

# Predictors of lower extremity injuries in team sports (PROFITS-study): a study protocol

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## ABSTRACT

**Introduction:** Several intrinsic risk factors for lower extremity injuries have been proposed, including lack of proper knee and body control during landings and cutting manoeuvres, low muscular strength, reduced balance and increased ligament laxity, but there are still many unanswered questions. The overall aim of this research project is to investigate anatomical, biomechanical, neuromuscular, genetic and demographic risk factors for traumatic non-contact lower extremity injuries in young team sport athletes. Furthermore, the research project aims to develop clinically oriented screening tools for predicting future injury risk.

**Methods:** Young female and male players (n=508) from nine basketball teams, nine floorball teams, three ice hockey teams, and one volleyball team accepted the invitation to participate in this four-and-half-year prospective follow-up study. The players entered the study either in 2011, 2012 or 2013, and gave blood samples, performed physical tests and completed the baseline questionnaires. Following the start of screening tests, the players will be followed for sports injuries through December 2015. The primary outcome is a traumatic non-contact lower extremity injury. The secondary outcomes are other sports-related injuries. Injury risk is examined on the basis of anatomical, biomechanical, neuromuscular, genetic and other baseline factors. Univariate and multivariate regression models will be used to investigate association between investigated parameters and injury risk.

## INTRODUCTION

More than 420 000 Finnish children and adolescents participate in organised sports outside of school hours, and team sports, such as ice hockey and floorball, are the most popular among this youth population.<sup>1</sup> Unfortunately, these popular sports also include a risk of traumatic and overuse injuries. In particular, the incidence of traumatic ankle and knee joint injuries is high,<sup>2–8</sup> most likely because players perform frequent

## Strengths and limitations of this study

- This study uses a multifactorial approach to investigate risk factors for traumatic lower extremity injuries.
- The sample size may not be sufficient for analysing all injury types separately.

rapid cutting manoeuvres. In addition, other traumatic injuries such as muscle strains and contusions, as well as overuse-related musculoskeletal problems in the lower extremities (LE), are common in these sports.<sup>2–8</sup>

An injury that appears to be a serious problem in many team sports is the ACL rupture.<sup>3 6 9</sup> These affect female players more often than male players and it has been estimated that female players have approximately 4–6 times higher risk for tearing the ACL than their male counterparts.<sup>9</sup> An ACL injury causes a long-term absence from sports and markedly increases the risk for post-traumatic degenerative joint disease.<sup>10–12</sup>

Despite the above, risk factor studies in youth sports are scarce. Moreover, most of the knowledge on the risk factors for traumatic LE injuries has come from studies that have focused on one or a few risk factors only, although it is believed that sports injuries result from a complex interaction of many factors and events.<sup>13–16</sup>

Earlier studies have revealed that LE injuries are prone to recur and that previous injury is the leading risk factor for both reinjuries and new injuries.<sup>17–19</sup> Other risk factors that have been discussed in the sports injury literature include joint laxity,<sup>20–22</sup> anterior pelvic tilt,<sup>23</sup> LE malalignment,<sup>23–25</sup> poor muscular strength and muscular imbalances,<sup>25 26</sup> poor balance<sup>27</sup> and deficits in



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neuromuscular control and movement patterns.<sup>25 28</sup>

However, very little is known about the wide variety of risk factors suggested and their potential interactions with LE injury in youth team sports. Therefore, we decided to investigate a series of different potential risk factors, and included several anatomical, neuromuscular, biomechanical, genetic and demographic screening measurements into this study to assess their role as potential predictors for traumatic LE injuries. If the screening tests could be used to detect young players with a higher risk of injury, this would represent an important advance in the development of more effective sports injury prevention.

## METHODS

### Objectives

The overall aim of this research project is to investigate anatomical, biomechanical, neuromuscular, genetic and demographic risk factors for traumatic non-contact LE injuries in young team sport athletes. The main research question is: Which factors are the main predictors for a future traumatic non-contact LE injury? In addition, the research project aims to develop clinically oriented screening tools that have good sensitivity and specificity for predicting future LE injury risk.

### Study design and definitions

This is a 4.5-year prospective cohort study with two different data collection periods. During the first 3-year study period (2 May 2011 to 30 April 2014), all new time-loss injuries, including overuse and traumatic injuries, were registered weekly, whereas over the second 1.5-year study period (1 May 2014 through 31 December 2015), two cross-sectional surveys are being conducted regarding the occurrence of new ACL injuries during the latter data collection period.

The validity and reliability of the study measurements and questionnaires were assessed in the pilot study in 2010 at the UKK Institute, Tampere, Finland. The definitions follow Fuller *et al*'s<sup>29</sup> guidelines for sports injury research.

### Team recruitment

We invited 27 teams (with about 650 players) from Finland to participate in the study: 10 basketball, 10 floorball, 3 ice-hockey, 2 handball and 2 volleyball teams. Basketball and floorball teams were recruited from six sports clubs from the Tampere City district, Finland. Ice-hockey, handball and volleyball teams were invited via the national sports associations of these sports. Twenty-one of the teams invited were youth male and female teams (aged 13–21 years) from the two highest youth league levels, and six were adult elite female teams. The reason for inviting the adult female teams was the high percentage of young players in them.

Managers of each sports club/sports association were contacted in January/February 2011 and they all agreed

to support team recruitment. Thereafter, we invited the coaches of the 27 teams to an information meeting where we encouraged the teams to participate in one or more baseline examination (May 2011, April/May 2012 and/or April/May 2013) and the ensuing data collection periods (through December 2015). Coaches from nine basketball teams, nine floorball teams, three ice-hockey teams and one volleyball team agreed to take part in the study. Final participation was based on informed written consent from each player (and parent/guardian, if the player was under 18 years of age). We included players if they were official members of the participating teams. The flow of players (n=508) can be seen in [figure 1](#).

### First data collection period (May 2011–April 2014)

In the first 3 years of the study, the baseline examinations, including questionnaires and physical tests, were performed annually in April–May at the UKK Institute, Tampere, Finland (2 teams performed their baseline examination in September). After each baseline examination (2011, 2012 and 2013) a 12-month follow-up was conducted during which all time-loss sports injuries as well as exposure data were recorded.

Each team could choose which of the three baseline examinations they wished to complete.

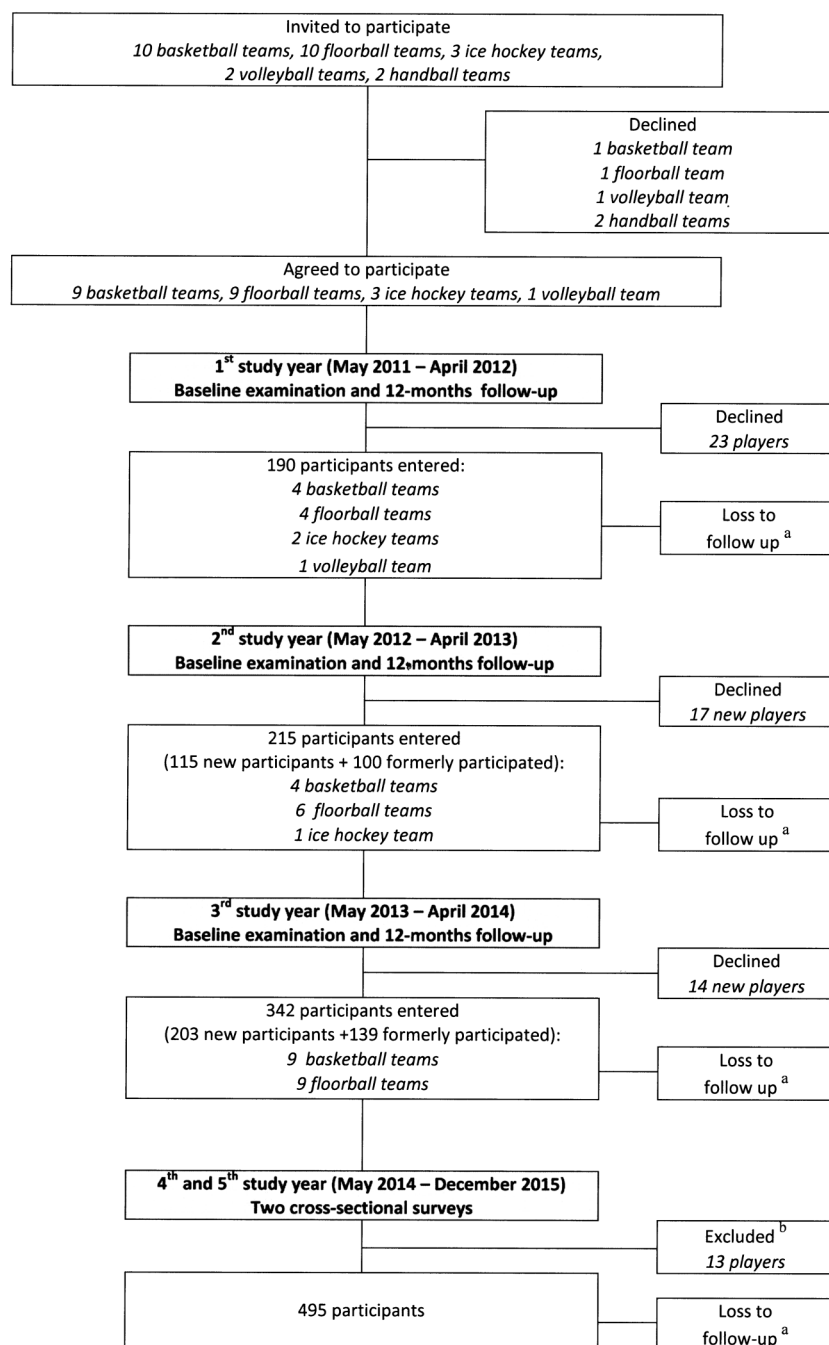
However, we encouraged teams and players to participate in all three test sessions (2011, 2012 and 2013), since various factors may change over time in this young cohort. Participants who did not appear for their next baseline examination received a web-based questionnaire to check the completeness and coverage of injury and exposure data collection during the foregoing follow-up period, as well as their willingness to take part in the next follow-up year. In total, 508 players entered the study, of whom 190 players joined the study in the first year, 115 players in the second and 203 players in the third study year ([figure 1](#)).

