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## Biomechanical Analysis Methods to Assess Professional Badminton Players' Lunge Performance

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**TITLE:**

Biomechanical Analysis Methods to Assess Professional Badminton Players' Lunge Performance

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**KEYWORDS:**

Behavior, badminton, lower-limb kinematics, ground reaction force, right forward, lunge

**SUMMARY:**

Here, we present a protocol to evaluate the differences in injury mechanisms between professional and amateur players when performing a badminton maximal right lunge movement by analyzing lower limb kinematics.

**ABSTRACT**

Under the condition of simulating a badminton court in the laboratory, this study used the injury mechanism model to analyze the maximal right lunge movements of eight professional badminton players and eight amateur players. The purpose of this protocol is to study the differences in kinematics and joint moment of the right knee and ankle. A motion capture system and force plate were used to capture data of the joint movements of the lower extremity and the vertical ground reaction force (vGRF). Sixteen young men who did not have any sports injuries in the past 6 months took part in the study. The subjects performed a maximal right lunge from the start position with their right foot, stepping on and fully contacting with the force plate, hit the shuttlecock with an underhand stroke to the designated position in the backcourt, and then returned to the start/end position. All subjects wore the same badminton shoes to avoid a difference in impact from different badminton shoes. The amateur players showed a greater range of ankle movement and reverse joint moment on the frontal plane, and a larger internal joint rotation moment on the horizontal plane. The professional badminton players exhibited greater knee moment on the sagittal and frontal planes. Therefore, these factors should be considered in the development of the training program to reduce the risk of sports injuries in knee and ankle joints. This study simulates the real badminton court and calibrates the range of activities of each movement of the subjects so that the subjects complete the experimental action in a natural state with high quality. A limitation of this study is that it does not combine joint load and muscle activity. Another limitation is that the sample size is small and should be expanded in future studies. This research method can be applied to the lower limb biomechanical research of other footwork in the badminton project.

## **INTRODUCTION:**

Badminton has always been one of the most popular sports in the world. In a game, the frequency of performing lunges is relatively high<sup>1</sup>. It is of vital importance to master the ability to quickly perform a lunge and return to the start position or move in the other direction<sup>2</sup>. The lunge not only is crucial to badminton but also is of great importance to tennis, table tennis, and other sports.

The forward lunge has been taken as a function evaluation method for anterior cruciate ligament (ACL) deficiency and knee stability<sup>3,4</sup>. Studies show that badminton players need both high muscular strength and professional techniques. In general, amateur players pay more attention to technical training than to muscular strength training. If an individual of low-strength ability takes a low-quality training, the training time becomes longer, therefore leading to an overload of the lower limbs and even to a sports injury.

High-intensity training results in a large load on the lower limbs, which may be the cause of sports injuries<sup>5</sup>. Lower limb injuries account for 60% of the total number of injuries. For both male and female badminton players, the knee and the foot are the most vulnerable parts<sup>6-9</sup>. Kinetic data analysis can be used to explain the lower limb injuries of players at different levels. It was reported that professional badminton players have considerable intratendinous flow which rises after repetitive load movements, especially in the patella tendon of the dominant leg.

Reports show that previously conducted research on racquet sports mainly assessed kinematic parameters but focused less on kinetics<sup>2,10</sup>. When a professional player has played a competition, the pressure is concentrated in their Achilles tendon and anterior knee tendons, especially in the dominant lunge leg<sup>5</sup>. In racquet sports, clinical analyses of injuries mainly focused on the lower limb, which exceeded 58%, specifically on the knee and ankle<sup>5,8,10-13</sup>.

Previous studies have evaluated the physiological indicators of badminton<sup>14,15,16</sup> and the features of physical abilities<sup>17-20</sup>. Due to these basic features, basic actions on the agility of badminton are proposed to improve the training effect and the on-the-spot performance of the players<sup>21,22</sup>. Previous studies on badminton focused on different movements or directions of lunge movement without comparing the movement characteristics between professional and amateur badminton players<sup>23-27</sup>. These differences in dynamics and joint movement make them susceptible to different mechanisms of sports injuries.

The aim of this study is to study the differences in kinematics and dynamics between professional badminton players and amateur badminton players, as well as the range of movement (ROM) of the dominant leg. It is assumed that professional and amateur badminton players show differences in the right forward lunge and that a greater ROM increases the risk of sports injuries.

## **PROTOCOL:**

The experiment was approved by the Ethics Committee of the Faculty of Sports Science in Ningbo University. All the participants have signed written consents and were told about the

requirements and process of the lunge experiment.

## 1. Gait Laboratory Preparation

1.1. When calibrating, remove or cover other potentially reflective items in the volume, avoid the effects of reflections from sunlight, light, and other reflective items on the identification, and ensure a reasonable fluorescent light in the laboratory.

1.2. Plug the dongle into the PC and turn on the motion capture cameras, proprietary tracking software, force platform amplifiers, and the external analog-to-digital converter (ADC).

1.3. Place eight cameras on both sides of the simulated badminton court. Initialize the cameras. Select the **Local System** node from the **System** resources pane, and each of the camera nodes will display a green light if selected correctly.

