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Biomechanical Evaluations of Impact Attenuation Related Biomechanics of Drop Landing, Drop Jump and Cutting Movements on a Synthetic Turf System with a Shock Pad

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Introduction

Using a shock pad as an underlayment with a synthetic turf is becoming popular in the synthetic turf installations. Since the practice with both synthetic turf and shock pad is new, research on effects of this combination on impact related variables and human biomechanics in dynamic movements is scarce in the literature.

Therefore, purpose of this study was to examine impact attenuation related biomechanical characteristics of drop landing, drop jump and cutting movement on a synthetic turf (TURF) and a synthetic turf plus a shock pad (PAD).

Methods

Participants

Twelve recreational football and soccer players (mean ±SD age: 21.9 ±2.7 years, height: 185.1 ±6.3 cm, mass: 78.5 ±9.4 kg) participated in this study. Each participant attended two testing sessions. A qualified participant met following inclusion criteria: 1) being injury free for past 6 months, 2) having no major injuries (fracture, ligament rupture, meniscus injury, etc.), 3) having played football or soccer for at least three years, and 4) for football players, having played receiver, running back, defensive back or free safety position.

Instrumentation

3D High-speed Video System: A motion capture system (240 Hz, Vicon Motion Analysis Inc., UK) with 12 cameras was used to obtain the three-dimensional (3D) kinematics during the test. Reflective anatomical markers were placed on the acromion processes, iliac crests, greater trochanters, medial and lateral epicondyles, medial and lateral malleoli, and the head of 1st and 5th metatarsals. A cluster of four reflective markers affixed to a semi-rigid thermoplastic shell was placed on the trunk, thighs, legs and feet respectively to track segment motions during testing. A static trial was taken. After the static trial, the movement trials were performed according to the results of the order of the movement conditions (see below).

Force Platform: Two force platforms (1200 Hz, BP600600, American Mechanical Technology Inc., Watertown, MA, USA) were used to measure the ground reaction forces (GRF) and the moments of forces during the movement trials, using the Vicon motion analysis system. Simultaneous collection of the 3D kinematics and ground reaction forces were conducted during the movement trials.

Standard Test Method for Impact Attenuation of Playing Surface Systems and Material (F335): This system was used to conduct a mechanical test (6) on the turf and the turf plus shock pad. A standard mass (9.1 ± 0.050 kg) was dropped from a 60 cm height for three trials on five different locations on each of the two surface conditions. The maximum decelerations were recorded and used for further analyses.

Synthetic Turf and Shock Pad: A 2" monofilament synthetic turf with 1/2" stitch gauge (PowerBlade Shaw Industries, Dalton, GA) was used in this study. The sand and crumb rubber were infilled into the synthetic turf according to manufacturer specifications. For the turf only condition (TURF), turf was affixed to the laboratory floor via double-sided carpet tape. For the turf on the force platform, a square piece of turf was cut separately and affixed to the force platform using double-sided carpet tape. The turf was first infilled with sand to a depth of 15.1 mm then with crumb rubber to a total depth of 32.1 mm. For the turf condition with a shock pad (PAD), double-sided carpet tape was used to attach the shock pad to the floor and to attach the turf to the shock pad. A separate piece of shock pad was attached to the top of the force platform. A foam based shock pad (POWERBASE/YSR, Brock International, Boulder, CO) was used in turf with a shock pad condition (Figure 1).

Football Cleats: The same style Nike football cleats (Nike Vapor Untouchable Pro, Nike, Beaverton, OR) were worn by the participants during movement trial testing.

Visual3D: Visual3D (C-Motion, Inc.) 3D biomechanical analysis software suite was used to compute 3D kinematic and kinetic variables.

Customized software: Customized software (VB_V3D and VB_Tables, Microsoft Visual BASIC, 6.0) was used to compute and determine critical events of the computed variables from Visual3D outputs, and organize the data for report and statistical analyses.