### Baseline questionnaires

At each baseline examination (2011, 2012, 2013), each player completed a detailed questionnaire covering questions about demographic information, such as age, gender, dominant leg, nutrition, alcohol and tobacco use, menstrual history, chronic illnesses, medication, oral contraceptive use, family history of musculoskeletal disorders, previous ACL injuries, playing years, player position, playing level and time-loss injuries, as well as training and playing history during the previous 12 months (see online supplementary appendix 1). The questionnaire was based on previous sports injury studies from our group.<sup>3 30–32</sup>

In addition, players completed questionnaires on their knee function (see online supplementary appendix 2) and history of low back pain (LBP) (see online supplementary appendix 3). Questions about knee function were based on the Knee and Osteoarthritis Outcome Score (KOOS) form,<sup>33</sup> which has been shown

**Figure 1** Flow of teams and players.



<sup>a</sup> Loss to follow-up will clear up when the data is completed

<sup>b</sup> Players who had not participated in blood test or physical tests 2011–2013 were excluded

to be a valid method to assess knee problems after surgical treatment. The LBP questionnaire was based on the standardised Nordic questionnaire of musculoskeletal symptoms<sup>34</sup> and on its modified version for athletes.<sup>35</sup> The standardised Nordic questionnaire for musculoskeletal health has been shown to be a valid and reliable method for data collection in adult populations.<sup>34</sup>

#### DNA sample

In total 5 mL of venous blood was extracted by an authorised health professional when players performed

their first baseline examination. We will investigate the relationship between injuries and genetic variants of genes encoding for structural components of tendons and ligaments (eg, the  $\alpha 1$  chain of type I collagen (COL1A1) gene and the  $\alpha 1$  chain of type V collagen (COL5A1) gene).<sup>36 37</sup>

#### Physical tests

A comprehensive test battery was used to investigate potential anatomical, biomechanical and neuromuscular risk factors for injuries (see online supplementary

**Table 1** Physical tests

Test station	Procedures
Station I	Anthropometric measurements <ul style="list-style-type: none"> <li>▶ Body weight (kg)</li> <li>▶ Height (cm)</li> <li>▶ Body dimensions according to Yeadon's Method<sup>41</sup></li> </ul>
Station II	Three-dimensional motion analyses <ul style="list-style-type: none"> <li>▶ Test preparations: placing the markers</li> <li>▶ 5 min warm-up by cycling</li> <li>▶ Hip stability<sup>42</sup></li> <li>▶ Running trials<sup>43</sup></li> <li>▶ Cutting technique 90° (new test)</li> <li>▶ Cutting technique 180° (new test)</li> <li>▶ Vertical drop jump<sup>28 44</sup></li> </ul>
Station III	Quadriceps and hamstring strength test <ul style="list-style-type: none"> <li>▶ 5 min warm-up by cycling and isokinetic warm-up sets</li> <li>▶ Quadriceps and hamstring strength<sup>45</sup></li> </ul>
Station IV	Joint laxity, muscle extensibility, balance and hip strength tests <ul style="list-style-type: none"> <li>▶ Knee joint laxity<sup>46</sup></li> <li>▶ Hip abductor strength<sup>47 48</sup></li> <li>▶ Hamstring extensibility<sup>49</sup></li> <li>▶ Genu recurvatum<sup>50</sup></li> <li>▶ Iliopsoas and quadriceps extensibility<sup>51 52</sup></li> <li>▶ Hip anteversion<sup>53</sup></li> <li>▶ Generalised joint laxity<sup>54 55</sup></li> <li>▶ Star excursion balance test<sup>27 56</sup></li> </ul>
Station V	Knee and pelvic control and foot pronation tests <ul style="list-style-type: none"> <li>▶ Warm-up exercises and test preparations</li> <li>▶ Single leg squat<sup>38</sup></li> <li>▶ Single leg vertical drop jump<sup>38</sup></li> <li>▶ Vertical drop jump<sup>28 38</sup></li> <li>▶ Foot pronation<sup>31 57</sup></li> </ul>
Station VI	Balance platform tests <ul style="list-style-type: none"> <li>▶ 5 min warm-up by cycling</li> <li>▶ Single leg balance<sup>17</sup></li> <li>▶ Double leg balance (good balance programme B)</li> <li>▶ Single leg drop jump (new test)</li> </ul>
Station VII	One repetition maximum leg press <ul style="list-style-type: none"> <li>▶ Warm-up sets</li> <li>▶ Leg press test<sup>31</sup></li> </ul>

appendices 4–18).<sup>31 38–40</sup> The screening test sessions included warm-up trials and physical tests, which were performed at seven test stations (table 1). Each player spent about 6 h in total to complete all tests. Players wore shorts, a sports bra (females) and indoor basketball or floorball shoes. Some of the tests were performed without shoes (eg, balance tests, foot pronation test and anthropometrics).

### Injury and exposure registration

During the first data collection period (May 2011–April 2014), all injuries were registered with a structured questionnaire, including the time of occurrence, place, cause, type, location and severity of the injury (see online supplementary appendix 19). The questions used in the injury form were based on validated questions of the previous floorball study.<sup>3 30</sup> Five study physicians were responsible for collecting the injury data. The

physicians contacted the teams once a week to check possible new injuries. After each reported injury, a study physician interviewed the injured player using the aforementioned structured questionnaire. An injury was recorded if the player was unable to fully participate in a game or practice session during the next 24 h. Severity of injury was defined as the number of days missed from training and playing. The player was defined as injured until she/he was able to train and play normally again.

During follow-up, each coach recorded player participation in practices and games on a team diary and also noted all injured players. Player attendance in a training session (yes/no), duration of a training session (h), contents of the training session (sports specific training/condition training) and attendance in each period of a game (yes/no), were recorded individually for each player. At the end of each follow-up month, the coach returned the team diary to the research group.



At the end of the first data collection period (May 2014), all participants received a web-based questionnaire to check the completeness and coverage of injury and exposure data collection during the previous follow-up year.

### Second data collection period (May 2014–December 2015)

In the final 1.5 study years the participating players were followed twice (May 2015 and December 2015) with an automatic text message questionnaire (short message service, SMS) regarding the occurrence of ACL injuries of the knee during follow-up: *Have you had an ACL injury of the knee (no/yes)?* After each new ACL injury, the study physician or physiotherapist contacted the injured player and interviewed her/him using a structured questionnaire (see online supplementary appendix 19). The injured players were asked for separate permission to allow the researchers to check the ACL injury information from their medical records. All players who had entered the study and participated in the blood test or at least in one physical test session (2011, 2012 or 2013) were included in this latter 1.5-year follow-up (n=495).

### Outcomes

The primary outcome is a traumatic LE injury (eg, ligament injury of the knee or ankle, hamstring strain) that occurs in non-contact circumstances. The secondary outcome is other sports-related injury. Injury risk is examined on the basis of anatomic, biomechanical, neuromuscular, genetic and other baseline factors (eg, age, gender, sport, previous injuries). We will also investigate the risk factors for non-contact ACL injuries, if the sample size is sufficient for the analyses.