1.3.1. In the **Camera** view pane, click **Properties** to adjust the camera parameters: set the **Strobe Intensity** to 0.95 to 1, the **Threshold** to 0.2 - 0.4, the **Gain** to times 1 (x1), the **Grayscale mode** to **Auto**, the **Minimum circularity ratio** to 0.5, the **Max blob height** to 50, and select **Enable LEDs**.

1.4. Select **Camera** in the **Perspective** pane and put the T-frame on the force plate. In the **System** resources pane, click the **MX Cameras**, and select multiple cameras to adjust the parameters.

1.4.1. In the **Setting** section, set the parameters of all selected cameras to ensure that data transmitted from each camera can be seen.

1.5. Select the **5 marker wand & T-frame** in the drop-down menu of the **T-frame** and select all the cameras.

1.6. Click the split screen button in the upper right corner of the **Properties** pane. Select the **Camera Positions** in the **Option** panel and click the **Off** button in the drop-down menu of the **Extended Frustum**.

1.6.1. Wave the T-frame around the capture volume and stop until the blue light of the camera stops flashing.

1.7. Start the calibration, which means the camera continuously collects the data of the markers and displays the collected valid data in the **MX Cameras Calibration Feedback** toolbar below the **Tools** pane. Finish the calibration; the progress bar returns to **0%**. Ensure the value displayed in the **Image Error** is less than 0.3.

1.8. Put the T-frame on the force plate (60 x 90 cm) with the axis along the edge of the plate. Ensure that the direction of the T-frame is in accordance with the experimental direction.

1.9. Ensure that the origin of the T-frame is also that of capture volume. Click the **Start** button

from the **Set volume origin** in the **Tool** pane to set the origin.

1.10. Ask the subjects to stand on the force plate. Confirm that the direction of the ground reaction vector is upward. Ask the subjects step off the force plate.

1.11. Before starting the trials, click the **Force**, and select **Zero Level**. Find the valid data collected in the **Wand Count** and ensure that each camera collects at least 1,000 frames of valid data.

1.12. Prepare 16 markers of 14 mm in diameter and paste double-sided tape on them in advance.

## **2. Subject Preparation**

2.1. Let potential subjects fill in a questionnaire survey. Obtain written informed consent from the subjects that fulfill the inclusion criteria.

NOTE: Questions: (i) How many years have you played badminton? (ii) Have you participated in professional national level badminton competitions? (iii) Have you suffered any sports injuries and received surgeries? Here, a total of 16 male participants took part in the study: eight professional badminton players and eight amateur badminton players.

2.2. Determine of the subjects meet the criteria.

NOTE: The criteria include the following items. All participants did not suffer from any injuries in the upper and lower limbs in the six months before the study; the subjects also did not take part in any high-intensity training or competition 2 d before the experiment; for all subjects, the right hand and leg were dominant. Half of the subjects were professional players, half were amateur players; this resulted in eight subjects who are professional badminton players (ages:  $23.4 \pm 1.3$  years; height:  $172.7 \pm 3.8$  cm; mass:  $66.3 \pm 3.9$  kg; badminton-playing years:  $9.7 \pm 1.2$  years) and have participated in professional national level competitions, and eight subjects who are amateur badminton players (ages:  $22.5 \pm 1.4$  years; height:  $173.2 \pm 1.8$  cm; mass:  $67.5 \pm 2.3$  kg; badminton playing years:  $3.2 \pm 1.1$  years).

2.3. Ask the subjects to wear T-shirts and tight shorts.

2.4. Measure the subjects' height (mm) and weight (kg), as well as the length of both left and right leg (mm) from the superior iliac spine to the ankle internal condyle, the knee widths (mm) from the medial to the lateral knee condyle, and the ankle widths (mm) from the medial to the lateral ankle condyle.

2.5. Mark the skin areas of the anatomical bony landmarks to place the makers.

2.5.1. Shave body hair as needed and wipe the skin with alcohol.

NOTE: The marker locations include spaces bilaterally located to the anterior-superior iliac spine,

posterior-superior iliac spine (PSI), lateral thigh (THI), lateral knee (KNE), lateral tibia (TIB), lateral ankle (ANK), heel (HEE), and toe (TOE).

2.6. Palpate to identify the anatomical landmarks. Paste the 16 markers on the lower limb.

2.7. Ask the subjects to wear the same brand and series of badminton shoes; then, let them perform a right forward lunge naturally, and ensure the markers on their lower limbs are captured by the cameras.

2.8. Ask the subjects to perform the right forward lunge at a comfortable low speed in the simulated court until they can perform the movement steadily, and instruct them to perform some auxiliary exercises (*e.g.*, marching lunge leg stretch) to warm up.

2.9. Ask the subjects to perform the right forward lunge at a comfortable high speed in the simulated court until they can perform the movement steadily at this speed; then, ask them to put their right leg in the designated area (position B in **Figure 1**) and underhand strike the shuttlecock to the backcourt (position C).

2.10. Instruct the subjects to perform a maximal right forward lunge from start position A (**Figure 1**) and underhand strike the shuttlecock to the backcourt (position C), ensuring that their right leg naturally steps on and fully contacts the force platform as they pass, and the subjects must go back to start position A after striking the shuttlecock.

