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Title: An Inertial Measurement Unit Based Method to Estimate Hip and Knee Joint Kinematics in Team Sport Athletes on the Field

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Author Questionnaire:

1. Microscopy: Does your protocol involve video microscopy? N

2. Does your protocol demonstrate software usage? Y

3. Which steps from the protocol section below are the most visually important?

3.1., 3.5., 3.7.-3.10.

4. What is the single most difficult aspect of this procedure and what do you do to ensure success?

2.7. The most crucial aspect of the procedure are the steps concerning attaching sensors to human body

2.11. The second most crucial aspect of the procedure is the sensor calibration procedure

5. Will the filming need to take place in multiple locations (greater than walking distance)? N

Script Length

Number of Shots: **40**

Section - Introduction

Videographer: Interviewee Headshots are required. Take a headshot for each interviewee.

1. REQUIRED Interview Statements (Said by you on camera): All interview statements may be edited for length and clarity.

1.1. **Michel S. Brink**: Achieving balance between training stimuli and recovery induces responses that lead to adaptation of the human body. Monitoring this process is essential for optimizing performance and reducing injury risk **[1]**.

1.1.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera

1.2. **Michel S. Brink**: The main advantage of this technique is that it focuses on the lower extremities of athletes and thereby provides additional information to current monitoring systems within the field **[1]**.

1.2.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera

OPTIONAL Interview Statements: (Said by you on camera) - All interview statements may be edited for length and clarity.

1.3. **Edwin A. Goedhart**: Muscle injuries are a serious problem in team sports. Using this method, we aim to reduce these injuries and to optimize performance in team sports athletes **[1]**.

1.3.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera

1.4. **Michel S. Brink**: Team sports such as soccer and hockey are characterized by fast changes of direction, accelerations, and decelerations that place high loads on the lower extremities and therefore require a specific sensor set-up **[1]**.

1.4.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera

Introduction of Demonstrator (Said by you on camera):

1.5. **Michel S. Brink**: Demonstrators of the procedure will be Bram J.C. Bastiaansen and Erik Wilmes, PhD students on our team **[1][2]**.

1.5.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera

1.5.2. The named technician, post doc, student looks up from workbench or desk or microscope and acknowledges the camera

Ethics title card: (for human subjects or animal work, does not count toward word length total)

1.6. Procedures involving human subjects have been approved by the Institutional Review Board (IRB) at The Centre For Human Movement Sciences.

Section - Protocol

2. Subject Preparation and IMU Sensor Calibration

2.1. ~~**[1].**~~ Obtain written informed consent from Subjects that meet the inclusion criteria **[2-TXT]**.

2.1.1. ~~WIDE: Talent measuring Subject height or weight~~ NOTE: 2.1.1 may have been combined with 2.2.1

2.1.2. Subject giving Talent filled out consent form **TEXT: See text for suggested inclusion/exclusion criteria** NOTE: This may be slated as 2.2.2.

2.2. Have the Subject fill out a questionnaire about their background in team sports **[1]**. Obtain information about the Subject's gender, age, body weight, and height **[2.1.1]**.

2.2.1. Shot of sample questionnaire OR Subject filling out questionnaire and talent measuring the subject's height/weight. NOTE: 2.2.1 and 2.1.1 combined

2.3. After the Subject has changed into sports clothing, align all IMUs (I-M-U's) next to each other **[1-TXT]** and push a button on top of the sensor to activate the IMUs **[2]**. The sensor is activated when the green light blinks **[3]**.

2.3.1. Talent aligning IMUs **TEXT: IMU: inertial measurement unit**
2.3.2. Talent placing button
2.3.3. Shot of blinking sensor

2.4. Then tap all of the IMUs together on a hard surface to ensure that a mechanical peak has been generated **[1]**.

2.4.1. Talent tapping IMUs on hard surface

2.5. Before attaching the IMUs, shave the Subject's body hair at the sacrum between both posterior superior iliac spines **[1]**, at the anteromedial part of both the right and left tibia **[2]**, and at the lateral part of both right and left thighs **[3]**.