### Sample size

On the basis of the Bahr and Holme,<sup>58</sup> the sample size needs to be 20–50 injuries to detect moderate to strong associations between risk factors and injury risk. Strong associations are defined as a relative risk higher than two. Estimates based on previous studies suggest that 0.2–0.6 non-contact LE injuries<sup>3–5 7 8 30</sup> and 0.02 ACL injuries<sup>3 4</sup> occur per player per year. Accordingly, we estimated that during the first 3 years of study at least 90 non-contact LE injuries will appear among participants, if we recruited 150 participants for each year (altogether 450 person-years). Correspondingly, the estimated number of ACL injuries during the total 4.5-year follow-up will be 30 injuries, where we have been able to recruit 150 new participants in each study year (2011, 2012 and 2013) and if we have managed to follow them until the end of the study (total 1575 person-years).

### Statistical analyses

Descriptive statistics of baseline characteristics of the participants will be reported by using mean, SD and 95% CIs. The injury incidence will be expressed as the number of injuries per 1000 h of training and playing (injuries registered during the first data collection

period May 2011–April 2014) and as the number of injuries per person-years (ACL injuries during the total 4.5-year follow-up). Univariate and multivariate regression models will be applied to investigate the association between the investigated parameters and injuries in order to identify the risk factors. In the data analysis by multilevel modelling we will take the clusters into account. Adjusted and unadjusted results will be presented. A p value <0.05 is considered significant.

### DISCUSSION

Several intrinsic risk factors have been suggested to be associated with increased LE injury risk, but, at the time being, there is limited knowledge on these. As this study combines measures of anatomical, biomechanical, neuromuscular, genetic and demographic factors, we will be able to study multiple factors that can predispose the player to a traumatic LE injury. Also, we can assess the relative importance of the different factors and their interactions. We will also perform risk factor analyses for specific injury subgroups, such as ACL injury, as well as other potential injury types where the number is sufficient.

Basketball, floorball, ice hockey and volleyball were chosen in this study, because they are the most popular team sports among youth in Finland. They also share somewhat similar injury patterns as well as comparable playing seasons. One playing season lasts approximately 7 months, from September/October to March/April, thus all the participating teams performed the baseline examinations during the preseason. Twenty teams performed the baseline tests in April/May, and the remaining two teams conducted them in September, due to their team schedule.

This study will provide valuable information, assessing the validity of screening methods for youth sport. Most of the screening tests used in this study are simple and easy to manage, meaning that implementation at the grass roots level will be possible. In addition, successful results from this project would provide a major contribution to tailor preventive methods, the effectiveness of which could be tested in prevention studies.<sup>59</sup> Better knowledge on risk factors will be used to optimise the current training programmes and target these to populations at risk. The findings will also be beneficial and adaptable to other pivoting sports with high sports injury risk.

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**Contributors** All the authors participated in conceiving and designing the study, revising the manuscript and read and approved the final manuscript. KP is the principal researcher and responsible for club recruitments (with TV), overall study arrangements, data collection and for familiarising study assistants with screening tests. GM, KS, TK and RB selected the measurements for the comprehensive testing battery, except for hip stability (MTR), running trials (J-PK), cutting technique 180° (KP), and iliopsoas and quadriceps extensibility (MTR). JA, JPe and J-PK were responsible for the 3D-motion capture technology and measurements. MTR contributed to the anatomical and balance tests. JPa and PK recruited and supervised the study physicians who carried out injury data collection. TV, AH and UMK recruited the study assistants and supervised data procedures. KP and MTR wrote the first draft of the paper. KP is the guarantor.

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**Competing interests** None declared.

**Patient consent** Obtained.

**Ethics approval** Before starting the study, the Ethics Committee of Pirkanmaa Hospital District, Tampere, Finland, (ETL-code R10169) approved the study plan. The study was conducted by following medical research ethics (the Declaration of Helsinki) and guidelines for good scientific practice. The participants took part in the study voluntarily, and signed a written consent of participation. For players under 18 years of age, their parents/guardians also provided written informed consent. The aim and execution of the study were clarified in the consent. The participants were also told that they are free to withdraw from the study at any time without providing a reason. The participants were asked for separate permission to allow the researchers to check possible injury information on their medical records. The collected information is stored in a locked room at the UKK Institute. The research information is handled anonymously according to the confidential obligations, and the collected data are only available to the research group. The data registry will be deleted 10 years after finishing the study. The data collected will be published anonymously.

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## Supplementary file PROFITS-study

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## Appendix 1. Baseline questionnaire

The questionnaire is based on the previous sports injury studies [1, 2, 3, 4].

- Dominant hand (left/right)
- Dominant leg (left/right)
- Chronic illnesses (no/yes, specify your illnesses)
- Regular use of medication (no/yes, specify your medication)
- Pain killer use during previous 7 days (no/yes)
- Musculoskeletal injuries/disorders of parents or siblings (no/yes, specify)
- Menstrual cycle (year of first menstruation, and length of menstrual cycle)
- Oral contraceptive use (no/yes)
- Special diets (no/yes, specify your special diet)
- Additional nutrients (no/yes, specify your additional nutrients)
- Alcohol use (no/yes, how often do you use alcohol?)
- Nicotine use (no/yes, which nicotine products, and how often do you use nicotine products?)
- Main sport (basketball / floorball / ice hockey / volleyball)
- Starting age
- Playing position
- Playing on adults highest league level (no/yes)
- Do you play other competitive sports regularly? (no / yes, specify)
- Training during previous season
  - o Sports specific training (number of practices per week, and training hours per week)
  - o Conditioning training (number of practices per week, and training hours per week)
  - o Other sports (number of practices per week, and training hours per week)
- Number of games during previous season
- Total hours of training and playing during previous year (<400h/400-549h/550-699h/>700h)
- Off-season length
- Time-loss injuries during previous 12 months (site and type of injury, time-loss from sports)
- Number of previous anterior cruciate ligament injuries (question separately for left and right leg)
- Number of previous traumatic knee injuries (question separately for left and right leg)
- Number of previous overuse knee injuries (question separately for left and right leg)
- Osteoarthritis of the knee (no/yes; question separately for left and right leg)
- Number of previous fractures on lower extremity (question separately for left and right leg)
- Number of previous traumatic ankle injuries (question separately for left and right leg)
- Number of previous hamstring strains (question separately for left and right leg)
- Number of previous groin injuries (question separately for left and right leg)
- Brace use (no/yes, specify the type of brace)

## **Appendix 2. Knee survey (KOOS)**

Questions about knee function are based on the Knee and Osteoarthritis Outcome Score (KOOS) form [5]. The questions are asked separately for the left and right knee.

### ***Symptoms***

These questions should be answered thinking of your knee symptoms during the last week.

- S1. Do you have swelling in your knee? (never/rarely/sometimes/often/always)
- S2. Do you feel grinding, hear clicking or any other type of noise when your knee moves? (never/rarely/sometimes/often/always)
- S3. Does your knee catch or hang up when moving? (never/rarely/sometimes/often/always)
- S4. Can you straighten your knee fully? (never/rarely/sometimes/often/always)
- S5. Can you bend your knee fully? (never/rarely/sometimes/often/always)

### ***Stiffness***

The following questions concern the amount of joint stiffness you have experienced during the last week in your knee.

- S6. How severe is your knee joint stiffness after first wakening in the morning? (none/mild/moderate/severe/extreme)
- S7. How severe is your knee stiffness after sitting, lying or resting later in the day? (none/mild/moderate/severe/extreme)

### ***Pain***

- P1. How often do you experience knee pain? (never/monthly/weekly/daily/always)

What amount of knee pain have you experienced the last week during the following activities?

- P2. Twisting/pivoting on your knee (none/mild/moderate/severe/extreme)
- P3. Straightening knee fully (none/mild/moderate/severe/extreme)
- P4. Bending knee fully (none/mild/moderate/severe/extreme)
- P5. Walking on flat surface (none/mild/moderate/severe/extreme)
- P6. Going up or down stairs (none/mild/moderate/severe/extreme)
- P7. At night while in bed (none/mild/moderate/severe/extreme)
- P8. Sitting or lying (none/mild/moderate/severe/extreme)
- P9. Standing upright (none/mild/moderate/severe/extreme)

### ***Function, daily living***

The following questions concern your physical function. For each of the following activities please indicate the degree of difficulty you have experienced in the last week due to your knee.