### 3. Static Calibration

3.1. Open the **Data Management** to create a new database. Select the **Location**, type in the name, and select **Based on | Clinical template**; then, click on **Create**.

3.2. Select the subject's name and click on **Open**. Click on **New patient classification | New patient | New session** in order to create the subjects' information.

3.3. At the beginning of the trials, select **Session** to capture data. Return to the **Nexus** pane, click on **Subjects**, and then, click the **New subject** button. Rename the trials if necessary.

3.4. Click on **Go Live**, select **Split horizontally**, and select **Graph** to view the **Trajectory Count**.

3.4.1. Check the number of the markers, which is 16, indicating that there is no unwanted light pollution and all the markers have been captured.

3.5. Start to capture static data. In the **Subject Preparation** section of the toolbar, select **Subject Capture** and click the **Start** button. Ask the subjects to stay still and capture 200 frames of images. Click the **Stop** button.

3.6. Click on **Run the reconstruct pipeline** to construct markers data. Select **Label**, identify in the

markers' list, and apply the labels to the corresponding markers. Click the **Save** button. Press the **Esc** key to exit.

3.7. Click the **Subject Preparation** and select the **Static plug-in gait** in the **Subject calibration** drop-down menu.

3.8. Click **Option** in the **Frame range** window that is newly displayed and select **Left foot** and **Right foot** in the pop-up window. Select the **Start** button and, then, save.

#### 4. Dynamic Trials

4.1. Ask the subject to be in the proper start position.

4.2. After creating the static template, click the **Go Live** button and select the **Capture**. Set the **Trial Type** and the **Session** in order. Type in a trial name, and the **Description** is optional.

4.3. Click the **Start** button in the last option to start capturing and stop after finishing the process. Just repeat the process for each trial.

4.3.1. In order to conduct experiments, ask the subjects to perform the lunge fast and naturally. Ensure there is a 2 min interval between each trial.

4.3.2. Ask the subjects the perform the right forward lunge, of which the last step is on the force plate. Require the subjects to perform the movement 6x. If the markers shift or drop, reattach them promptly and capture again.

4.4. Select **Stop** after the subjects perform a maximal right forward lunge and go back to position A (start/finish position).

#### 5. Postprocessing

5.1. Use special software for postprocessing. Open **Data management**, double-click the **x** icon under **Files**, and click the **Run the reconstruct pipeline and labels** button; then, click **Play** under the **Perspective** pane to play the captured video.

5.2. Drag the pointers on the progress bar under the **Perspective** pane to set the start and end time of the video.

5.3. Place the cursor within the progress bar, and right-click to select **Zoom to Region-of-Interest**.

5.4. The identification step is the same as the static identification process. Check the markers and click **Fill**. Check if all the markers are identified by observing their trajectories. Right-click on unlabeled markers and select **Delete all unlabeled**.

5.5. Click **Start**, and the files will be exported in .csv format for postprocessing.

## 6. Data Analysis

6.1. Filter kinematic and kinetic data using low-pass Butterworth filters with frequencies at 10 Hz and 25 Hz.

6.2. Calculate the ROMs of the knee and the ankle on sagittal, frontal, and horizontal planes, and obtain the knee and ankle moments through the approach of three-dimensional inverse dynamics.

NOTE: The ROMs of the ankle and knee were obtained from the maximum and minimum joint angles on three-dimensional movement planes.

6.3. Divide the lunge into four phases, which include the initial impact peak (I, 5% of the stance), the secondary impact peak (II, 20% of the stance), weight acceptance (III, 40% - 70% of the stance), and the drive-off (IV, 80% of the stance).

6.4. Standardize all joint moment data by using the subjects' weights.

6.5. Collect ground reaction forces and kinematic data at the same time. For each subject, use the mean values of the kinematic and kinetic data of six successful trials for statistical analysis.

NOTE: The parameters include the joint (*i.e.*, ankle, knee, and hip) three-dimensional ROMs and the knee and ankle moments.

6.6. Transmit the data to the software for analysis.

## 7. Statistical Analysis

7.1. Examine the data of the captured ankle and knee ROMs and the joint moments, using independent-sampled *t*-tests between the professional players and the amateur players. Use a two-sample *t*-test to calculate the appropriate number of subjects. Indicate the joints' ROMs and moments by mean values. Set the significance level at  $p = 0.05$ .

### REPRESENTATIVE RESULTS:

**Figure 2** shows the mean vGRF of phases I, II, III, and IV (*i.e.*, the initial impact peak, secondary impact peak, weight acceptance, and drive-off phases, respectively) of the professional players and the amateur players when they performed a lunge. There is no significant difference in phases I, II, and III. However, the vGRF of the professional players is markedly higher than that of the amateur players, indicating a significant difference (**Figure 2**).

