THE EFFECT OF SURFACES ON THE KNEE BIOMECHANICS OF A 90 DEGREE CHANGE OF DIRECTION

Samantha Rhodes[1,2], Richard Jones[1], Lee Herrington[1] and Chris Bramah[1]

[1] University of Salford, Manchester, UK
[2] The Manchester Institute of Health and Performance, Manchester, UK

Assessments following anterior cruciate ligament (ACL) injuries are commonly on surfaces that do not represent the playing or training surface. This study aimed to investigate how different surfaces, specifically a running track and artificial grass, influence biomechanics during a 90-degree change of direction (COD). Seventeen participants performed a 90-degree COD on both a running track surface and an artificial grass surface. Motion capture and force plate data were collected. No significant differences were observed in kinematic variables between surfaces. However, the knee extensor moment and posterior braking force were significantly higher on the running track compared to artificial grass ($P<0.05$). Vertical GRF and approach speed showed no significant differences. This could have implications when assessing ACL injury risk or return to sport readiness.

KEYWORDS: ACL, knee, surface, biomechanics, change of direction.

INTRODUCTION: Anterior cruciate ligament (ACL) injuries are one of the most debilitating knee injuries within sport and commonly results in significant pain and instability, time away from sport and an increased risk of future knee injury (Beynnon *et al.,* 2014; Wang *et al.,* 2020). The ACL is the primary constraint for anterior tibial translation and injuries occur when the forces exerted on the ligament are greater than its capacity to withstand this force. Most ACL injuries that occur are non-contact in nature, typically occurring during change of direction COD) movements (Nessler, Denney & Sampley, 2017). Biomechanical risk factors of sustaining an ACL injury during a COD movement include reduced knee flexion, larger external knee extension moments, higher ground reaction forces (GRF) and dynamic knee valgus (Yu & Garret, 2007; Nessler, Denney & Sampley, 2017;). COD is therefore important to assess following ACL injury to assess readiness to return to play and future injury risk.

Assessments following an ACL injury usually take place on surfaces such as indoor wooden or concrete flooring, rubber gym flooring or a running track surface, which can differ from the surface that an athlete trains/plays on. The properties of the surface, such as hardness, friction and stiffness can influence movement strategies and athletic performance (Wannop *et al.,* 2020; Jones *et al.,* 2023). Jones *et al.* (2023) found biomechanical differences when performing a 90-degree COD on different surfaces and concluded that assessing an athlete on a different surface to their playing surface can misrepresent ACL injury risk. Wannop *et al.,* (2020) found that changing the stiffness of artificial turf altered kinematics during a COD action. This highlights the importance of external validity – such as the correct surface - in relation to athletic testing, particularly after an injury.

The aim of this study was to determine whether there were any biomechanical differences between two surfaces during a 90-degree COD. The purpose of this was to determine whether the type of surface athletic testing – particularly COD – occurs on has an influence on knee biomechanics. This could have implications when considering injury risk and readiness to return to sport, especially for ACL injuries.

METHODS: This study was part of a larger scale study looking at the reliability and repeatability of functional tasks commonly used during biomechanics assessments following ACL injury. A power analysis was conducted using a significance level of 0.05, a power of 80% and a minimum accepted reliability of 0.6 and an expected reliability of 0.9, a sample size of 14 participants was required (Arifin, 2024). When accounting for a 10% drop out rate, a minimum participant sample size of 16 was determined.

To determine whether a playing surface influences the biomechanics of a 90-degree COD, a repeated measures design was used. Seventeen participants were recruited (eight females, nine males). To be eligible participants had to have been over the age of 18 and have been free from any injury within the 6 months prior. The participant must have never sustained an ACL injury or had knee surgery of any type. Participants must have been participating in some form of multi-directional sport at least twice a week for 60 minutes (such as football, netball, and rugby). The involvement in this type of sport should have meant that the participant was familiar with and able to perform a COD at high-speed. Data collection was undertaken at the Manchester Institute of Health and Performance (MIHP). The motion capture hall at the MIHP is comprised of 29 infra-red cameras (Oqus 700, Qualysis AB, Sweden) and eight force plates (six Gen 5 plates, two Optima plates, AMTI, USA) embedded between two surfaces (a running track surface and a 3rd generation astroturf artificial grass surface). Participants attended two sessions at the MIHP. For the purpose of this study, the first session was used as a familiarisation session.