- A1. Descending stairs (none/mild/moderate/severe/extreme)

- A2. Ascending stairs (none/mild/moderate/severe/extreme)
- A3. Rising from sitting (none/mild/moderate/severe/extreme)
- A4. Standing (none/mild/moderate/severe/extreme)
- A5. Bending to floor/pick up an object (none/mild/moderate/severe/extreme)
- A6. Walking on flat surface (none/mild/moderate/severe/extreme)
- A7. Getting in/out of car (none/mild/moderate/severe/extreme)
- A8. Going shopping (none/mild/moderate/severe/extreme)
- A9. Putting socks/stockings (none/mild/moderate/severe/extreme)
- A10. Rising from bed (none/mild/moderate/severe/extreme)
- A11. Taking off sock/stockings (none/mild/moderate/severe/extreme)
- A12. Lying in bed (turning over, maintaining knee position) (none/mild/moderate/severe/extreme)
- A13. Getting out/in of bath (none/mild/moderate/severe/extreme)
- A14. Sitting (none/mild/moderate/severe/extreme)
- A15. Getting on/off toilet (none/mild/moderate/severe/extreme)
- A16. Heavy domestic duties (moving heavy boxes, scrubbing floors etc)  
(none/mild/moderate/severe/extreme)
- A17. Light domestic duties (cooking, dusting etc) (none/mild/moderate/severe/extreme)

### ***Function, sports and recreational activities***

The following questions concern your physical function when being active on a higher level. What degree of difficulty you have experienced during the last week due to your knee?

- SP1. Squatting (none/mild/moderate/severe/extreme)
- SP2. Running (none/mild/moderate/severe/extreme)
- SP3. Jumping (none/mild/moderate/severe/extreme)
- SP4. Twisting/pivoting on your knee (none/mild/moderate/severe/extreme)
- SP5. Kneeling (none/mild/moderate/severe/extreme)

### ***Quality of life***

- Q1. How often are you aware of your knee problem? (never/monthly/weekly/daily/constantly)
- Q2. Have you modified your life style to avoid potentially damaging activities to your knee? (not at all/mildly/moderately/severely/totally)
- Q3. How much are you troubled with lack of confidence in your knee? (not at all/mildly/moderately/severely/extremely)
- Q4. In general, how much difficulty do you have with your knee? (none/mild/moderate/severe/extreme)

### **Appendix 3. Low Back Pain questionnaire**

The questionnaire is based on the standardized Nordic questionnaire of musculoskeletal symptoms [6] and on its modified version for athletes [7].

- Have you ever experienced LBP?
- Have you ever had surgery because of LBP?
- Have you ever had radiating LBP?
- Have you ever had sleeping difficulties because of LBP?
- How many days have you had LBP during the past 12 months: none, 1-7 days, 8-30days, >30days but not daily, daily?
- Have you had LBP during the previous 7 days?
- Have you been examined or treated for LBP by medical personnel in the previous 12 months?
- How did your LBP symptoms occur: sudden, gradual, both?
- How many days of practicing have you missed because of LBP during the past 12 months: none, 1-7 days, 8-30 days, >30 days?
- How many matches have you missed because of LBP during the past 12 months: none, 1-3 matches, 4-10 matches, >10 matches?
- Have you had LBP during the following parts of the previous season: basic training period, competitive season, off-season?
- Have you had LBP as a result of body contacts in training or playing?
- Have you experienced LBP during the following training: sports specific training, strength training, plyometric training, other training?

#### Appendix 4. Anthropometric measurements

All anthropometric measurements are assessed in a standing position. Altogether 95 variables are assessed to estimate inertia parameters with Yeadon's method [8]. The equipment needed for measuring are: a measuring tape, a caliper (Bahco, SNA Europe, Cergy Pontoise, FRANCE), a high-precision scale (Sartorius F150S-D2, Goettingen, Germany), and a standard tape height measure (Gima S.p.A., Milano, ITALY).

Torso				p	w	h	P=perimeter w=width h=height
Ls0 hip joint centre							
Ls1 umbilicus							
Ls2 lowest front rib							
Under BH (Ls2b)							
Ls3 nipple						Distance shoulder joint centre	Depth shoulder
Ls4 shoulder joint centre							
Ls5 acromion/neck							
Ls6 beneath nose						Depth above ear	
Ls7 above ear							
Ls8 top of head							
Left arm	p	w	h				
La0 shoulder joint centre						Length finger - finger	
La1 mid-arm						ASIS distance	
La2 elbow joint centre						ASIS - umbilicus	
La3 maximum forearm perimeter						Umbilicus - proc. xyphoid	
La4 wrist joint centre						Proc. xyphoid. - C7	
La5 length hand						C7 - top of head	
Right arm	p	w	h				
Lb0 shoulder joint centre							
Lb1 mid-arm							
Lb2 elbow joint centre							
Lb3 maximum forearm perimeter							
Lb4 wrist joint centre							
La5 length hand							
Left Leg	p	w	h				
Lj0 hip joint centre							
Lj1 crotch							
Lj2 mid-thigh							
Lj3 knee joint centre							
Lj4 maximum calf perimeter							
Lj5 minimum calf perimeter							
Lj6 ankle joint centre							
Lj7 ankle-floor height							
Lj8 length foot							
Right Leg	p	w	h				
Lk0 hip joint centre							
Lk1 crotch							
Lk2 mid-thigh							
Lk3 knee joint centre							
Lk4 maximum calf perimeter							
Lk5 minimum calf perimeter							
Lk6 ankle joint centre							
Lj7 ankle-floor height							
Lj8 length foot							
Width, length, height	Right	Left					
Width femur condyles							
Width tibia condyles							
Length foot							
Width foot							
Width ankle							
Width elbow							
Width hand							
Height floor-hip joint centre							
Height floor-shoulder							

Length finger - finger	
ASIS distance	
ASIS - umbilicus	
Umbilicus - proc. xyphoid	
Proc. xyphoid. - C7	
C7 - top of head	

Height

Weight

Height

Weight



## **Appendix 5. Three-dimensional (3D) motion analyses**

3D-motion analyses are used to investigate the athletes kinematics and kinetics during dynamic movements in a 3D-laboratory. Eight infrared cameras (Vicon T40, Oxford, UK) and two force platforms (AMTI, Watertown, Massachusetts) are needed to record marker positions (Plug-In Gait full body model, Vicon, Oxford, UK) and ground reaction force (GRF) data synchronously at 300 and 1500 Hz, respectively.

First, the reflective markers are placed on the athlete's skin. Bilateral placement of markers is carried out according to Plug-in Gait full body model (Vicon, Oxford, UK).

The markers:

- 1 on the shoe over the second metatarsal head
- 1 over the posterior calcaneus
- 1 on the lateral malleolus
- 1 on the lateral shank
- 1 on the lateral knee
- 1 on the lateral thigh
- 1 on the anterior superior iliac spine (ASIS)
- 1 on the posterior superior iliac spine (PSIS)
- 1 on the clavicle
- 1 on the sternum
- 1 on the C7 vertebra
- 1 on the Th10 vertebra
- 1 on the shoulder
- 1 on the elbow
- 2 wrist markers
- 1 on the finger
- 4 head markers.





After the markers are placed, the 5 minutes cycling warm-up and a static calibration trial are performed. The testing protocol contains five tasks. Prior each task 1-3 practice trials are allowed. The trials are accepted if the entire foot lands on the force plate and the markers stay tightly on the athlete's skin throughout the task.

