on the side lying hip abduction. For the other exercises, rubber bands (Kappi, Oslo, Norway) were used as resistance. The rubber bands were fixed around the knee joint, 2 cm distal to the patella when participants stood in upright posture with feet together, adding medially directed resistance during the exercises. Participants started training with eight repetitions and three sets on all exercises. Between sets they were given a resting period of 1 min. When participants successfully performed eight repetitions, they progressed to ten repetitions on next session. Progression increased to completion of 12 successful repetitions in all three sets. When performing 12 repetitions and three sets resistance increased with heavier ankle weights and thicker rubber bands. Progression was determined for each participant by the researchers.

Data analysis and statistics

Kinematics and kinetics were collected in take-off and landing phase of the counter movement jump and in the landing phase from the one-legged jump landing and the in-jump. A customized Matlab (v.2013b The MathWorks, Inc., MA, USA) script was designed to calculate knee angle and knee abduction moments. The period of 300 msec after initial contact was analyzed. For the counter movement jump the last 200 msec before take-off was also analyzed. Initial contact was defined as the moment were plates registered forces over 10 N. Take-off was defined as the last time point where the force plates registered forces of 10 N before flight time. Knee abduction moments were a product of the magnitude of the vertical ground reaction force and the moment arm in frontal plane and were averaged from all three jumps performed in each of the four different jump tasks. Exceptions were for the one-legged landing at baseline where the last to landings were averaged. Synchronization between the camera system and force plates was performed before each test day. Each camera collected data with 250 Hz, each force plate collected at a rate of 500 Hz.

Scores from the FMS tests was analyzed as categorical variables with test performance as outcome. The value 0 were used when participants reported pain performing test, 1 was categorized as low test performance, 2 as medium test performance and 3 as good test performance. MVC values obtained with the hand-held dynamometer was treated in the statistical analysis as an ordinal variable.

The statistical software SPSS (v. 21, International Business Machines Corp, NY, USA) was used in the analysis. Variables in the first analysis was total FMS score for each participant, bilateral MVCs with legs in extended position and with knee and hip joint flexed to 90° and knee abduction moments from take-off and landing phases in the counter movement jump at baseline. Further, change (post-test – baseline) between these variables was analyzed. At last, baseline and change in scores from the FMS sub-tests and knee abduction moments from the in-jump and one-legged landing were analyzed. Descriptive statistics are presented as means ± standard deviation (SD). The data set was tested for normality using Shapiro-Wilk tests. Since FMS variables were categorical and the results from normality tests, Spearman’s rho (ρ) correlation test was used to analyze correlations between variables. T-test (2-tailed) and one-way analysis of variance were used to investigate differences between groups. Intraclass correlation test was used to calculate reliability of the hand-held dynamometer.

Figure 2. Pictures of the FMS tests in this study. A – D illustrates start positions of the deep squat, the hurdle step, the in-line lunge and the one-legged squat test, respectively. E – H illustrates the stop position of the screening tests in the above-mentioned order.

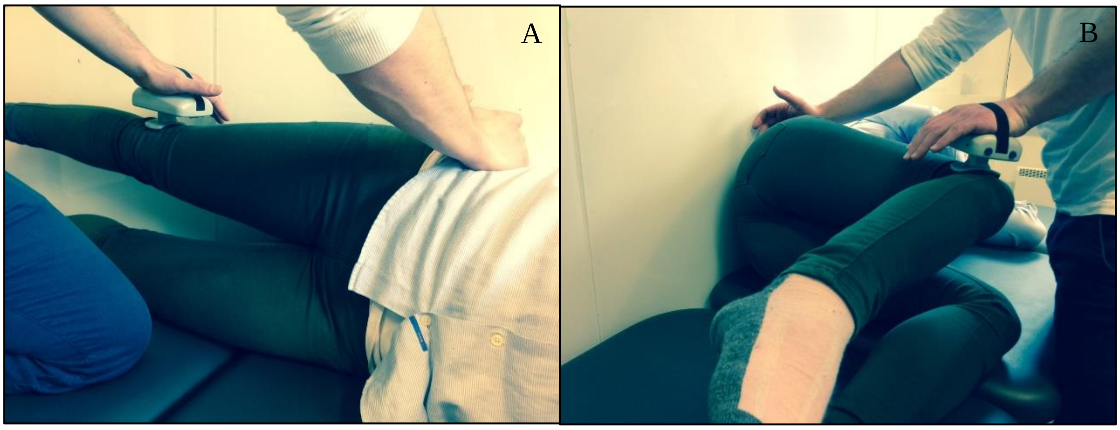

Figure 3. Hip abduction strength test with the hand-held dynamometer. Picture A illustrates dynamometer placement and stabilization of participants during testing with extended leg. Picture B illustrates dynamometer placement and stabilization of participants during testing with knee and hip joint flexed to 90°.