<u>Experimental Protocol</u>

Each participant attended two test sessions. The testing protocol for test sessions one and two were identical, except for the two surface conditions. The surface condition for test session one was the 3rd generation synthetic turf (TURF), and the surface condition for test session two was the synthetic turf plus a shock pad (PAD). The order of the test session presentation for participants was counter-balanced. In each of the test session, the participants performed five successful trials in each of the three testing movement conditions: drop landing, drop jump, and 90° cut. The order of the three movement conditions was randomized for each surface condition for each participant.

Drop landing. Participants were asked to perform the drop landing trials from two different heights set by a motorized over-head bar: 40 and 60 cm. We initially were going to use three landing heights. But the pilot test results showed that 20 cm drop landing was too low to obtain consistent results. The actual maximum knee flexion angles under each height conditions were determined in several pilot study testing sessions. During the actual testing session, the participant were asked to land with the pre-determined maximum knee flexion angle within a range of ±8°.

Drop jump. Participants were asked to perform the drop jump trials from a raised platform of the one height of 40 cm. For the same reason, we did not use the 20 cm drop height. It has been recommended that drop jump be kept at 40 cm or below for drop jump movements for optimal jumping performance. The participant were asked to step off from the landing platform of two different heights with the right leg leading forward and drop onto the respective testing surface, then perform a maximum vertical jump as soon as after they contacted the surface, and land symmetrically in a balance fashion. During the testing, they were asked to reach the overhead bar with both of their hands, which was set at a height of the participant's maximum standing vertical jump height. This maximum jump height was determined as the average of three maximum standing vertical jump trials of the participant using a Vertec system.

90° Cutting Movement. For the cutting movements, the participant performed five successful trials in each of two approaching speed conditions: 3.0±0.3 and 4.0±0.4 m/s. The participant accelerated from a starting cone towards the force platform. A minimum of three trials was used as a familiarization protocol. The participant cuts with his dominant foot (defined as dominant leg for kicking a ball) on the force platform and accelerate toward the opposite side at a 90° angle (Figure 1). The approach velocity was monitored using a pair of photo cells and an electronic timer.