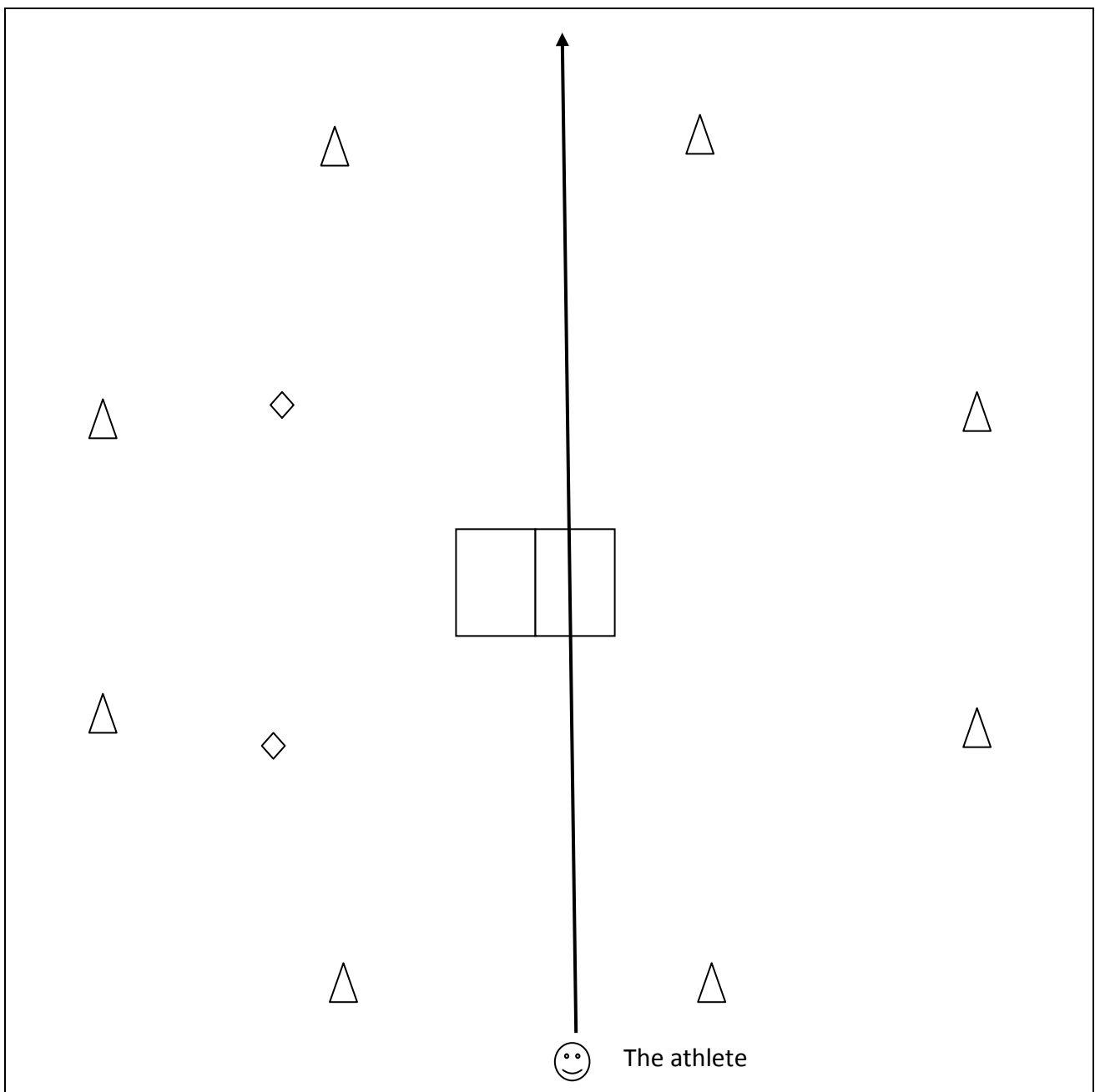
The 3D-tasks:

1. *Hip stability* [9]. Modified version of the Trendelenburg test to assess hip stability. The athlete stands with 20 cm stance, one leg on each force plates. First, the athlete is instructed to lift a dominant leg twice by flexing hip and knee. Then same trial is performed twice with a non-dominant leg.
2. *Running trials* [10]. The athlete performs approximately 10-15 running trials over the force plates until five accepted trials are captured for both legs. Two photocells are used to control the velocity ( $4.0 \text{ ms}^{-1} \pm 0.2 \text{ ms}^{-1}$ ) between 8-10m section of the runway. Set up of the test is described on the page 9.
3. *Cutting technique 90°* (new test). The athlete stands at the corner of the testing lab with a floorball stick in her/his hands, and a study assistant with a stick and the ball stands at the diagonal corner. The athlete runs towards the assistant who is holding the ball. Then the assistant passes the ball to another assistant standing on the opposite site, and simultaneously the athlete performs a 90° turn on the force plates and accelerates towards the second assistant. Three valid trials are collected from both sides. Only ice hockey and floorball players perform this test. Set up of the test is described on the page 10.
4. *Cutting technique 180°* (new test). First, the athlete stands on the starting point with proper playing posture. The athlete receives a pass from a study assistant and passes the ball back to the assistant (short one-touch pass). Then the athlete accelerates for 4 meters on her/his lateral direction, performs a quick 180° turn on the force plates and returns as fast as possible at the starting point where she/he receives and passes the ball again. Three valid trials are collected from both sides. Ice hockey, floorball and basketball players perform the test. Set up of the test is described on the page 11.
5. *Vertical drop jump (VDJ)* [11, 12]. The test is carried out using a 30 cm box. Static recording of the athlete in an anatomically neutral position with feet 30 cm apart is measured before the test starts. The athlete is instructed to drop off the box and land symmetrically on both feet, one foot on each force plate, and perform a maximal jump immediately after landing. To ensure the jump with maximum effort, a high jump stand with upholstered bar is placed above the force plates, and the athlete is instructed to touch the bar with a head. Three valid trials are collected.

## Three-dimensional (3D) motion analyses





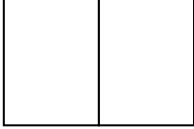
### *Set up for the running trials*

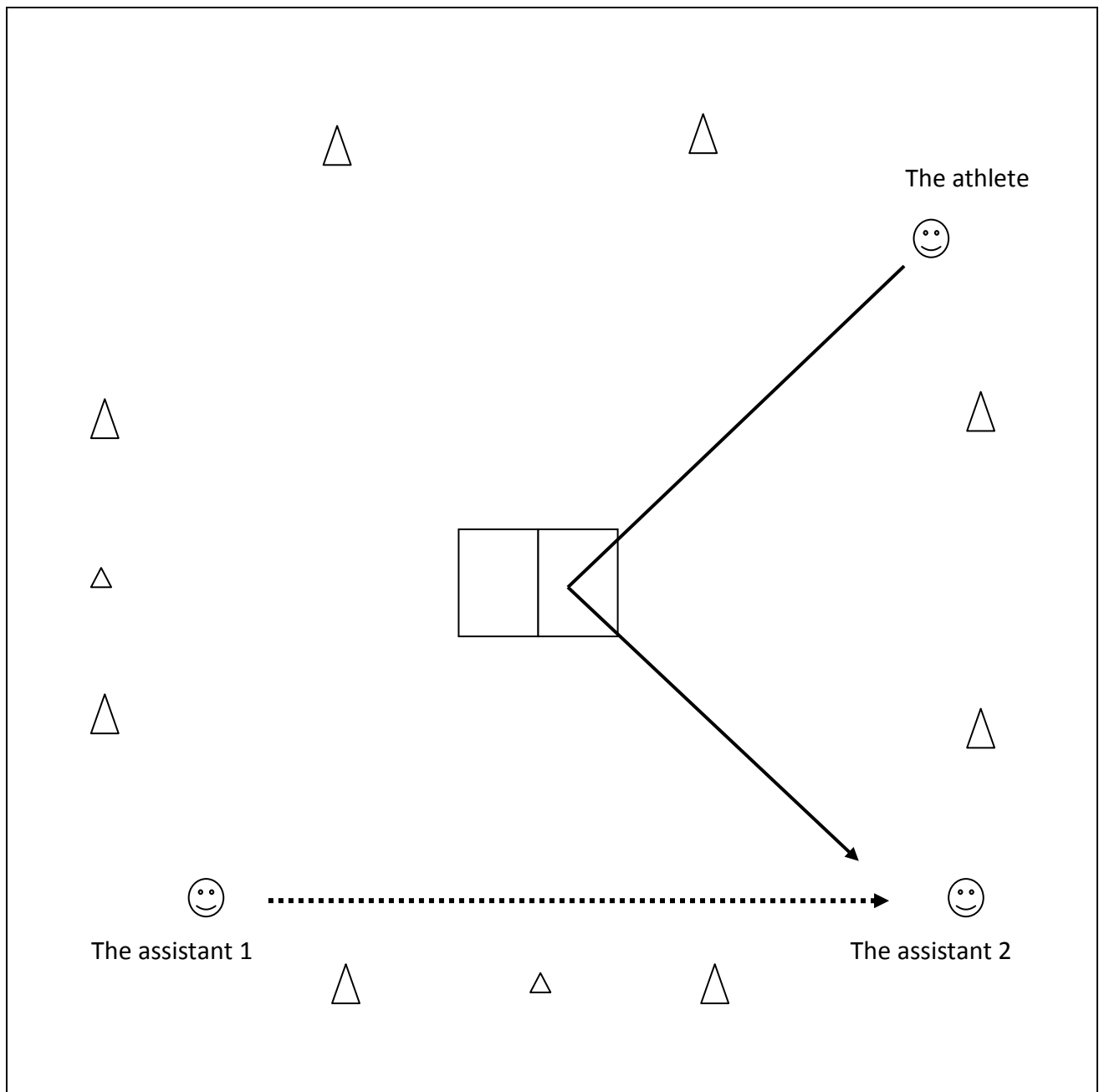
- Size of the room: 15 m x 15 m
-  = high-speed camera
-  = photocell
-  = athlete's running track
-  = two force-plates