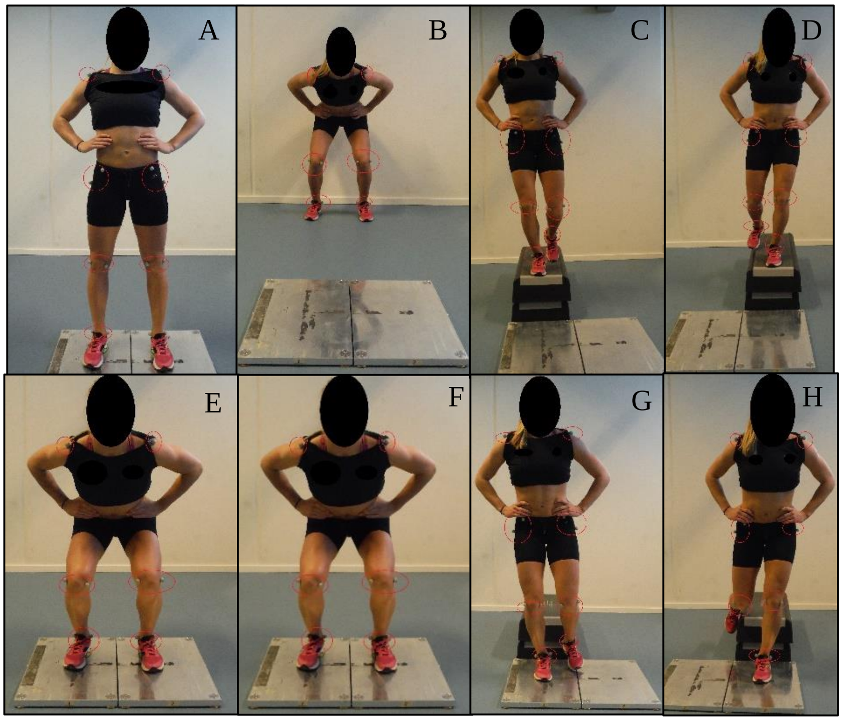

Figure 4. Picture A is the start position of the counter movement jump, B illustrates start position on in-jump, C and D is the start position of the one-legged landing on right and left foot respectively. Picture E-H represents the landing positions of the jump tasks, respectively.