**Figure 3** shows the three-dimensional planes of the right knee and the ankle of the professional players and the amateur players when they stand. Results from independent *t*-tests reveal the



difference between the professional players and the amateur players in the ROM of the ankle, with professional players showing a greater ROM in the dorsiflexion/plantar flexion on the sagittal plane. The ankle shows a significant difference on the frontal and horizontal plane. The amateur players present a greater ROM in the inversion/eversion movement on the frontal plane, but a smaller ROM in the external/internal rotation movement on the horizontal plane. The knee indicates a significant difference between the professional players and the amateur players in the external/internal rotation movement on the horizontal plane. The professional players display a larger ROM in the flexion/extension on the sagittal plane and in the abduction/adduction on the frontal plane.

**Figure 4** shows the three-dimensional planes of the players' ankle moments. The amateur players present a smaller plantar flexion moment or a greater dorsiflexion moment in the four phases when performing a lunge. The professional players reveal a greater eversion moment in the weight acceptance phase when performing a lunge, which shows a significant difference, and they have a smaller internal rotation moment or greater external rotation moment in the drive-off phase when performing a lunge. **Figure 5** illustrates the knee moments. The professional players show a greater extension moment in the secondary impact peak phase, indicating a significant difference, and a greater abduction moment in the initial impact peak.

#### FIGURE LEGENDS:

**Figure 1: Experimental protocol.** The right foot naturally steps on and fully contacts with the force plate during the trial. (A) This indicates the start/stop position. (B) This indicates the landing position. (C) This indicates the shuttlecock landing area.

**Figure 2: Illustration of the mean vertical ground reaction force (vGRF) (with standard deviation) pattern of badminton players in the stance of the lunge.** There is a significant difference between the professional and amateur players in phase III.

**Figure 3: The ROMs of ankle and knee joints of the professional players and amateur players on sagittal, frontal, and horizontal planes.** (A) This panel shows the results of the sagittal planes. (B) This panel shows the results of the frontal planes. (C) This panel shows the results of the horizontal planes. The error bars indicate standard deviation. The \* indicates the significance level  $p < 0.05$ .

**Figure 4: The mean values of the ankle joint moment of the landing posture of the professional players and amateur players on sagittal (plantar flexion/dorsiflexion), frontal (eversion/inversion), and horizontal (internal/external rotation) planes.** The \* indicates significance level  $p < 0.05$ .

**Figure 5: The mean values of the knee joint moment of the landing posture of professional players and amateur players on sagittal (extension/flexion), frontal (abduction/adduction), and horizontal (internal rotation) planes.** The \* indicates significance level  $p < 0.05$ .

## DISCUSSION:

One of the disadvantages of most studies analyzing the biomechanical characteristics of the badminton lunging step is that they ignore the skill level of the badminton players performing the lunge. This study divides the subjects into professional players and amateur players to explore the differences in joint ROM and joint moment at different levels when performing a right forward lunge.

As for the ankle joint ROM on the frontal plane, the amateur players exhibited greater ROM than the professional players, indicating a significant difference, which may be related to the muscle strength of the ankle joint<sup>28</sup>. As for the ankle joint moment on the frontal plane, the professional players revealed a greater eversion moment in the weight acceptance phase, showing a significant difference with the amateur players, which may be related to the risk of ankle injury<sup>29</sup>. The amateur players showed a smaller ankle eversion moment, which may result from the poor lunge landing posture of the dominant leg. It is beneficial for training guidance and ankle rehabilitation. The professional players have a greater ankle moment in plantar flexion/dorsiflexion on the sagittal plane. In addition, the amateur players showed a greater internal rotation moment than the professional players, indicating a significant difference and showing different stability mechanisms of the ankle.

Given the difference in lunge landing posture between the professional players and the amateur players, the vGRF pattern can be divided into four phases, namely impact peak, secondary impact peak, weight acceptance, and drive-off (**Figure 2**). The difference in vGRF between the professional players and the amateur players found in the fourth stage may be due to the fact that elite badminton players have stronger knee extensors<sup>30</sup>.

A common goal of competitive sports is to reduce sports injuries so as to extend the athlete's athletic life. For amateur athletes, it is recommended to develop a comprehensive and reasonable training plan to standardize the correct technical movements, especially to reduce the damage caused by a wrong landing posture<sup>31</sup>. For professional athletes, the joint's load capacity should be considered, and the related protective gear and special sports equipment for athletes can be used to reduce ligament damage<sup>32,33</sup>.

The results rely on a great many important steps in the protocol. First, it is necessary to remove other reflective items in the experimental environment, to avoid their effect on camera identification, and to ensure reasonable fluorescent light in the experimental environment. Second, it is critical to adjust the camera parameters to a reasonable range for the accuracy of motion capture during the experiment. Third, it is of vital importance to identify anatomical landmarks, accurately attach the markers to the landmarks, and pay attention to whether the markers are shifted or dropped and promptly reattach them properly. Fourth, it is crucial to calibrate the force plate to its zero level before each dynamic capture. Another key step in the experiment is the data postprocessing. One of the limitations of this study is that the sample size is small, and it should be expanded in future studies. Another limitation is that it did not collect the lower-extremity muscle activities of the professional and the amateur badminton players during the lunge experiment when explaining the results of this study. Muscle activation and

strength count a lot in explicating the differences between professional and amateur badminton players. Future studies should assess different movement features of players with skills of different levels, combining joint load and muscle activity.