## Three-dimensional (3D) motion analyses





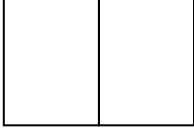
### *Set up for the Cutting technique 90°*

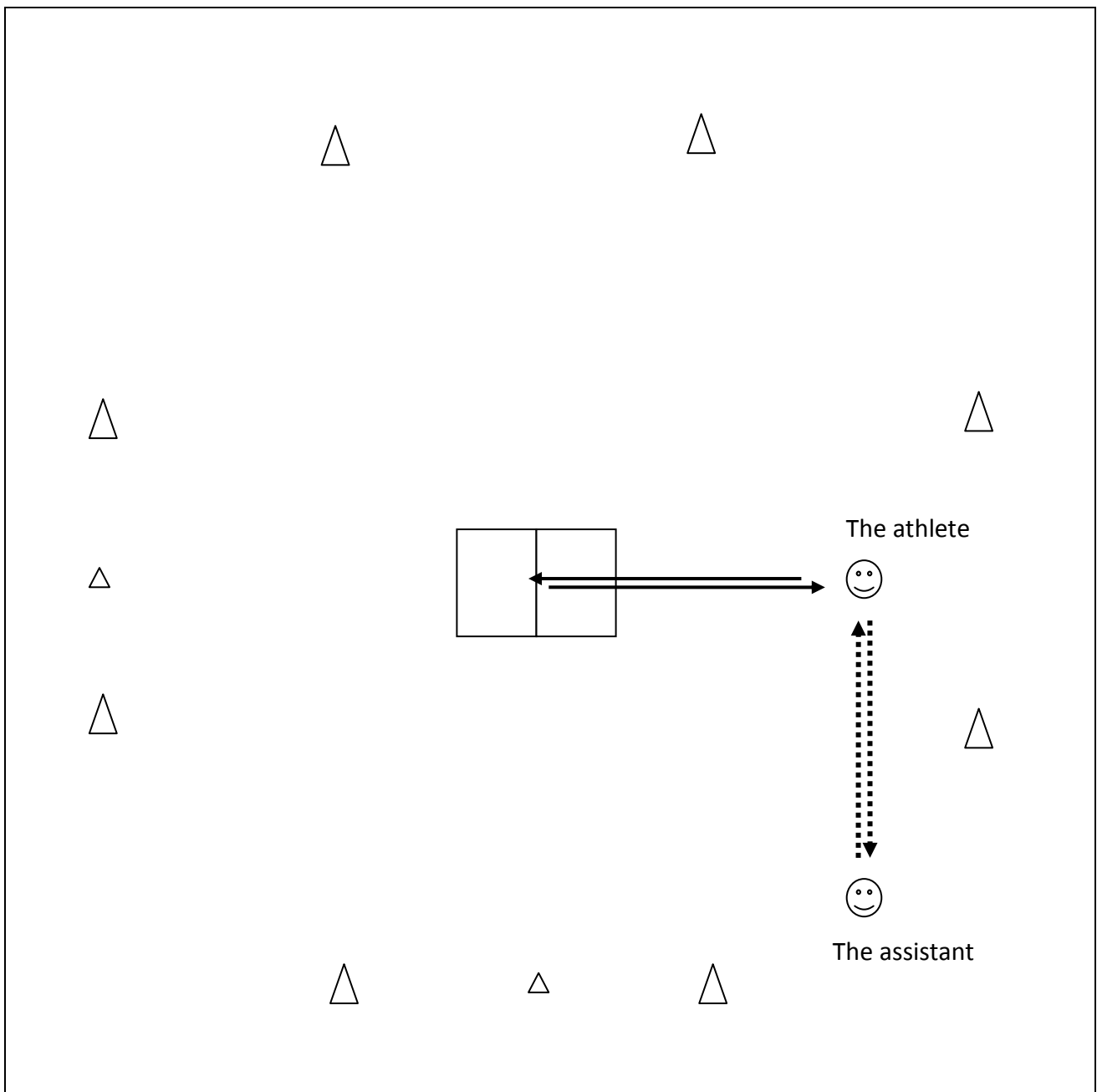
- Size of the room: 15 m x 15m
-  = high-speed camera
-  = basic video camera
-  = athlete's running track
-  = pass from assistant 1 to assistant 2
-  = two force-plates



## Three-dimensional (3D) motion analyses

### *Set up for the Cutting technique 180°*

- Size of the room: 15 m x 15 m
-  = high-speed camera
-  = basic video camera
-  = short passes
-  = athlete's running track
-  = two force-plates





## **Appendix 6. Quadriceps and Hamstring strength**

Maximal isokinetic quadriceps and hamstring concentric strength [13] of both legs is tested with a Biodex Multi-Joint System Pro dynamometer (Biodex System 4, Biodex Medical Systems, Inc., Shirley, NY, USA). Isokinetic muscle strength testing is a widely used method and has been established as a reliable tool for assessing muscle force [13].

Prior to the test the athlete performs a warm-up by 5 min cycling and two isokinetic warm-up sets with 20 seconds recovery between the sets (1<sup>st</sup> set = two repetitions with 30% of maximal power, 2<sup>nd</sup> set = three repetitions with increasing power 40%-60%-80%).

The real test includes three repetitions with maximum power. The test range of motion is 90° through 15° of knee flexion with an angular velocity of 60°/s. Strength is reported as the maximal (peak) torque recorded.

## **Appendix 7. Knee joint laxity**

The KT-1000 arthrometer (MEDmetric Corp, San Diego, California) is used to measure anterior-posterior (A-P) knee laxity (A-P displacement of the tibia relative to the femur). The reliability of KT-1000 arthrometer measurements has been shown to be good [14, 15].

The athlete is in a supine position on an examination table. The knee joint space line is marked medially with the knee in slightly flexed position ( $25^{\circ} \pm 5^{\circ}$ ). The athlete is asked to relax her/his leg muscles and hold both hands on the stomach. First, posterior-directed forces are applied to the tibia to establish a zero reference point, followed by anterior-directed forces (134 N) to measure anterior knee joint laxity (mm). Two trials are performed for both legs. If the athlete has suffered an ACL injury previously, the test is performed on the healthy leg first.

## **Appendix 8. Hip abductor strength**

Maximal isometric hip abductor strength is tested with a hand-held dynamometer (Hydraulic Push-Pull Dynamometer, Baseline® Evaluation Instruments, White Plains, NY, USA). Similar procedures have been established as reliable for testing hip abductor and adductor strength [16, 17].

The test is conducted with the athlete lying in supine position on a bench and legs extended. A belt is positioned over the pelvic and another one over the thigh. The dynamometer is positioned approximately 2 cm proximal to the lateral ankle malleolus with the leg in neutral position and the foot in slight dorsiflexion. The athlete's arms are held across the chest during the test. The muscle contraction is held for approximately two seconds. One practice trial is allowed, and after that two maximal contractions for each leg are performed with a 10 s rest period between the two attempts.

## **Appendix 9. Hamstring extensibility**

Testing of hamstrings extensibility is performed on an examination table with a firm surface and lumbar support. The athlete is lying on the bench in supine position with the pelvis and the non-tested leg stabilized using belts to avoid accessory movements. The hip of the testing leg is fixed at 120° flexion using a belt, and the athlete supports against further hip flexion by pressing with both hands distally on the femur. The ankle and foot are relaxed, and the hip is in neutral rotation, abduction and adduction. Three landmarks are placed on the leg: lateral fibular malleolus, lateral femoral epicondyle and the greater trochanter of femur. The knee is extended passively with an 8kg load (a fish scale, Salter Super Samson, Taylor Precision Products, Inc., Illinois, USA). A goniometer (HiRes, Baseline® Evaluation Instruments, White Plains, NY, USA) is placed to point of knee joint line and flexibility is measured as static range of motion. Davis and co-workers [18] have recommended to measure knee joint's angle as the most reliable method of testing the hamstrings extensibility.