2.5.1. Talent shaving sacrum
2.5.2. Talent shaving bony part of one tibia
2.5.3. Talent shaving lateral part of one thigh

2.6. When all of the regions have been shaved, apply adhesive spray to the exposed skin in a sweeping motion, holding the applicator at least 10 centimeters away from the skin**[1]**.

2.6.1. Adhesive being sprayed

2.7. After waiting 5-10 seconds for the spray to dry, remove the protective layer from the double-sided adhesive tape on the IMUs **[1]** and place each IMU at one of the shaved locations **[2]**. Sensor placement is a critical step for accurate estimation of lower extremity kinematics in the field **[3]**.

2.7.1. Talent removing tape
2.7.2. Talent placing IMU onto shaved location, with other placed IMUs visible in frame as possible. Vid NOTE: on shot 2.7.2. take 1 my voice says 2.7.1 *Videographer: Difficult step*
2.7.3. Added shot: videographer step 2.7.2., take 2. – Overview of sensor setup.

~~2.8. .~~

~~2.8.1.~~

2.9. Write down the IMU labels and anatomical locations for later reference **[1]** and attach stretching tape over each measurement unit to make sure the sensors are secured to the skin **[2]**.

2.9.1. IMU being labelled
2.9.2. Tape being placed over IMU

2.10. To calibrate the IMU sensors, instruct the Subject to stand still in a neutral position with their feet hip-width apart and their hands at their side for 5 seconds **[1]**.

2.10.1. Talent gesturing, while Subject assumes position

2.11. Next, instruct the Subject to perform a calibration procedure consisting of left hip flexion, followed by right hip flexion and a bowing movement **[1]**.

2.11.1. Talent gesturing, while Subject is performing calibration procedure *Videographer: Difficult step*

2.12. After waiting at least 5 seconds, have the Subject repeat the calibration procedure **[1]**.

2.12.1. Talent gesturing, while Subject repeats calibration procedure

3. 30-Meter Linear Sprint Test

3.1. Instruct the Subject to perform a warmup procedure, before starting the 30-meter linear sprint test **[1-TXT].**

~~3.1.1. WIDE: Talent gesturing, Subject warming up *Videographer: Important step* **TEXT: *e.g.*, the FIFA 11+ warmup program**~~

NOTE: Use shots frm 3.2., 3.3., 3.4. or 3.5 here.

3.2. To start the test, instruct the Subject to stand on the field **[1]** with their preferred foot on the starting line **[2]** and their shoulders behind the starting line **[3]**.

3.2.1. Subject getting into starting position
3.2.2. Shot of Subject foot on starting line
3.2.3. Shot of Subject w/ shoulders behind line *Video Editor: if possible/appropriate, indicate shoulders behind starting line*

3.3. Inform the Subject that the Test Leader will count down from 3 to 0 and shout "Start!" **[1-TXT]**.

3.3.1. Talent indicating Test Leader will countdown and yell Start **TEXT: Test begins when Start is called**

3.4. Instruct the Subject to sprint as fast as possible until the 30-meter end point has been reached **[1]**, at which point the Subject should decelerate as quickly as possible to a standstill position **[2]**.

3.4.1. Talent at 30-m end point indicating end point and/or sprinting
3.4.2. Talent miming stopping as quickly as possible Vid NOTE: slated as 3.4.1 take 4

3.5. Allow the Subject to ask questions **[1]** and to perform a practice run when desired **[2]**.

3.5.1. Subject asking questions while Talent listens *Videographer: Important step*
3.5.2. Subject performing practice run *Videographer: Important step*

3.6. After confirming that the Subject is ready **[1]**, make sure the Subject is in the correct starting position **[2]** before having the Test Leader initiate the test **[3]**.

3.6.1. Talent asking/Subject indicating thumbs up or similar
3.6.2. Subject getting into place NOTE: 3.6.2 also includes 3.6.1
3.6.3. Test Leader counting down and yelling Start

3.7. Start the timer when the start sign has been given and the Subject has started the sprint test **[1]**.

3.7.1. Talent starting timer/Subject starts sprint *Videographer: Important step*

3.8. Verbally encourage the Subject to achieve maximal performance during the sprint **[1]** and stop the timer when the Subject has reached a standstill position **[2]**.