The results of this study indicate that there exist different risks of injury between professional and amateur badminton players. Amateur badminton players should consider these differences when developing training programs and injury prevention strategies to reduce potential damage to the ankle and knee.

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#### **DISCLOSURES:**

The authors have nothing to disclose.

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Figure 1: Experimental protocol. The right foot naturally steps on and fully contacts with the force plate during the trial (start/stop

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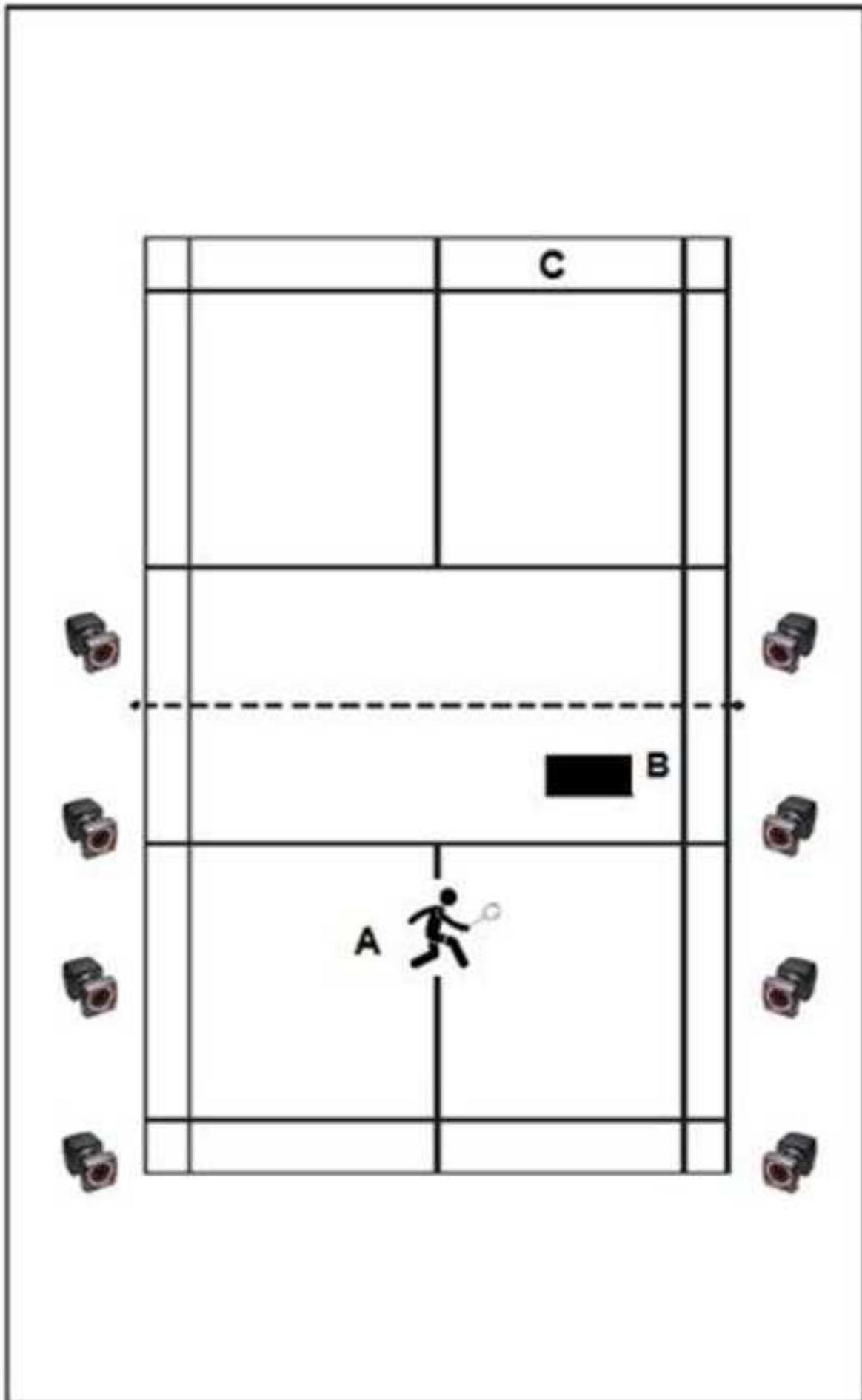
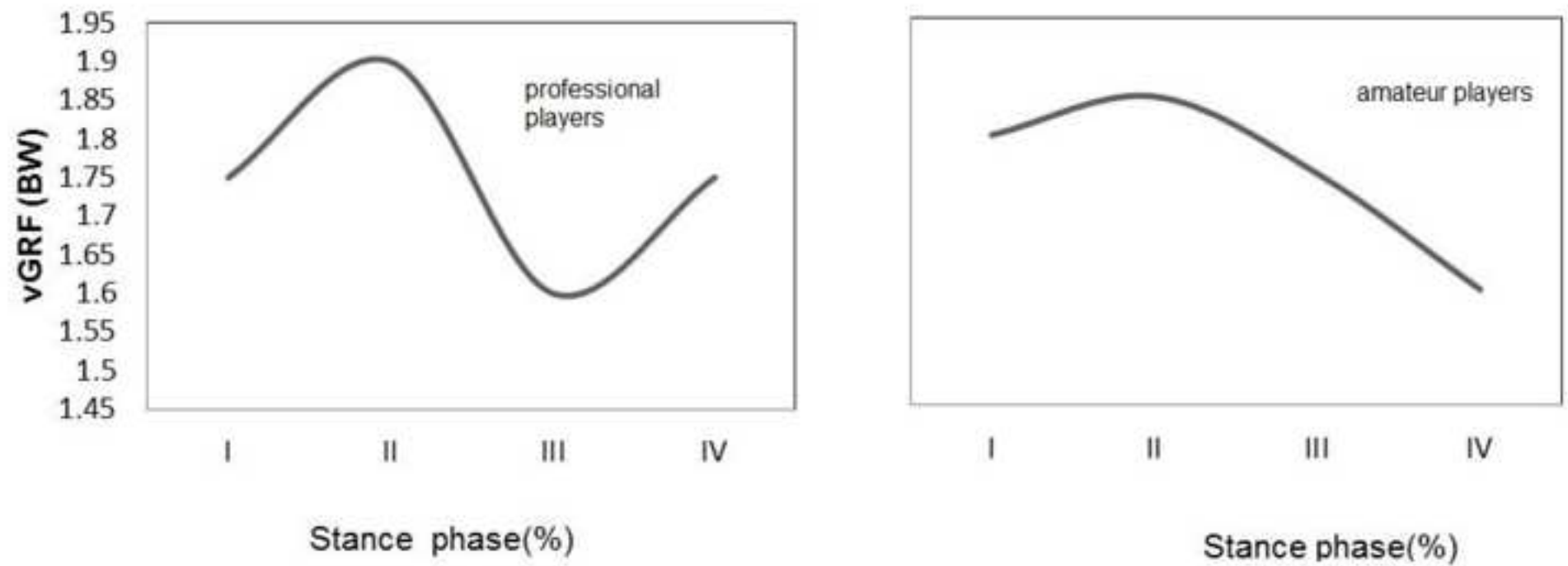