## **Appendix 10. Genu recurvatum**

Knee hyperextension [19] is tested on an examination table. The athlete lies in supine position and a small bolster is placed under the distal aspect of the tibia. The anterior and posterior portions of the lateral knee joint line are palpated and a mark placed at the midpoint in the sagittal plane. The most prominent aspect of the lateral malleolus and the greater trochanter are palpated and marked. The athlete is then asked to fully relax and keep the hands on the stomach while the physiotherapist aligns the goniometer (HiRes goniometer, Baseline® Evaluation Instruments, White Plains, NY, USA) for measurement. The axis of the goniometer is positioned over the mark on the joint line, and the angle formed by a line from the lateral joint line to the greater trochanter. A line from the lateral joint line to the lateral malleolus is measured to the nearest degree with a goniometer.



## **Appendix 11. Iliopsoas and quadriceps extensibility**

Modified Thomas' test [20] is used to measure extensibility of iliopsoas and rectus femoris muscles. The athlete is placed in a supine position on an examination table with both ischiums on the edge of the table. She/he is instructed to flex one knee to the chest and hold it tight, and then the opposite lower limb is measured. To assess the extensibility of iliopsoas muscles, position of the thigh relative to the examination table surface is assessed with an inclinometer (Bubble Inclinometer, Baseline® Evaluation Instruments, White Plains, NY, USA). Second, the angle of the knee is measured with a goniometer (HiRes goniometer, Baseline® Evaluation Instruments, White Plains, NY, USA) to assess extensibility of the quadriceps muscles.

## Appendix 12. Hip anteversion

Craig's test [21] is used to measure hip anteversion. The athlete lies in prone position on a bench and with the head and neck in a relaxed position on the bench (no pillow), while the physiotherapist passively flexes the knee to 90°. The athlete is fixed with a belt over the pelvis. The hip is passively rotated internally and externally until the most lateral portion of the greater trochanter is palpable. In this position, the angle between the true vertical and the shaft of the tibia is measured to the nearest degree. The measure is taken with a universal goniometer (Absolute+Axis™ Baseline® Evaluation Instruments, White Plains, NY, USA) modified with a bubble level to ensure that the stationary arm is held at true vertical. Anteversion is measured as a positive angle and retroversion as a negative angle. According to Ruwe and colleagues [21] ***the Craig's test is more*** reliable than the radiological techniques in evaluating anteversion of the hip.

### **Appendix 13. Generalized joint laxity**

Generalized joint laxity is measured using the Beighton scale [22]. The athlete is measured for excessive joint laxity at the trunk, the fifth fingers, thumbs, elbows, and knees. The score of four points or more on a scale of 0-9 indicates generalized joint laxity. Two goniometers (HiRes, Baseline® Evaluation Instruments, White Plains, NY, USA) are used to measure the fifth fingers, elbows, and knees.

The score:

- 1 point (each small finger): passive dorsiflexion of small finger metacarpophalangeal joint beyond 90°
- 1 point (each thumb): passive apposition of the thumb to the flexor aspect of the forearm
- 1 point (each elbow): hyperextension of elbow beyond 10° (landmarks: oleoid, epicondyle, shoulder center)
- 1 point (each knee): hyperextension of knee beyond 10° (landmarks: trochanter, femur condyle, malleolus)
- 1 point: forward flexion of the trunk with the knees fully extended and placement of the palms flat on the floor.

## **Appendix 14. Star Excursion Balance Test**

The athlete's dynamic balance of the lower extremities is measured by the Star Excursion Balance Test (SEBT). The test has been found reliable for investigating balance and ankle stability deficits [23, 24]. The test is performed without shoes. The standing foot is placed on the center point (marked area). From the center point, three bars with tape measures are attached to the floor in the anterolateral, mediolateral, and posterolateral directions ( $45^\circ$  in between antero- and mediolateral as well as between medio- and posterolateral directions). The aim is to find a stability and balance on the standing leg and reach out and push steadily the sliding measurement tool above the bar with the contralateral leg as far as possible while the heel of the standing foot is held down. The physiotherapist marks the distance (cm) of each trial. The athlete's hands have to be held on the iliacal crests during the whole testing. One practice trial in each direction is allowed and final test includes three complete rounds of each direction. Both legs are tested, and the test starts with balancing on the dominant leg.

## Appendix 15. Knee and pelvic control

The athlete's frontal plane knee and pelvic control is measured by three tests: single leg squat (SLS) [25], single leg vertical drop jump (SLVDJ) [25] and vertical drop jump (VDJ) [3, 11, 25]. Small pieces of sports tape are attached to the athlete's left and right anterior superior iliac spine and tuberositas tibiae.

Set up of the knee and pelvic control tests is described on the page 23. The frontal plane knee and pelvic control is estimated by marking the left and right anterior superior iliac spine and tuberositas tibiae. First, the athlete's ability to keep control of the knee and pelvis during the trials is subjectively assessed by the study physiotherapist with a frontal view. According to the study of Stensrud and co-workers [25] a graded scale (0-1-2) is used to classify the athletes' ability to keep the control of the knee and pelvis during the trials (0 corresponds to "good performance", 1 "reduced performance" and 2 "poor performance").

The scale:

- *0 Good performance* = good knee and pelvic control: no obvious valgus motion of the knee, no medial/ lateral movements or shivering of the knee, and no significant lateral tilt of the pelvis during the three trials
- *1 Reduced performance* = reduced knee and pelvic control: slight valgus position of the knee, some medial/ lateral movements or shivering of the knee, and some lateral tilt of the pelvis during the three trials
- *2 Poor performance* = poor knee and pelvic control: a patently knee valgus position, clear medial/ lateral movements or shivering of the knee, and clear lateral tilt of the pelvis during the three trials

In addition, the digital camera (Sony® Digital HD Video Camera Recorder HXR-NX70E, Sony Corporation, Tokyo, JAPAN) is situated in the front of the athlete. From the video image, the frontal plane knee and pelvic angles can be estimated by marking the estimated ankle, knee and hip joint centres in the image.

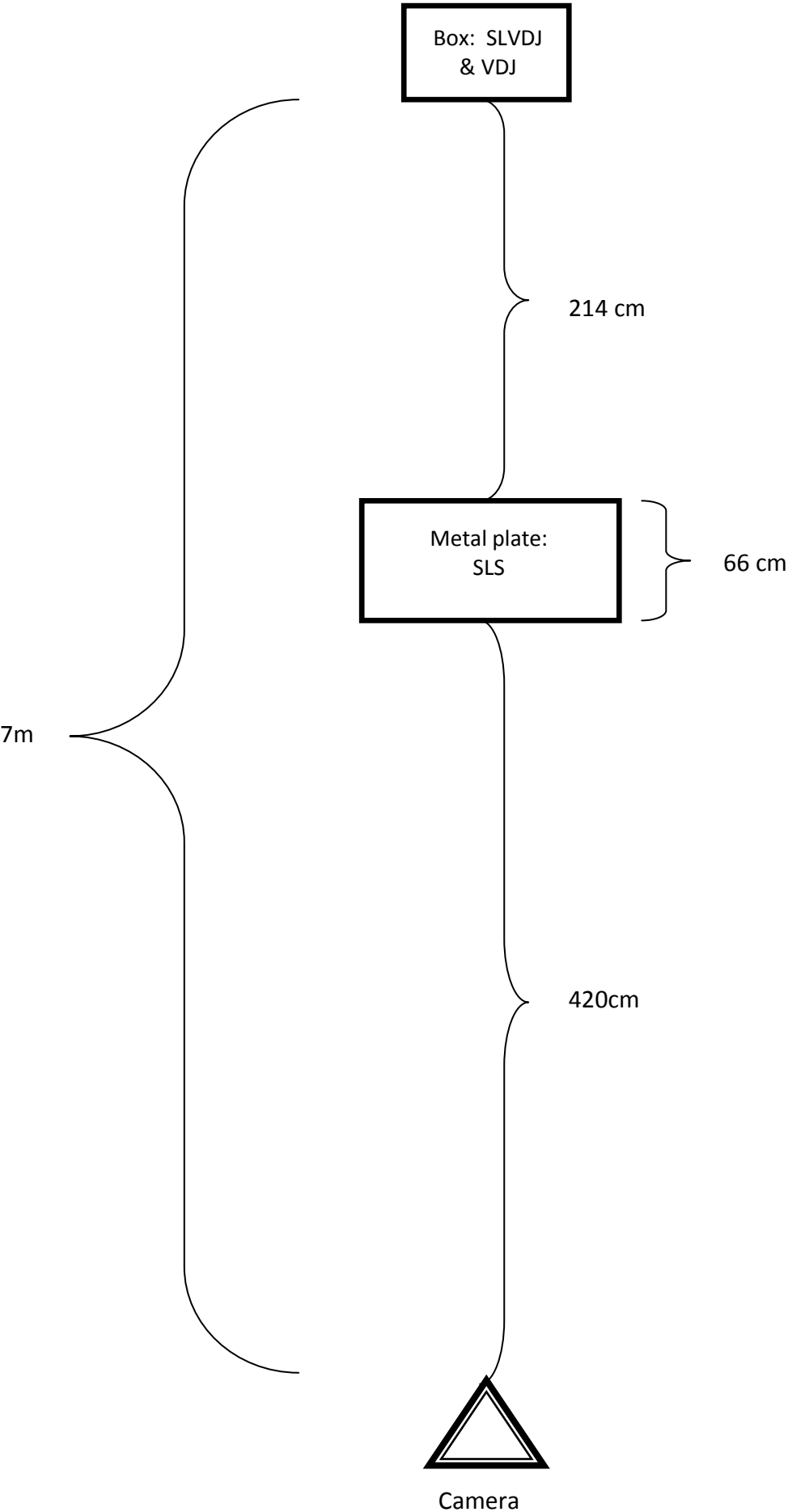
Prior to the tests the athlete executes warm-up exercises that consisted two-legged squats (2 x 8 repetitions), and two-legged jumps (2 x 5 repetitions) with 30 seconds recovery between sets. One valid practice trial is allowed ahead of each test, and then the athlete performs three trials on each test (SLS and SLVDJ are performed three times with left and right leg).