The larger scale study involved eight tasks being performed on the track and three tasks performed on the artificial grass surface. These included running, walking, hopping and squatting tasks. Before the first visit it was randomised which surface the participant would perform the tasks on first. This was done with random computer-generated numbers representing one of the surfaces. Participants were provided with standardised footwear (Goletto VIII, Adidas, Germany) that were suitable to be used on both the running track and the artificial grass surface. The sizes available ranged from size five to 13. Retro-reflective markers were attached to the participant in order to represent the skeleton underneath. The marker placement used followed the Calibrated Anatomical System Technique (CAST). This used 30 markers, including four tracking clusters made up of four markers each. The first step was to capture a static calibration file on the first surface with the participant standing in the anatomical position. The dynamic trials were then completed on the first surface. Another static calibration file was then captured for the second surface, before completing the dynamic tasks for this surface. For this study, only the 90-degree COD was used. Participants were instructed to approach the COD at maximal velocity from five meters away, perform a 90-degree COD, and then accelerate for another five meters. The start, finish and COD area were all marked out using cones. Data was collected and labelled using Qualisys Track Manager (Version 2022.1). Once labelled the data was exported to Visual 3D (Version 6; C-motion Inc, USA). The model was derived from the static trial – this determined the local coordinate system for the different segments. The CODA pelvis was used to locate the left and right hip joint centres. This was defined using the anterior superior iliac spine (ASIS) and the posterior superior iliac spine (PSIS) markers. The model was then applied to the dynamic trials. The data was filtered for both kinematics and kinetics using a fourth order low pass, Butterworth filter (cut off frequency 12Hz). A Cardan sequence of sagittal, frontal, and transverse (XYZ) rotations were used during this analysis.

The COD was normalised to time (0-100%). This was from the initial contact of the foot to the end of contact at toe-off. These events were identified according to specific criteria. Initial contact was determined when a force greater than 20 Newtons was registered and the end of contact was determined when the force decreased to less than 20 N. The maximum knee flexion, knee extensor moment, posterior GRF force, vertical GRF, knee abduction, knee adduction and knee flexion at initial contact for each participant were exported. The mean from three successful trials were used for statistical analysis.

The statistical analysis was performed using the Statistical Packages for Social Sciences (SPSS, Version 29.0.1.0, IBM corp., USA). A paired t-test was used to compare each variable measured on the track compared to each variable measured on the artificial grass to determine any significant differences ($P<0.05$).

RESULTS: There was no significant difference in any of the kinematic variables when comparing the track to the artificial grass (*shown in table 1*).

There was a significantly increased knee extensor moment on the track compared to the artificial turf ($P<0.05$). The 95% confidence interval difference of the mean was from 0.06 to 0.41 and the effect size was 0.67 (95% CI 0.15 to 1.21). The posterior braking force was also significantly increased on the track compared to the artificial turf ($P<0.05$). The 95% confidence interval of the mean difference was from -0.18 to -0.02 and the effect size was -0.65 (95% CI -1.17 to -0.12).

There was no significant difference in approach speed on the track (3.67 m/s ± 0.40) and the artificial grass (3.76 m/s ± 0.50).

Table 1: Means, standard deviations (SD) and P-value of the kinematic variables.

Item	Mean (SD)		P-Value
	Track	Artificial grass	
Maximum knee flexion	63.39 (5.15)	63.05 (5.31)	0.330
Initial contact knee flexion	25.05 (5.00)	25.68 (4.01)	0.243
Maximum knee adduction	1.60 (3.61)	0.80 (4.11)	0.106
Maximum knee abduction	-10.50 (4.17)	-11.24 (4.85)	0.147

Table 2: Means, standard deviations (SD) and P-value of the kinetic variables.

Item	Mean (SD)		P-Value
	Track	Artificial grass	
Maximum knee extensor moment	2.81 Nm/kg (0.32)	2.57 Nm/kg (0.47)	**0.006**
Posterior braking force	-1.06 N/kg (0.19)	-0.96 N/kg (0.17)	**0.008**
Vertical ground reaction force	1.94 N/kg (0.18)	1.94 N/kg (0.13)	0.485

DISCUSSION: This study assessed whether there were differences in knee biomechanics when performing a 90-degree COD on a running track surface compared to an artificial grass surface. Retro-reflective markers were attached to the participant, they then performed a 90 degree COD on the two different surfaces. This was captured using motion capture cameras and coupled with forces from force plates embedded underneath each surface. It was found that there was an increase in knee extensor moment and posterior braking force when performing the COD on the running track surface. There were not differences between surfaces in kinematics, approach speed or vertical GRF.

An increase in GRF has been attributed to an increased risk in sustaining an ACL injury. This study found an increased posterior braking force on the track compared to the turf. This is similar to Jones *et al.* (2023) who also found an increased posterior braking force on a track surface compared to artificial grass. Posterior GRFs that have been associated with ACL rupture reportedly range from -2.6 to -0.5 times body weight (Grund *et al.,* 2010). The values for both the track and artificial grass fall within this range for this study. An increase in vertical GRF has also been associated with an increased risk of ACL injury. Harder surfaces have been linked with an increase in vertical GRF (Jones *et al.,* 2023). However, no difference in GRF was identified during this study. The properties of the two surfaces in this study were not determined, therefore it cannot be claimed that one is harder than the other. This may explain that lack of difference in vertical GRF.