Figure 2: The illustration of mean vertical ground reaction force (vGRF) pattern of badminton players in the stance of lunge.



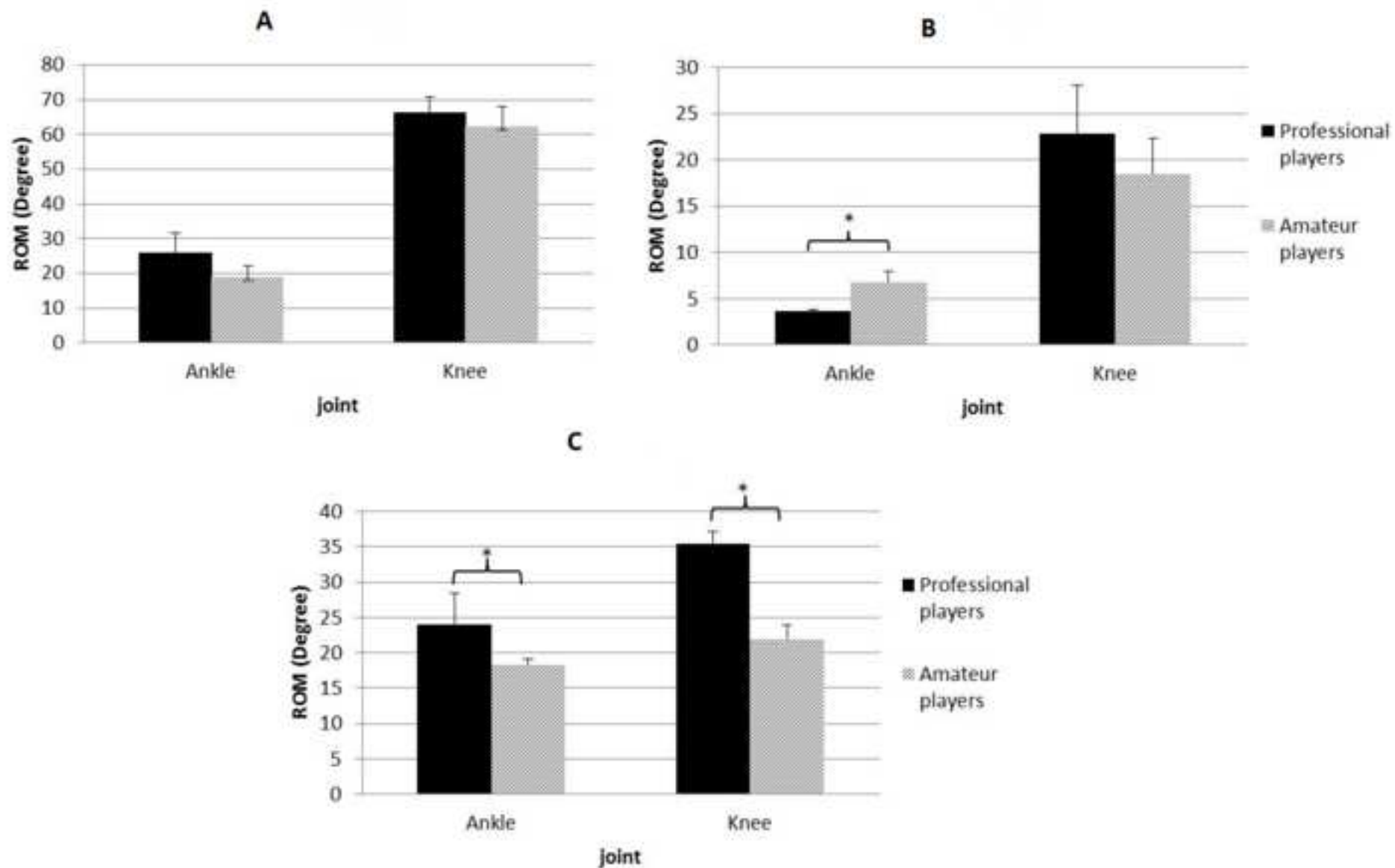




Figure 4: The mean values of ankle joint