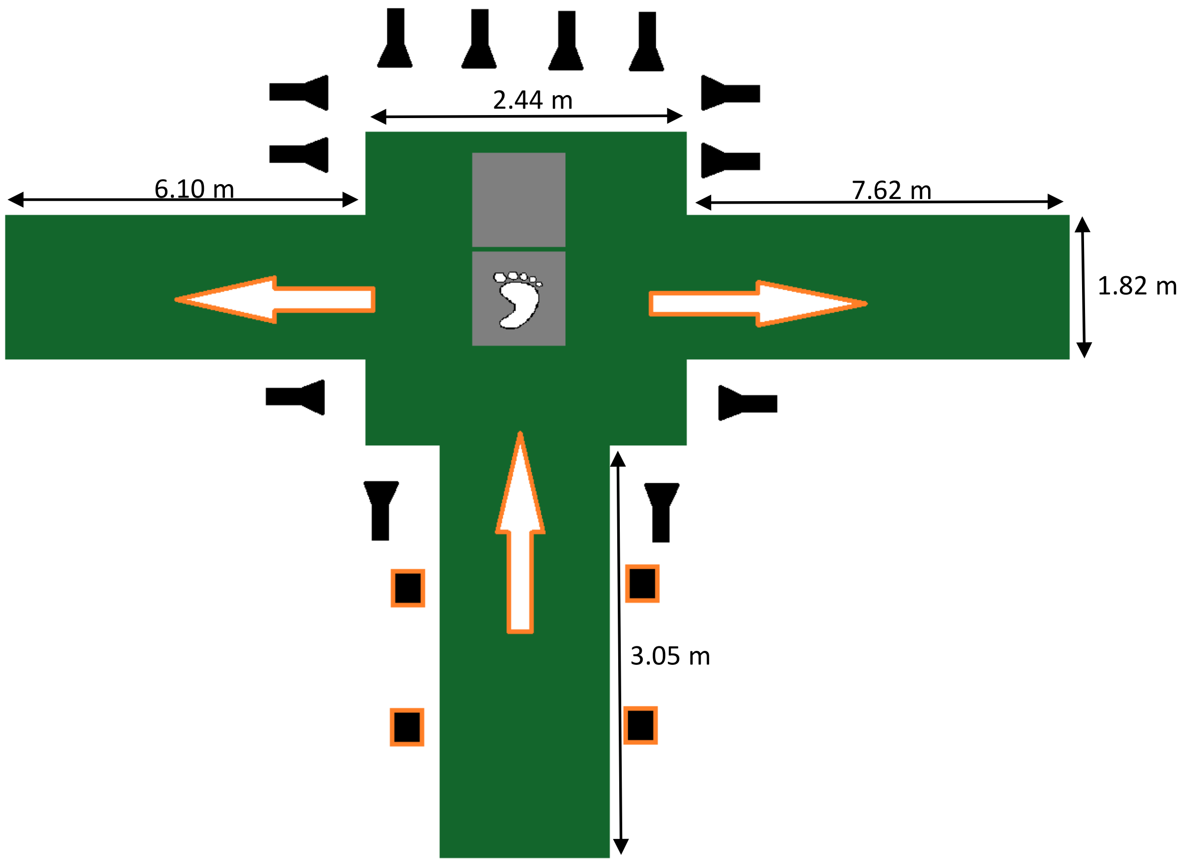

Figure 1. Setup for the cutting movement testing.

Data Processing and Analyses

Visual3D software suite was used to compute the 3D joint angular kinematics and kinetics of the three lower extremity joints: hip, knee and ankle. Ground reaction forces and joint moments were normalized by each participant's body weight and mass, respectively. The VB_V3D was used to determine critical events of the interested 3D kinematic variables from the output of

Visual3D, and compute additional parameters. The VB Table was used to organize the discrete events of the interested variables from the output of the VB_V3D for assembly of variable tables and statistical analyses.

Dependent variables included peak angle and range of motion in sagittal and frontal planes of hip, knee and ankle joints, peak vertical GRF and its loading rate, peak lateral GRF and its loading rate, peak extension moment, power and impulse of knee, ankle and hip joints in sagittal plane, peak moment and impulse of knee, ankle and hip joints in frontal plane for the 90° cut. Only sagittal plane variables were analyzed in the drop landing and drop jump movements. Mechanical tests for G_{max} (ASTM F355, Cadex, St-Jean-sur-Richelieu, Canada, and Clegg Impact Soil Tester, Lafayette Instruments, Lafayette, IN), vertical deformation, energy reduction, and force reduction (Advanced Artificial Athlete, Deltec Equipment, Duiven, The Netherlands), and head impact criteria (ASTM F1292, IPEMA, Harrisburg, PA) values were collected for each surface condition.

Statistical analysis. A 2 x 2 (turf x speed or turf x height) repeated measures ANOVA was used to determine differences for the drop landing and cutting movements. A pair-sample t-test was used to determine differences of the two turf conditions for the drop jump movements. All statistical procedures were performed using IBM SPSS Statistics (version 22) at an alpha level of 0.05 set a priori.

Results

Drop Landing

Significant differences with respect to the landing height and turf main effects and their interactions were all found in the sagittal plane related variables. The peak vertical GRF results showed that both peaks increased with increased landing height (Table 1). No interactive and turf effects were found for these variables. A significant height effect was also found for the peak plantarflexion moment, peak plantarflexion power, peak plantarflexion angle, and dorsiflexion range of motion (ROM), suggesting that the values of these variables increased with the increased landing height. However, there was a significant interaction of Turf and Height main effects for the peak plantarflexion moment and dorsiflexion ROM. The post hoc comparisons showed that the peak plantarflexion moment was greater for the TURF compared to the PAD at the 40 cm height ($p = 0.008$), and was smaller at 40 cm compared to 60 cm in the PAD condition ($p < 0.001$, Table 1).

The peak knee extension moment showed a significant turf effect showing that it was smaller in the pad condition compared to the turf only condition ($p = 0.029$, Table 2). This was especially the case at 40 cm landing where greater reduction was seen in the peak knee extension moment with the interaction of Turf and Height close to be significant ($p = 0.067$). Significant height main effect was seen for the peak knee extension moment, eccentric power and flexion ROM, suggesting that the values of these variables increased with the increased landing height.