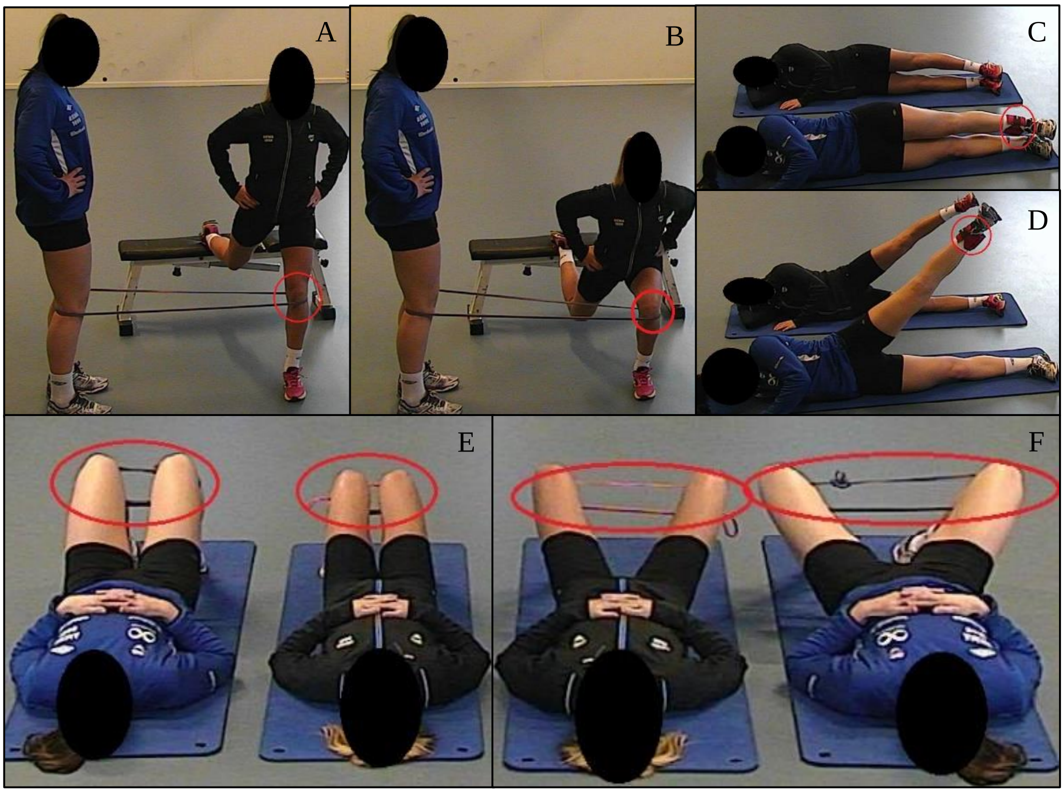

Figure 5. The three first exercises in the training program. Picture A and B illustrates start and stop position of the Bulgarian squat with rubber bands used as medially directed resistance. C and D is the start and stop position of the side lying hip abduction with ankle weights used for extra load. E and F is start and stop position of the supine hip abduction with rubber bands used as resistance. In the stop position, participants held for 3 sec before returning to the start position.

Figure 6. Pictures illustrates take-off, flight and landing of the squat jump exercise in the training program. Rubber bands were used as medially directed resistance.

Results

Results from the pilot testing are presented in table 2. The test protocol demonstrated good to excellent reliability using a hand-held dynamometer for testing of hip abduction strength.

Table 2. Intraclass correlation coefficients from pilot testing of hip abduction strength with a hand-held dynamometer

	Intraclass correlation	95 % confidence interval
Right leg extended	0.99	0.94 – 1.00
Right leg 90° hip and knee	0.85	0.27 – 0.98
Left leg extended	0.98	0.88 – 1.00
Left leg 90° hip and knee	0.95	0.68 – 0.99

Thirty-one participants completed both baseline and post intervention testing. Descriptive statistics for each group are presented in table 3. There was no significant differences between the intervention group and control group at baseline.

Table 3. Descriptive statistics of participants

	Intervention group (n=17)	Control group (n=14)	P-value
Age, years±SD	21.7 ± 1.7	20.4 ± 2.7	0.12
Height cm±SD	170.2 ± 4.8	172.9 ± 5.2	0.15
Weight baseline kg±SD	73.6 ± 8.5	69.0 ± 7.0	0.12
Weight post-test kg±SD	72.7 ± 8.7	68.5 ± 7.1	0.16
Dominant leg, left/right	2/15	2/12	0.84

Baseline

Results from the Spearman’s rho at baseline are presented in table 4. The only significant association was between the total FMS score vs knee abduction moments in the take-off phase of the counter movement jump. These data are also presented in figure 7.

Table 4. Correlations between total FMS score, MVC and knee abduction moments from the counter movement jump at baseline

	n	Spearman's ρ	P-value
Total FMS score vs MVC			
Left leg 90° hip and knee	31	0.14	0.48
Right leg 90° hip and knee	31	0.13	0.49
Left leg extended	31	0.05	0.78
Right leg extended	31	-0.01	0.95
MVC vs knee abduction moments			
Left leg 90° hip and knee and take-off	28	-0.04	0.85
Left leg 90° hip and knee and landing	28	-0.34	0.08
Right leg 90° hip and knee and take-off	27	0.01	0.98
Right leg 90° hip and knee and landing	27	-0.06	0.74
Left leg extended and take-off	28	-0.11	0.57
Left leg extended and landing	28	-0.29	0.14
Right leg extended and take-off	27	0.06	0.75
Right leg extended and landing	27	-0.07	0.71
Total FMS score vs knee abduction moments			
Take-off left leg	28	**-0.48**	**0.01**
Take-off right leg	27	**-0.42**	**0.03**
Landing left leg	28	-0.26	0.18
Landing right leg	27	-0.22	0.26