moment on sagittal, frontal, and horizontal planes of the professional and amateur badminton players (\* indicates significance)

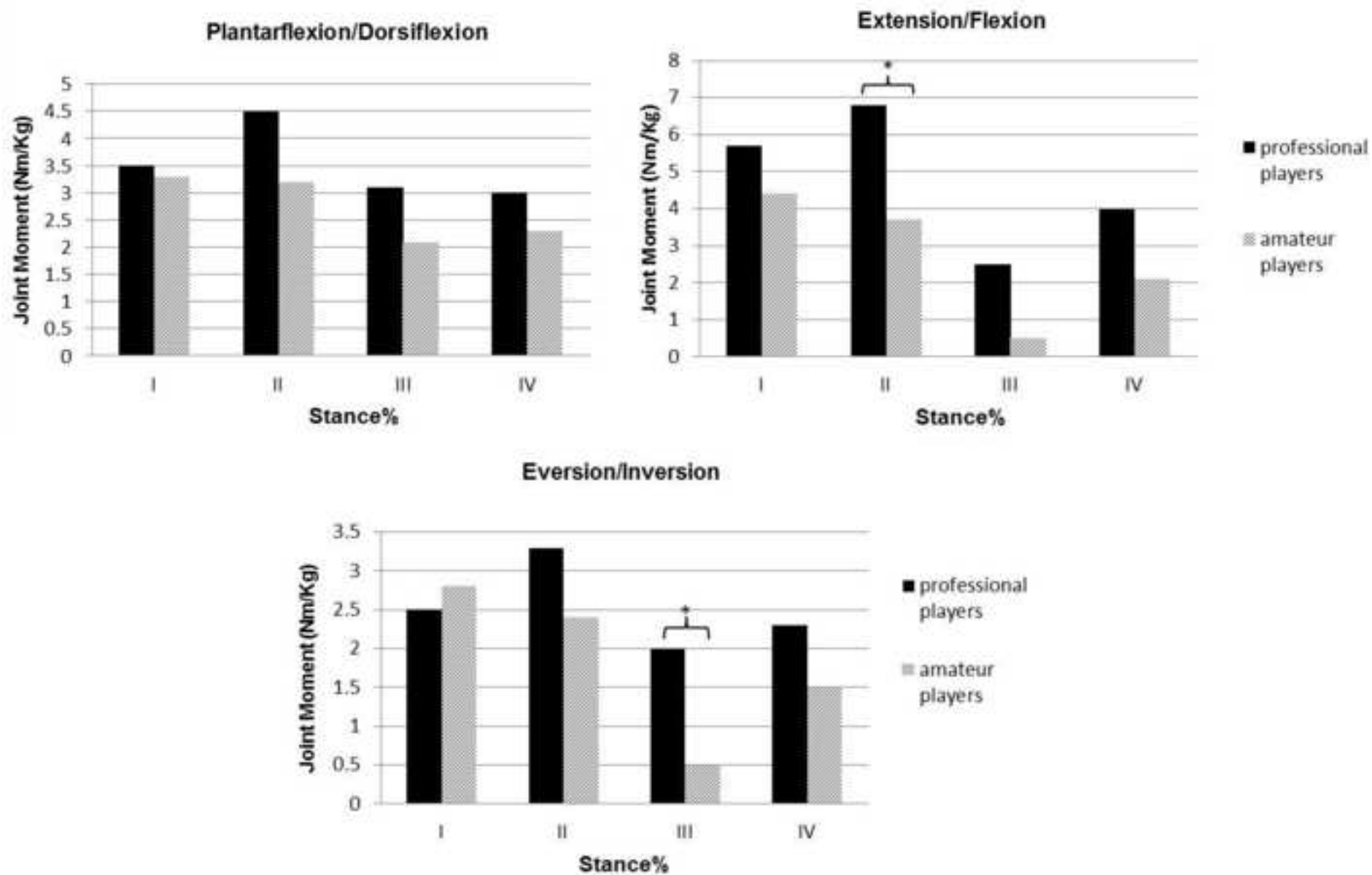
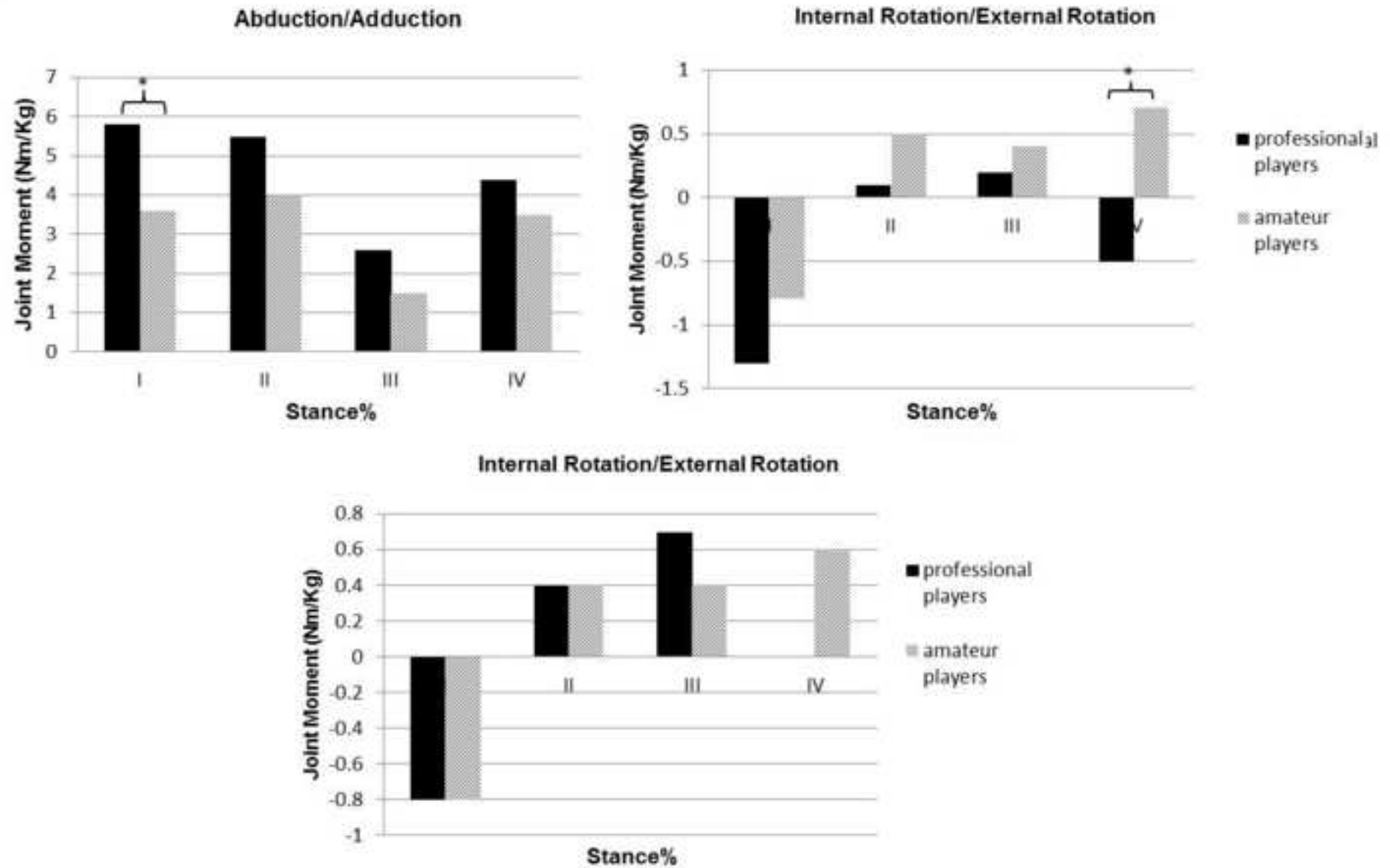