For the hip related variables, a significant height main effect was seen for the peak hip extension moment, eccentric power, and flexion ROM and the values of these variables increased with the increased drop landing height (Table 3).

Drop Jump

The statistical results of drop jump from the 40 cm height showed that there were no significant differences between the two turf conditions for the peak landing and takeoff vertical GRF, ankle plantarflexion moment, ankle eccentric (landing) and concentric (takeoff) powers, and ankle dorsiflexion ROM (Table 4). Similarly, there were no significant differences between the two turf conditions for the peak knee extension moment, peak knee eccentric (landing) and concentric (takeoff) powers, and knee flexion ROM (Table 5). For hip joint, there were no significant differences between the two turf conditions for the peak hip extension landing and takeoff moments, peak hip eccentric (landing) and concentric (takeoff) powers, and hip flexion ROM (Table 6).

90° Cut

In terms of differences in the surface conditions, the only detected difference was found in knee frontal-plane power. During early stance, there was an increase in frontal-plane peak loading eccentric power and during late stance, there was a decrease in frontal-plane peak push-off eccentric power when cutting on the PAD condition compared to cutting on the TURF condition (Table 9).

When comparing approach velocities, there were significant increases in initial peak posterior and lateral GRFs as the approach velocity increased (Table 7). For peak vertical GRF, there was a significant increase in 1st peak but a significant decrease in 2nd peak with increases in velocity.

Both ankle loading inversion ROM and peak ankle eversion moment increased as approach velocity increased (Table 8). Furthermore, sagittal-plane peak ankle concentric power, frontal-plane peak ankle eccentric power, and frontal-plane peak ankle concentric power were significantly greater at the faster cutting approach velocity.

At the knee joint, there were significant increases in the knee abduction ROM, peak knee extension moment, peak knee loading adduction moment, and peak push-off knee adduction moment as approach velocity increased (Table 9). A significant interaction was found for sagittal-plane peak knee eccentric power (Table 9). Post hoc comparisons revealed that sagittal-plane peak eccentric power increased for the fast velocity compared to the slow condition on the PAD condition ($p > 0.001$). In terms of other power variables, the fast velocity also caused significant increases in sagittal-plane peak concentric power, frontal-plane peak loading concentric power, and frontal-plane peak push-off eccentric power.

In terms of hip moments, there were significant increases in peak loading extension moment, peak push-off extension moment, and peak loading adduction moment as the approach velocity increased (Table 10). There were also increases in sagittal-plane peak eccentric power and sagittal-plane peak concentric power.

Mechanical Testing

Synthetic turf mechanical tests of the F355 A missile test showed that there was a decrease in the G_{MAX} value for the PAD condition (Table 11), while the F355 E missile test showed that there was an increase in the critical fall height for the PAD condition (Figure 2).

Discussion

The purpose of this study was to examine impact attenuation related biomechanical characteristics of drop landing, drop jump and cutting movement on a synthetic turf and a synthetic turf plus a shock pad. The results of peak loading variables (GRF) across the two turf conditions, turf only and pad, from this study showed that no significant changes were observed in all three movements, drop landing, drop jump and 90° cut. This is true for the peak vertical GRF variables for the three movements as well as the shear (anteroposteior and mediolateral) loading GRF variables for the 90 cut (Tables 1, 5 and 8). These results seem to suggest that adding the shock pad to the existing synthetic turf does not affect the overall loading to the body during these three different types of movements.

Human body makes adjustments to adapt to changes in external loading during human movements. These adjustments are most evident in the drop landing for the ankle and knee related variables in the PAD condition. There were significant interactions of the turf and landing height for the peak ankle plantarflexion moment and ankle dorsiflexion ROM. The post hoc results showed that the athletes exerted smaller peak ankle plantarflexion moment in the PAD condition in 40 cm drop landing. They also made smaller dorsiflexion ROM at 40 cm drop landing on PAD than that in 60 cm drop landing on PAD. Additionally the athletes also exerted smaller peak knee extension moment in the PAD compared to the TURF conditions. This was especially the case for the 40 cm drop height and no difference in the 60 cm drop height between the two turf conditions was observed, with a marginal difference of the interaction ($p = 0.067$). No significant changes were seen for the hip related variables. These results suggest that the shock pad offers some protective effects to the knee and ankle joints, mostly at the 40 cm landing height. However, landing from a 40 cm is considered as sub-maximal efforts in landing related activities (landing from a jump). The protective effects seem to diminish at the 60 cm height.