Further analysis revealed no significant correlations between MVC tests at baseline vs the scores of the FMS sub-tests, i.e. the deep squat, the hurdle step or the in-line lunge (data not shown). However, the score from the one-legged squat test was significantly correlated with the MVC at 90° hip and knee flexion in left ($\rho = 0.43$; $p = 0.017$) and right leg ($\rho = 0.44$; $p = 0.013$). These correlations were not found for the MVC tests with leg extended ($\rho = 0.27$-0.31; $p = 0.10$-0.14). The MVC with leg extended was significantly correlated with knee abduction moments at initial contact on the in-jump task ($\rho = -0.53$; $p = 0.005$) only for the left leg.

No correlations were found between MVC with leg extended vs knee abduction moments at initial contact on the one-legged landing task in either leg. MVC with 90° hip and knee flexion was significantly correlated with knee abduction moments at initial contact on the in-jump for left ($\rho = -0.61$; $p = 0.001$) and right leg ($\rho = -0.61$; $p = 0.001$). Left or right leg MVC with 90° hip and knee flexion was not correlated significantly with any of the other knee abduction moments. No significant correlations were found between the deep squat or hurdle step and any of the knee abduction moments. Points from the in-line lunge and knee abduction moments at initial contact on the one-legged landing were significantly correlated only on the right leg ($\rho = -0.46$; $p = 0.02$). The in-line lunge was not correlated with any of the other knee abduction moments. The one-legged squat test correlated significantly with the left leg knee abduction moments on the in-jump (ρ = -0.39; *p* = 0.04). However, it was not correlated with the right leg or any other knee abduction moments.

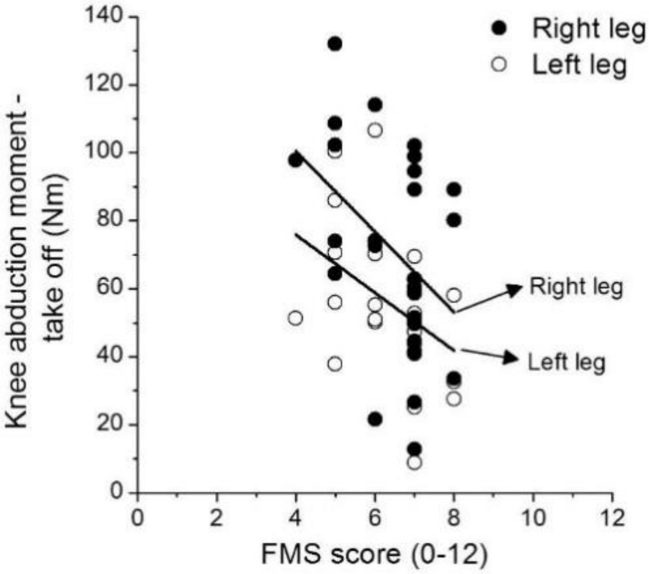

Figure 7. Scatterplot of total FMS score and knee abduction moments during take-off phase in counter movement jump at baseline.

Change from baseline to post-test

Table 5 shows results from the analysis of change between baseline and post-testing. A significant association between the extended right leg MVC and knee abduction moments from the take-off phase in counter movement jump were found. No other significant associations were found.

There were no significant associations between the changes in deep squat, hurdle step, in-line lunge and change in MVC. Change in score on the one-legged squat test and the left leg MVC with knee and knee joints flexed to 90° was significantly associated (ρ = -0.37, *p* = 0.04). There were no other significant associations between the one-legged squat test and the MVC tests. The only significant association between the change in knee abduction moments from the in-jump task, was a negative association between right leg knee abduction moments from the in-jump task and the MVC with leg extended (ρ = -0.54, *p* = 0.01). Correlations between the FMS sub-tests and knee abduction moments were mostly weak and non-significant. However, there was a negative significant correlation (ρ = -0.49, *p* = 0.01) between change in score on the deep squat and knee abduction moments from the right leg on the one-legged landing task.