During the deceleration phase of the COD, posterior braking forces are produced. At this time the quadricep contracts eccentrically to control the knee. The higher knee extensor moment seen on the track is likely as a product of the larger posterior braking force. It has been suggested that this increased knee extensor moment contributes to proximal anterior shear forces therefore increasing ACL loading and the risk of injury (Yu and Garrett 2007). Larger braking forces can occur as a result of an increased approach speed. Wannop *et al.* (2020) identified softer surfaces had an increased approach velocity to the COD. It was hypothesised that the compliance of the softer surface allows the participant to enter the COD without fear of losing traction. However, there was no significant difference in approach speed found between the track and the artificial grass surface in this study. The differences found in this study could have been due to an increased traction on the track surface, increasing the posterior GRF and therefore the knee extensor moment. However, traction was not quantified within this study.

Reduced knee flexion and increased knee abduction have both been associated with an increased risk of ACL injury during COD. No differences were identified in kinematic variables during a 90-degree between the two surfaces in this study. In contrast to this, Jones *et al.*

(2023) found a reduced knee flexion angles on a harder track surface when compared to an artificial grass surface. One possibility for the difference in the comparison of these studies could be due to the composition of the artificial turf. Wannop *et al.* (2020) assessed athletic movement on a number of artificial turfs in varying surface. The change of stiffness was achieved by altering infill composition, compaction of surface and fibre density. Kinematic and performance differences were identified between these surfaces. Jones *et al.* (2023) used no infill in the artificial grass whereas this study did. This highlights a difficulty in comparisons between studies even with the appearance of the same surfaces.

A limitation of this study is that is only considered discrete variables. Whilst the magnitude of these discrete variables may or may not be different, the timings may differ. This may misrepresent differences in knee biomechanics between the two surfaces. Previous studies have found differences in the timings of peak knee biomechanical variable. In the future, the whole waveform of the movement should be analysed such as with an SPM analysis. The use of standardised footwear could be seen as a limitation as this study discusses the need for external validity. Wearing cleats on the artificial grass would be more externally valid however the standardised footwear allows differences to be attributed to the change in surfaces rather than the change in footwear. The set-up of the artificial grass in this study is a particular strength. The force plates are embedded within the surface. Often, biomechanical research on an artificial turf uses mats placed over the force plates. This has limitations such as a potential for slippage of the mats, an impact on forces and inconsistent surface properties. However, the artificial grass used in this study still may not be synonymous with an athletes' playing surface, but it is closer than using a track or concrete surface.

CONCLUSION: This study found significant differences when comparing a 90-degree COD on a running track surface compared to an artificial grass surface. Variables which have been associated with ACL injury risk were increased on the running track surface compared to the artificial turf. This shows that it is important to use a surface that is closer to the athletes' playing/training surface in order to get a true representation of ACL injury risk or readiness to return to sport.

REFERENCES

Arifin, W. N. (2024). Sample size calculator (web). Retrieved from http://wnarifin.github.io

Beynnon, B.D., Vacek, P.M., Newell, M.K., Tourville, T.W., Smith, H.C., Shultz, S.J., Slauterbeck, J.R. & Johnson, R.J. (2014). The effects of level of competition, sport, and sex on the incidence of first-time noncontact anterior cruciate ligament injury. The American journal of sports medicine, 42(8), 1806-1812.

Grund, T., Reihl, I., Krosshaug, T., Senner, V., & Gruber, K. (2010). Calculation of ankle and knee joint moments during ACL-injury situations in soccer. Procedia Engineering, 2(2), 3255–3261.

Jones, H. S. R., Stiles, V. H., Verheul, J., & Moore, I. S. (2023). Assessments performed on harder surfaces can misrepresent ACL injury risk. Sports Biomechanics, 1-23.

Nessler, T., Denney, L. & Sampley, J. (2017). ACL injury prevention: what does research tell us?. Current reviews in musculoskeletal medicine, 10, pp.281-288.

Yu, B., & Garrett, W. (2007). Mechanisms of non-contact ACL injuries. British Journal of Sports Medicine, 41(Supplement 1), i47–i51.

Wang, L.J., Zeng, N., Yan, Z.P., Li, J.T. & Ni, G.X. (2020). Post-traumatic osteoarthritis following ACL injury. Arthritis research & therapy, 22(1), 1-8.

Wannop, J., Kowalchuk, S., Esposito, M. & Stefanyshyn, D. (2020). Influence of Artificial Turf Surface Stiffness on Athlete Performance. Life, 10(12), 340.