EXPLORING THE PERFORMANCE – ACL INJURY RISK CONFLICT DURING ANTICIPATED AND UNANTICIPATED SIDESTEPPING TASKS

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The aims of this study were i) to determine if performing regression models with high-risk datasets compared to full datasets could help to understand better which biomechanical variables could really be considered ‘at-risk’ and/or ‘better for performance’ and ii) to determine the effect of anticipation on ‘at-risk’ biomechanical variables. Basketball players (n=33) completed 6 changes of direction in anticipated or unanticipated conditions. Kinematics, dynamics and performance were measured with motion capture and force plates. A lower number of predictors were found for high-risk dataset compared to full dataset. Hip adduction and trunk lateral lean could be both considered ‘at-risk’ and ‘better for performance’. Moreover, anticipation impacts the “at-risk” technique, so training instructions should differ between anticipated and unanticipated sidestepping tasks.

KEYWORDS: Knee joint loading, Change of direction, Cutting, Methods.

INTRODUCTION: Anterior cruciate ligament (ACL) rupture is a major injury occurring mostly during landings or changes of direction (Boden et al., 2000). Different biomechanical risk factors have been identified in the literature, at the lower limb level (Donelon et al., 2020) but also for the pelvis and trunk control (Duchene et al., 2022; Hughes, 2014). These risks factors have been mainly computed through video analysis of injuries (Della Villa et al., 2020) or by using the peak knee abduction moment (PKAM) as a screening variable for the ACL injury risk (Hewett et al., 2005). However, some technical variables considered ‘at-risk’ have also a positive impact on performance (e.g. wide foot plant, knee flexion, or trunk lateral lean) (Donelon et al., 2020). Interestingly, the majority of the regression models computed to seek for PKAM predictors consider mostly low level of PKAM. Therefore, they do not perfectly reflect which biomechanical variations would made the PKAM switch from a relatively low risk to a high risk (considered over 1.25 Nm/kg-bw by Lin et al. (2009)). Moreover, analysing high and low PKAM could help to understand better the role of the ‘at-risk’ and ‘better for performance’ (i.e. shorter change of direction completion times) variables by removing non-pertinent data from the model. Besides, other injury risk conflicts have been recently noticed, arising interrogation about the general technical recommendations. For instance, the trunk axial rotation seems to have opposite relationship with knee joint loading if the change of direction is anticipated or not (Frank et al., 2013; Staynor et al., 2020; Duchene et al., 2022).

Therefore, the aims of this study were i) to determine if performing statistical regression models with high-risk only compared to full datasets could help to understand better which biomechanical variables could really be considered ‘at-risk’ and/or ‘better for performance’; and ii) to determine the effect of anticipation on ‘at-risk’ biomechanical variables. We hypothesized that i) high-risk significant variables will be different in the high-risk dataset compared to the one significant from the full dataset; ii) trunk lateral lean, internal rotation, hip adduction and knee flexion will be present in both ‘at-risk’ and ‘better for performance’ groups; iii) trunk rotation in the opposite of the new direction will be positively linked to higher PKAM in anticipated conditions and negatively linked in unanticipated conditions.

METHODS: Thirty-three male basketball players (age: 22 ± 3 years old; height: 1.83 ± 0.08m; mass: 74.5 ± 10.4kg) participated in the study. They did not have a previous history of serious knee injury or any current pain, and were playing at regional or national level. Prior to testing, all participants were informed about possible risks and gave written informed consent.

Participants were asked to perform six trials in two different change of direction tasks, anticipated or unanticipated, on a force plate (1000Hz, AMTI, Watertown, USA) in a randomized order, either a right or left cutting maneuver to 60°. After a 5m run-up, participants stepped in an Optojump (Microgate, Bolzano, Italy) located 2m before the force plate, triggering an arrow displayed on a large TV screen, 4 meters far from the platform. At this point, the approach speed (computed with sacrum horizontal displacement) was 3.62 ± 0.35 $m.s^{-1}$. In anticipated condition, participants knew the direction before running. In both conditions, they had to perform the cut as fast as possible to a target, crossing the exit gate located at 1.5m from the center of the platform. Kinematics of the trunk and dominant lower limb were captured in 3D at 200 Hz (14 cameras, Arqus 12MP, Qualisys, Sweden). Data was only analyzed for the 60° cutting on their dominant limb.

Marker trajectories and force data were filtered with a low-pass Butterworth filter (4th order, 15 Hz cut-off frequency). Inverse dynamics were computed and the peak knee external abduction moment (PKAM) was calculated during the first 30% of the stance. Kinematics data for the trunk, the hip and the knee at the initial contact were calculated for the 3 dimensions. Kinematics variables were positive for extension, adduction and internal rotation. The time from the initial contact to the exit gate was the chosen variable to depict performance (i.e. completion time). Shorter time was considered as better performance. From the 'Full' dataset, a 'High' dataset was computed based on PKAM values (>1Nm/kg-bw).

The selected parameters were averaged across the six trials to display descriptive results. A total of 198 trials were used to perform linear mixed models analyses to address the three hypotheses. Such models take account of within-participant effect, allowing an analysis with individual trials as data points. For each condition, two linear mixed models were used to determine the association between PKAM and the 9 kinematic variables (i.e. trunk, hip and knee angles in 3D) for 1) the full dataset, 2) only high PKAM trials. Then, another linear mixed model (for each condition) was used to determine the association between performance and kinematic variables for the full dataset. Backwards elimination of independent variables (fixed effect) was performed by sequentially removing nonsignificant predictors until all predictors were significant. A k-fold (k=5) cross-validation was performed by randomly assigning the trials across 5 folds to compute average estimate parameters. Then, the relationship between the predicted values, computed with the mean parameter estimates, and the measured values was assessed by Pearson's correlations (R^2). The level of significance was set at 0.05.