3.8.1. Talent encouraging Subject *Videographer: Important step*
3.8.2. Talent stopping timer/Subject reaching standstill position *Videographer: Important step*

3.9. Include a 2-minute rest period between each trial **[1]** and have the Subject repeat the test two more times **[2-TXT]**.

3.9.1. Subject stretching or wiping face or other "resting" action *Videographer: Important step*
3.9.2. Subject returning to starting position and/or starting trial *Videographer: Important*

step **TEXT: Use fastest sprint for data analysis**

3.10. After the third trial, instruct the Subject to perform a cooling down procedure **[1]** before detaching the IMUs from the Subject **[2]**.

3.10.1. Talent instructing/Subject cooling down *Videographer: Important step*
3.10.2. Talent detaching IMUS *Videographer: Important step*

4. Data processing

4.1. To process data, open MATLAB **[1]** and import the raw IMU data files **[2]**.

4.1.1. WIDE: Talent opening MATLAB, with monitor visible in frame
4.1.2. SCREEN: Screenshot_1: 00:11 – 00:19

4.2. To align the sensor coordinate frame to the body segment, select the index numbers of the data file from when the subject was standing still during the calibration **[1]**.

4.2.1. SCREEN: Screenshot_1: 02:18-02:37 *Video Editor: please speed up*

4.3. Then select the index numbers of the data of the trunk movement during the calibration **[1]** and the index numbers of the data of the calibration movements of the right and left legs **[3-TXT]**.

4.3.1. SCREEN: Screenshot_1: 02:37 – 02:57 *Video Editor: please speed up*
~~4.3.2.~~
4.3.3. SCREEN: Screenshot_1: 2:58 – 03:35 *Video Editor: please speed up and, if possible, emphasize moments that data points are selected.* **TEXT: Save processed data for later analysis**

Section – Results

5. Results: Representative Kinematic Data for One Trial of a Linear 30-Meter Sprint Test

5.1. In this example, kinematic variables obtained by the IMUs are used in a segmental model to detect alterations **[1]**. The kinematic data of the subject **[2]** can be changed to the variables of interest **[3]**.

5.1.1. Screen: Screenshot_2: 00:23-00:35 *Video editor: please emphasize segmental model on right of screen*
5.1.2. Screen: Screenshot_2: 00:23-00:35 *Video editor: please emphasize kinematic graphs on left of screen*
5.1.3. Screen: Screenshot_2: 00:36 – 00:48

5.2. This figure illustrates an example of kinematic data of the lower extremity during the linear sprint test. **[1].** Note that the kinematic data for the subject changed when the subject was decelerating **[2]**.

5.2.1. LAB MEDIA: Figure 3
5.2.2. LAB MEDIA: Figure 3 *Video editor: please emphasize the decelerating part of the kinematic variables*

Section - Conclusion

6. Conclusion Interview Statements: (Said by you on camera) - All interview statements may be edited for length and clarity.

6.1. **Bram J.C. Bastiaansen**: The most important thing to remember is that the sensor placement and sensor calibration are crucial steps for an accurate registration of the joint kinematics in the field **[1]**.

6.1.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera (2.7., 2.11.)

6.2. **Michel S. Brink**: Combining our method with commonly used monitoring systems, such as global position registration systems, enables sport scientists and practitioners to obtain a better understanding of the loads to which athletes are exposed **[1]**.

6.2.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera

6.3. **Michel S. Brink**: In the future, our method could be integrated into smart garments, which could help professionals to gain new insights into evaluating and optimizing training and rehabilitation programs **[1]**.

6.3.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera

6.4. *Videographer/Video Editor/Voiceover Talent: no shot, no voiceover* **[1-TXT]**

6.4.1. **TEXT: Disclaimer: All measurements were performed in line with the current Covid-19 precautionary regulations.**