These results from the drop landing movement provide support for the mechanical testing results of F355 E and A. The decreased G_{MAX} values for the PAD condition suggest that synthetic turf systems with a shock pad has the potential to improve field safety without negatively influencing human movement performance. These findings could have substantial influence for future synthetic turf installations. The design of the shock pads is primarily to reduce HIC and G_{MAX} values and increase the critical fall height to improve field safety. However, there were concerns that the increased displacement in the surface with a shock pad would increase the risk of lower extremity injury. The findings of this study suggest that for the one shock pad model tested, there is little evidence to suggest that the inclusion of a shock pad would increase the risk of lower extremity injury, while reduced HIC values suggest that the inclusion of a shock pad may improve overall field safety and reduce risk of head injury and concussion . However, the discrepancy between the mechanical turf testing and human biomechanical testing remains and warrants further investigations into how these two factors interact.

During the drop jump, no significant changes were seen in both joint kinematic and kinetic variables across all three lower limb joints. The ankle peak eccentric power during the landing phase was close to be significantly lower with the PAD compared to the TURF with a p value of 0.082.

For the 90° cut, only two variables, peak knee frontal-plane loading eccentric power and peak knee frontal-plane push-off eccentric power, were found significantly different in the two turf conditions. Specifically, the peak knee frontal-plane loading eccentric power were increased in the PAD conditions regardless of cutting speeds. This suggests that during the initial loading phase of stance, there were increased eccentric contractions of the muscles crossing the knee joint to stabilize the joint. However, the peak sagittal-plane extension moment and peak knee eccentric loading power were not different between the two turf conditions, suggesting that overall loading to the knee joint during the loading phase was not likely increased.

A reason for the lack of more significant differences between the two turf conditions across the testing movements may be potentially due to the limitations of inverse dynamics. For the TURF condition with less surface compliance, this could have resulted in increased muscle co-contraction to help stabilize the joint, which cannot be reflected in the results of inverse dynamics. Furthermore, the lack of reductions in peak vertical and horizontal GRFs may have been due to subjects adjusting their muscular controls, resulting in decreased co-contractions for the PAD condition rather than kinematic or kinetic differences.

As expected, the increase in the landing height and approach speed caused increases in peak GRFs, peak ankle plantarflexion moments eccentric powers, peak knee extension moment and eccentric power, and hip extension moments and powers in the drop landing and 90° cut movements, respectively. The participants seem to respond to the PAD and TURF surface conditions consistently across the different landing heights and approach speeds. These results suggest that both surface conditions seem to offer similar protective effects when mechanical loading increases during these movements.

Beside the concerns of the injuries, one important aspect of any sporting surface is their impact on performance. During the drop jump, the kinetic variables during takeoff, e.g. peak vertical GRF, peak ankle plantarflexion moment and concentric power, peak knee extension moment and concentric power as well as peak hip extension moment and concentric power, were not different in the PAD surface compared to the TURF surface. Similarly, there were no difference in these variables vertical peak GRF variables and sagittal-plane joint kinetic variables between the PAD and TURF surface conditions in the 90° cutting movement. Furthermore, the mediolateral peak GRF, peak ankle, knee and hip frontal-plane joint moments and powers were all similar between the two surface conditions during the pushoff phase of the cutting movements. These results provide evidence that the inclusion of the shock pad did not negatively affect the sport performance on the surface.

In summary, the results from this research project demonstrate that the inclusion of the shock pad with the synthetic turf did not affect the overall loading to the body during the drop landing, drop jump and 90° cut movements. However, the inclusion of the shock pad did provide some protection to the ankle joint in the landing movement. These results also suggest that the shock pad inclusion did not negatively influence the performance related variables during the drop jump and 90° cut.