RESULTS: The High group contained 59 trials in the anticipated sidestep (ANSS) condition and 55 trials in the unanticipated sidestep (UNSS) condition. Completion time was hardly predicted by the kinematic variables, with R^2 values under 10% in both conditions (Tables 1 and 2). Average completion times were 551 ± 57ms in ANSS condition and 558 ± 41ms in UNSS condition. The PKAM average values were respectively of 0.78 ± 0.39 Nm/kg-bw and 0.76 ± 0.42 Nm/kg-bw for the ANSS and the UNSS conditions.

In ANSS condition, larger knee, hip internal rotation, trunk axial rotation opposite to the cutting direction, and hip adduction, are linked to an increase of PKAM for both datasets. An increase in knee varus decreases PKAM, only in the Full dataset (Table 1). Moreover, an increase of hip adduction is linked to both a larger of completion time and a decrease in PKAM.

In UNSS condition, for both models, the R^2 were relatively small and larger trunk axial rotation towards the new direction was linked to greater PKAM. For the Full dataset model, an increase in knee valgus, hip internal rotation and trunk lateral lean was related to a larger PKAM (Table 2). Besides, an increase of trunk lateral lean was linked to both a smaller completion time and an increase in PKAM.

Moreover, trunk axial rotation towards the cutting direction was related to decrease of PKAM in ANSS condition but related to an increase of PKAM in UNSS condition.

Table 1. Significant kinematic variables detected for the 3 linear mixed models in anticipated sidestep (ANSS) condition. The variables presented are all significant predictors ($p<0.05$). Only the sign of each variable estimate is presented to ease the understanding.

ANSS					
Completion time		**PKAM**			
Full. $R^2=0.05$		**High.** $R^2=0.37$		**Full.** $R^2=0.46$	
Variable	Estimate	Variable	Estimate	Variable	Estimate
Hip adduction	+	Knee internal rotation	+	Knee internal rotation	+
Trunk extension	+	Hip adduction	-	Hip adduction	-
Hip extension	-	Hip internal rotation	+	Hip internal rotation	+
		Trunk rotation	+	Trunk rotation	+
				Knee varus	-

Table 2. Significant kinematic variables detected for the 3 linear mixed models in anticipated sidestep (UNSS) condition. The variables presented are all significant predictors ($p<0.05$). Only the sign of each variable estimate is presented to ease the understanding.

UNSS					
Completion time		**PKAM**			
Full. $R^2=0.08$		**High.** $R^2=0.13$		**Full.** $R^2=0.16$	
Variable	Estimate	Variable	Estimate	Variable	Estimate
Hip extension	+	Trunk rotation	-	Trunk rotation	-
Hip adduction	+			Knee varus	-
Trunk lateral lean	-			Hip internal rotation	+
Trunk extension	+			Trunk lateral lean	+
Knee extension	+				

DISCUSSION: The main findings of the present study were that i) a lower number of predictors were found for High-risk group compared to Full dataset; ii) that hip adduction and trunk lateral lean could be both considered ‘at-risk’ and ‘better for performance’; iii) that trunk rotation in the opposite of the new direction was positively linked to higher PKAM in anticipated conditions and negatively linked in unanticipated conditions.

Firstly, it seems that reducing the dataset to theoretically more adequate bounds didn’t modify the relationships between kinematics and PKAM. Indeed, the only modification was a reduction of the number of significant predictors, probably because of the reduced number of trials and participants. We performed *a posteriori* two models with similar number of trials, representative of Full dataset, and found four predictors of PKAM for both ANSS and UNSS. Therefore, these results lead us to think that this kind of data clustering can improve the selection of the most impactful kinematic variables for knee joint loading. Our results underlined the role of the knee valgus, hip internal rotation, abduction, trunk lateral lean and trunk axial rotation on the PKAM, as previously reported in the literature (Donelon et al., 2020).

A performance - injury risk conflict has been reported in the literature. Indeed, wide foot plant (dependent of hip abduction) might be necessary for performance for sharp (>70°) cutting tasks (Donelon et al., 2020) but not with a cutting angle of 45° (Sankey et al., 2020). Our results suggest that a 60° angle cutting performance is dependent of the hip adduction. Possibly, the sharper the angle, the more important the hip adduction for performance, but care must be taken because of the small R^2 of our statistical models. Also, trunk lateral lean seems to be an effective strategy to increase performance by probably allowing the centre of mass to accelerate in the new direction (Patla et al., 1999; Duchene et al., 2022).

When comparing anticipated and unanticipated conditions, one major difference was the effect of the trunk axial rotation. Indeed, we observed opposite relationship between this variable and PKAM. In anticipated sidestepping, it is suggested that the rotation of the trunk towards the new direction moves the ground reaction force vector towards the center of mass, reducing the PKAM (Frank et al., 2013). In unanticipated sidestepping, the increase of the PKAM with trunk orientation in the new direction might be the consequence of misalignment of the trunk with the lower body (Staynor et al., 2020). The time constraint probably induces difficulties to have an efficient coordination if the trunk has an early rotation, while the body, in anticipated condition, can adapt its posture to limit the injury risk. Therefore, during change of direction training, it is recommended to adapt instructions to the athletes depending the execution modality, i.e. full anticipation or with decision-making.

CONCLUSION: The ACL injury risk, depicted by the PKAM, is predicted by trunk, hip and knee kinematics. However, kinematics relationship with performance in the change of direction was small. The theoretical performance / injury risk conflict was not observed, as no kinematic variable showed a link with better performance and higher knee joint loading. The time constraint of the unanticipated tasks induces opposite relationship of the trunk axial rotation compared to anticipated tasks. Care must therefore be taken when training athletes to perform changes of direction.

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