Table 5. Associations between change in total FMS score, MVC and knee abduction moments from the counter movement jump at baseline.

	n	Spearman's ρ	P–value
Total FMS score vs MVC			
Left leg 90° hip and knee	31	- 0.34	0.06
Right leg 90° hip and knee	31	- 0.09	0.62
Left leg extended	31	- 0.03	0.87
Right leg extended	31	- 0.23	0.21
MVC vs knee abduction moments			
Left leg 90° hip and knee and take-off	27	0.12	0.54
Left leg 90° hip and knee and landing	27	- 0.18	0.38
Right leg 90° hip and knee and take-off	25	0.20	0.34
Right leg 90° hip and knee and landing	24	0.01	0.95
Left leg extended and take-off	27	0.04	0.86
Left leg extended and landing	27	- 0.03	0.89
Right leg extended and take-off	25	**0.48**	**0.01**
Right leg extended and landing	24	0.03	0.89
Total FMS score vs knee abduction moments			
Take-off left leg	27	- 0.29	0.14
Take-off right leg	25	- 0.08	0.69
Landing left leg	27	0.18	0.37
Landing right leg	24	0.04	0.84

Discussion

The main findings in this study was a negative correlation between knee abduction moments during the take-off phase in the counter movement jump and total FMS score at baseline. Further, a negative correlation between MVC with 90° hip and knee flexion and knee abduction moments in the landing phase in the in-jump task was found at baseline. MVC with 90° hip and knee flexion was positively correlated with the scoring of the one-legged squat test. All other results were either weak, non-significant correlations or they were found only for one of the legs. No significant associations for both legs between the different tests were found when analyzing results of the change between baseline and post-test.

The negative correlation between knee abduction moments at take-off and the total FMS score indicates that participants with increased stability and neuromuscular control of the lower extremities had decreased knee valgus during take-off. However, the forces affecting the knee joint at take-off are lower compared to forces at initial contact. The finding that strength measurements with hip and knee joints flexed to 90° has a correlation with both knee abduction moments in the landing phase of in-jump and performance on the one-legged squat test is interesting. Especially since the strength measurements taken with the leg fully extended was not correlated with the same variables. This may suggest that biomechanical demands associated with landing from an in-jump and controlling the knee and hip joint in a one-legged squat are similar. Furthermore, strength measurements of hip abductors taken with knee and hip joints flexed seem to be more relevant compared to strength measurements obtained with extended legs.

The significant correlations at baseline were not found when analyzing the change between baseline and post-test. This can be a result of the increase in screening points and decreased knee abduction moments in the intervention group, and no significant changes in hip abductor strength. The training program conducted by the intervention group might therefore have led to increased stability and neuromuscular control of hip, knee and ankle joints. However, it was expected that the intervention group would increase hip abductor strength. The absence of increased strength might be a result of to low external loading or low compliance to the program.

Three out of the seven original tests in the FMS^{TM} were included in this study. In addition, the one-legged squat test from the Nine-test screening battery was included. These four tests demands neuromuscular control of muscles and joints in the lower extremities. The deep squat requires mobility in hip, knees and ankles and strength in flexor and extensor muscles of the lower extremities (27, 28). The hurdle step does not include the same mobility demands as the deep squat. Instead, this test is used to assess coordination and stability of the hip and torso as well as single leg balance (27, 28). The in-line lunge demands control over rotational forces and maintenance of balance and body alignment (27, 28). It is also used to assess quadriceps flexibility and knee joint stability (27, 28). The one-legged squat test provides an assessment of stability and mobility in the lower extremities, hip and core (48). The four other tests in the FMS^{TM} assess rotary stability of the torso, shoulder mobility, hamstring mobility and sagittal plane trunk stability (26, 29). These tests were not found relevant to the purpose of this study and was therefore excluded from the screening procedure.

When testing hip abductor strength with the hand-held dynamometer the “make” test technique was preferred over the “break” test technique in this study. This tradeoff was done to ensure that the strength of the participants did not overcome the strength of the tester. Either of the two techniques has an advantage over the other regarding reliability (40). With a mechanical advantage for the tester compared to the person being tested, the reliability is high regardless of experience with the hand-held dynamometer (44). However, comparing isometric strength with results from dynamic motions like screening exercises and knee abduction moments from different jumps might be difficult. The “break” test technique is used to measure eccentric force of the muscles being tested. An eccentric dynamic test instead of isometric test protocol might have correlated better with knee abduction moment since the hip abductors are activated eccentrically when an individual attempt to resist knee valgus, maintain stability and control the knee and hip joint. More research is necessary to decide which strength measurement is most relevant for assessment of knee and hip control.