1. *Single leg squat (SLS)* [25]. In preparations for this test the athlete is asked to do a two-legged squat down to 90 degrees of knee flexion, which is measured with a standard goniometer (HiRes, Baseline® Evaluation Instruments, White Plains, NY, USA). In this static position a string with a small metallic object in one end is attached to the lateral aspect of the proximal thigh, with the metallic object slightly touching the ground. When the athlete performs a single leg squat standing on a metal plate (86cm x

66cm x 8mm), she/he hear a sound when reaching 90 degrees of knee flexion and is allowed to return to the starting point. The athlete is instructed to hold her/his hands at the waist and focus straight forward during the squat. A trial is failed 1) if the other leg is held in front, or to the side, of the body during the squat, 2) if the other leg touches the ground, 3) if the athlete fells, 4) if the athlete removes hands from the waist, or 5) if the athlete looks down during the trial.

2. *Single leg vertical drop jump (SLVDJ)* [25]. In the SLVDJ-test the athlete drops directly down from a 10cm box with one leg and immediately performs a maximum vertical jump on the same leg. The athlete is allowed to use her/his arms freely during the performance. To ensure that the athlete performs the jump with maximum effort a regular volleyball is attached above, and the athlete is instructed to touch the ball with both hands. A trial is failed 1) if the athlete jumps of the box instead of dropping, 2) if the other leg touches the ground, 3) if the athlete is clearly out of balance, or 4) if the athlete fells during the test.
3. *Vertical drop jump (VDJ)* [3, 11, 25]. The athlete starts on top of a 30 cm high box with the feet 30 cm apart (distance is measured between to markers on top of the box). The athlete is instructed to drop off the box and directly perform a maximum vertical jump. To ensure that the athlete performs the jump with maximum effort a regular volleyball is attached above, and the athlete is instructed to touch the ball with both hands. A trial failed 1) if the athlete reaches for the ball with only one hand, 2) if the athlete loses balance, or 3) if the athlete fells during the performance.

Set up for the knee and pelvic control tests



## **Appendix 16. Foot pronation**

Foot pronation is evaluated by the Navicular drop test [26]. The athlete stands on the platform, while the most prominent aspect of the navicular bone is marked by a marker pen. To determine navicular height in subtalar joint neutral position, the thumb and forefinger are used to palpate the anterior-medial and anterior-lateral head of the talus respectively, while the athlete rolls the ankle in and out. Subtalar joint neutral is defined as the position where the medial and lateral aspects of the talar head are equally palpable. From this position, a straight edge ruler (which is positioned perpendicular to the transverse plane) is used to measure the distance from the mark on the navicular to the floor to the nearest millimeter. The athlete is then instructed to relax her/his foot and evenly distribute weight between the left and right feet. In this relaxed stance, the distance between the mark on the navicular and the floor is again measured. Navicular drop is calculated by subtracting the standing relaxed from the standing subtalar joint neutral navicular height positions.



## Appendix 17. Balance platform tests

The athlete's balance is tested by three tests with the Good Balance system (Good Balance®, Metitur, Jyväskylä, Finland). Prior to the tests the athlete executed 5 min warm-up by cycling. One practice trial is allowed before each test, and then the athlete performs the test trials.

1. *Single leg balance* [27]. The athlete stands on one foot on a balance pad (Airex® Balance Pad Elite, 48cm x 40cm x 6cm, Alcan Airex, Sins, Switzerland) placed on the platform. The athlete is instructed to avoid any contact between the thighs, any contact to the balance pad or floor with the other leg. The arms and hands are held in a relaxed position in front of the body. The athlete is also instructed to look straight forward. Each leg is measured three times, 20 seconds each time.
2. *Double leg balance* (Good Balance procedure, program B). The athlete stands with both feet on the platform. Foot stance is on the shoulder width. Posture is symmetric to the line on the platform. The heels are close to the measuring line posteriorly and both hands were held on the hips. The athlete performs the test three times.
3. *Single leg drop jump* (new test). The athlete stands on one foot on the 60 cm height bench behind the platform with the toes slightly over the edge. Two balance pads (Airex® Balance Pad Elite, 48cm x 40cm x 6cm, Alcan Airex, Sins, Switzerland) are situated on the platform (one on the other). Also, a 5kg disc is placed on the peak top of the platform to compensate the impact of a drop jump. The hands are held on the hips. The athlete performs a drop-jump down on the pads with the same foot as vertical as possible, and aims to stabilize for five seconds. Three performances for both legs are measured.

## **Appendix 18. One repetition maximum (1RM) leg press**

A seated leg press machine (Technogym®, Gambettola, Italy) is used to measure the maximal extension strength of the lower extremity muscles. The distance between feet is 20 cm, end of the shoes are 10 cm above from the lowest end of the foot plate, and the back of the seat is set on 30° angle relative to the floor. A vertical bar is placed at the point where the knees reach the target knee angle (80°) (the weight holder of machine touches the bar when the correct knee angle is reached). The target knee angle is measured with a goniometer (HiRes, Baseline® Evaluation Instruments, White Plains, NY, USA) [3].

Warm-up protocol prior the test consists three warm up sets with 1 minutes recovery between the sets (1<sup>st</sup> set = 8 repetitions with 50kg, 2<sup>nd</sup> se = 4 repetitions with 80-90kg, and 3<sup>rd</sup> set = 1-2 repetitions with 120kg). Young athletes with minor weight training experience perform warm-up trials with 30kg lower weights.

The 1RM (repetition maximum) test protocol starts with 150kg (young athletes with 80-100kg). First, the physiotherapist helps the athlete to press the weight platform all way up. At the starting point the athlete's legs are extended. Then the athlete lowers the weights until the knees form the correct angle, and returns the weights back at the starting position. After each successful trial the weights are increased by 10-30 kg (Olympic Iron Weight Plates, Leoko Oy, Tampere, FIN) for the next attempt. Recovery period between the attempts is 2 minutes. In valid trial the weight holder touches the bar before the athlete presses the weight platform up again. The test ends when 1RM level is reached.

## Appendix 19. Injury questionnaire

The questions in the injury form are based on validated questions of the previous floorball study [1,2]. The definitions follow Fuller and co-workers' guidelines [28] for sports injury research.

- Date of injury
- Where did the injury occur? (in official game / friendly game / sports specific training / conditioning training / other)
- Questions for game injury
  - o Playing position
  - o Game period
  - o Time of game period
- Surface (wooden / artificial / other, specify)
- Injured body part (according to Fuller et al. 2006)
- Injured body side (right / left / both / not applicable)
- Type of injury (according to Fuller et al. 2006)
- Onset of injury (acute / overuse)
- New / recurrent injury?
- Question for recurrent injury
  - o Specify date of return to full participation from the previous injury
- Use of protective or supportive equipment (no/yes, specify)
- Was the injury caused by contact or collision? (no / yes, contact with another player / yes, contact with the ball, stick or other object)
- Question for contact injury
  - o Direct contact to the injured body part / indirect contact
- Describe the injury situation
- Existing video material of the injury situation (no / yes)
- Where the injury was treated?
- Medical investigations (MRI / ultrasound / other, specify)
- Diagnosis
- Orthopedic operations due to the injury (no / yes, specify)
- Time-loss from training (number of days)
- Time-loss from games (number of games)
- Time-loss from school/work (number of days)
- Previous menstruation (date)
- Direct costs of the injury

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