Figure 5: The mean values of knee joint moment on sagittal, frontal, and horizontal planes of professional and amateur badminton players (\* indicates significance level p



Name of Material/ Equipment	Company	Catalog Number	Comments/Description
Motion Tracking Cameras	Oxford Metrics Ltd.,		
Valid Dongle	Oxford, UK		n= 8
	Oxford Kistler, Switzerland		Vicon Nexus 1.4.116
Force Platform Amplifier	d		n=1
Force Platform	Switzerland		n=1
Vicon Datastation ADC	Metrics		-
T-Frame	Metrics	-	-
reflective Marker	Metrics		n=16
Double Adhesive Tape	Metrics		For fixing markers to skin
			MATERIAL: Standard
			Grade Carbon Fiber
			WEIGHT: 81-84 grams
			OVERALL LENGTH: 675mm
		BADMINTON	GRIP LENGTH: 200mm
		RACKET CLUB	BALANCE POINT: 295mm
		PLAY BLADE 1000	TENSION: Vertical 20-24
Badmionton racket	Li-ning, Chin	[AYPL186-4]	lbs, Horizontal 22-26 lbs



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Dear editor,

We are pleased to resubmit for publication the revised version of JoVE58842 “Biomechanical Analysis Methods to Assess Professional Badminton Players’ Lunge Performance”. We appreciated the constructive criticisms of you and the reviewers. We have carefully addressed each of their concerns as outlined below.

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