Knee abduction moments in this study were calculated from the magnitude of the vertical ground reaction force and the moment arm in frontal plane. This is in accordance with other studies and literature, which have investigated knee abduction moments and other factors related to knee injuries (45-47). The correlations between total screening points and knee abduction moments from the take-off phase are interesting since it was expected to find this association at initial contact. This means that the higher forces related to landings resulted in higher knee abduction moments for the participants. They were not able to resist knee valgus at landing and therefore no associations were found between hip abductor strength, total FMS score and knee abduction moments at initial contact in the counter movement jump.

At the first visit to eligible teams, all players conducted the adapted FMS test. Players that obtained ≥ 9 points out of 12 points were excluded and did not conduct any of the other baseline tests. When players with score of 9 points or more were excluded, it was supposed that the included participants were those with the poorest neuromuscular control of the lower extremities. The cut-off value of 9 points were decided out from other studies, which have investigated risk of injury in association with the FMS^{TM}. Two-thirds of the total possible score have previously been suggested as a crucial cut-off point for increased risk of injury (30-32). However, with an adapted FMS procedure it cannot be certain that two-thirds of the total still is valid as cut-off point. Further, if players with 9 points or more were included in this study, stronger correlations at baseline or correlations between the change values could have been found. This question remains to be answered and future research should in particular investigate if adapted screening procedures with only lower extremity tests or upper body tests are associated with injuries in that specific part of the body.

An apparent strength of this study are the high reliability of the hand-held dynamometer. Intraclass correlation coefficients from the pilot testing in this study were of similar strength as results reported in another study investigating reliability of hip abductor strength testing in side-lying position (38). The controlled design of this study is considered as a strength. The low number of teams did not allow a cluster-randomization, therefore the controlled design was chosen over a randomized design. If a randomized design for group allocation of participants had been conducted, participants in the control group could have been exposed to the training program by being on the same handball team as participants in the intervention group. The controlled design allowed whole teams in either control or intervention group and thereby blinding of the control group to the training program. By using this controlled design there were a risk of selection bias between the two groups. However, there were no significant differences between the groups in either the descriptive statistics or mean values on test performance at baseline. Another strength of this study was the supervision of the training program in the intervention group. At least one of the researchers involved in this study was present at all training sessions conducted by the intervention group and could instruct all participants properly and register compliance at each session.

There are also some limitations to this study. More reflexive markers could have been used during the biomechanical assessment. Especially, since some markers were masked when the participants performed the different jump tasks, leading to missing data on some participants regarding knee abduction moments. Lack of effect of the training program on hip abductor strength is a clear limitation of the study. In the design phase of this study, it was decided that it would be most effective to conduct the training program immediately after usual team training to maximize compliance. Low adherence to the training program, especially at the end of the intervention period might be a reason to the absence of change in hip abductor strength. A reason to this could have been large match exposure in the last weeks of the intervention period. This led to low attendance on usual team training sessions, which again influenced compliance in this study. Almost all of the training sessions in the intervention group were conducted immediately after the usual team training. However, a minority of our training sessions were conducted before intervention teams usual training. On these sessions, participants were given at least 30 min recovery before team training began. The physiotherapist who performed all screening tests at baseline and post-test were blinded to group allocation of the participants. Although, the physiotherapist might have remembered persons and screening points between baseline and post-test. Further, many Spearman rho correlation tests were done in the analysis of these results. This could have led to some spurious correlations. Emphasis have not been paid to results were correlations on only one of two legs existed. Significant correlations on both legs of similar strength are more trustworthy than results found on only one leg.

There were no reported injuries due to the testing procedure or the functional strength training program. However, the risk of delayed onset of muscular soreness as a response to the training program were present. The training program was conducted immediately after the interventions teams finished their team training. Subjects who participated as controls were offered the possibility to perform the training program after post-test was completed.

In conclusion, some correlations were found between the three testing procedures at baseline. The training program conducted by the intervention group increased knee control during screening and reduced knee valgus in take-off phase of counter movement jump and at initial contact of an in-jump task. However, hip abduction strength was not increased during the intervention period. Thus, when returning from an injury or signing on for new team athletes should therefore be revised to a comprehensive evaluation including different testing procedures, since none of the testing procedures analyzed in this study can predict outcome of the other procedures.

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