THE FREE MOMENT IN CUTTING MANEUVERS – AN UNDERESTIMATED CONTRIBUTOR TO THE MOVEMENT?

Sina David[1] and Wolfgang Potthast[1]

Institute for Biomechanics and Orthopaedics, German Sport University Cologne[1]

The purpose of this study was to identify the relationship between different movement strategies during 90° cutting maneuvers and the free (reaction) moment. It is observed that the orientation of either a positive or negative free moment is generated by different orientations of the foot segment at initial touch down. These finding impacted the rotational moment that is transferred to the knee joint: A higher internal reaction moment is observed when athletes are exposed to a positive free reaction moment, which potentially increases load on the ACL. The most important finding was that it is possible to generate differently orientated reaction moments during the same movement, which highlights the importance of investigating movement strategies in order to understand potential injury risk factors.

KEY WORDS: movement strategies, body orientation, foot position, change of direction

INTRODUCTION: The prevalence of serious lower limb injuries is high during fast changes of direction and landing tasks which occur often during team sport games (Hootman, Dick, & Agel, 2007). It is currently advocated that a combination of unfavourable knee valgus and internal rotation moments together with a nearly extended knee joint are amongst the biomechanical factors associated with anterior cruciate ligament (ACL) injuries (Mclean, Huang, Su, & van den Bogert, Antonie J, 2004; Mclean, Huang, & van den Bogert, 2008; Mclean, Huang, van den Bogert, & Mclean, 2005). This combination of forces and joint motions was investigated in groups of participants that are exposed to a higher injury risk in comparison to athletes at lower risk (e.g. Havens & Sigward, 2015; McLean, Walker, & van den Bogert, 2005). While these studies reported differences in the kinematics, no effect was found for joint kinetics. Dempsey, Lloyd, Elliott, Steele, and Munro (2009) showed that it is possible to modify kinetic based risk factors by changes in the body posture during the cutting maneuver. Recent studies of our work group identified specific movement strategies that increase the load on the knee joint (David, Komnik, Peters, Funken, & Potthast, 2017). However, most of these studies focus on the frontal plane knee joint moments as transverse plane motion in the knee joint is small and its measurement error prone. The overloading of the ACL by an increased internal rotation of the tibia against the femur was not addressed so far although the limitation of internal rotation is one of the main functions of the ACL. The rotation of segments can be introduced by an top-down mechanism as seen in runners (Willwacher, Goetze, Fischer, & Brüggemann, 2016), where the motion of the arms and legs generate a rotation. With the foot planted to the ground, a rotation in the opposed direction is generated that acts bottom-up. The moment that is responsible for this phenomenon is known as the free (reaction) moment (FM). In running, the FM is an important factor that allows to explain knee related overuse injuries (Willwacher et al., 2016). Wannop, Worobets, and Stefanyshyn (2010) reported higher knee external rotation moments during 45° cutting maneuvers when wearing high traction shoes, indicating an increased transfer of segmental rotation to the ground and reverse. Adding to this, high-traction shoes were shown to lower curve sprinting performance when exceeding a critical traction value (Luo & Stefanyshyn, 2011). It was concluded that the musculoskeletal system cannot stabilize the joints in the frontal plane which prevents the athlete from a further performance improvement. In an exploratory analysis Robinson and Donnelly (2017) could show a relationship between the FM during 45° cutting maneuvers and the knee joint moments. However, they report the small number of subjects as a limiting factor of their study and it is unclear whether the athlete's movement strategy contributes to the relationship between FM and knee joint loading.

To our knowledge, the relationship between the athlete's movement strategy and the generation of FMs was not investigated so far. We hypothesize that the FM in athletes with different movement strategies significantly contributes to musculoskeletal loading and allows for further understanding of the overall movement mechanics.

METHODS: Planned 90° full effort cutting maneuvers were investigated in 52 athletes with 231 valid trials. For better comparability of the shoe-surface traction values all athletes were using the same shoes (Under Armour Speed Force ID) on a PVC flooring. Lower limb marker trajectories and ground reaction forces of the execution and first acceleration step were recorded in a 3D motion capture setup with 14 cameras (200Hz, Vicon, Oxford, UK) and 2 force plates (1000 Hz, Kistler, Winterthur, Switzerland).
Inverse dynamics calculations were carried out with an anatomic-landmark-scaled Lower-Body-Model (Lund, Andersen, Zee, & Rasmussen, 2015) in order to determine the kinematics and kinetics (Version 6.0, AnyBody Technology, Aalborg, Denmark). GRFs and marker trajectories were filtered with a recursive 4th order low pass filter and a cutoff frequency of 20 Hz (Kristianslund, Krosshaug, & van den Bogert, Antonie J, 2012). For final data analysis Matlab (2018a, Mathworks, Natick, USA) was used. The FM was extracted by using the btkToolkit (http://biomechanical-toolkit.github.io).
The FM is expressed as reaction moments normalised to body mass. According to the sign convention a positive FM resists an external rotation of the foot (Figure 1). To understand the relation between movement strategies and the generation of FM patterns, the FM (Nm/kg), the orientation of the pelvis and foot segment in the global transverse plane (°), and the knee internal rotation moment (Nm/kg) were calculated (Figure 1).
Functional principle component analysis (FPCA) was used on functions of the time series of the FMs as input parameter (231 FM waveforms of the 52 athletes, time normalized to 101 frames).

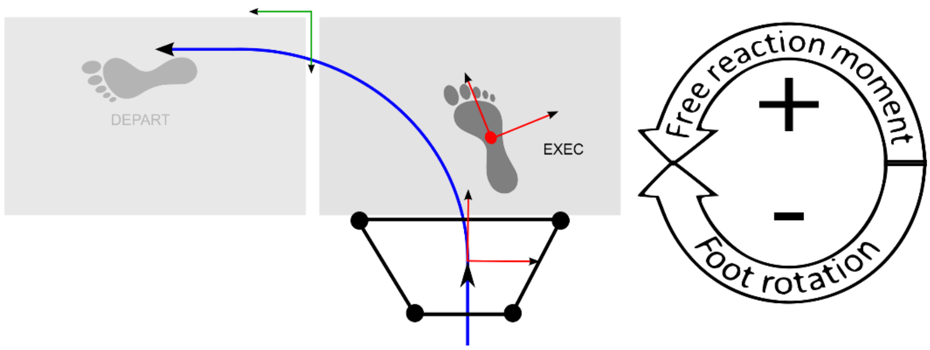

Figure 1: Laboratory setup. The orientation of the pelvis (black trapeze) and the foot coordinate systems (red) relative to the global reference frame (green) were calculated in order to understand their relationship with the FMs. A positive FM acts counterclockwise meaning a rotation towards the new movement direction (blue arrow).

RESULTS: The first three eigenfunctions determined by the FPCA explained 86% of the variance in the FM. For a better understanding, only the first eigenfunction will be discussed in this abstract. To facilitate the interpretation of the eigenfunctions, the effect of the first eigenfunction on the grand mean of the FM dataset was extracted (Figure 2). The first eigenfunction describes the general positive and negative characteristic of the FM waveform. High scores of the first eigenfunction describe an internal rotation (positive values) while low scores are assigned to external rotation (negative values). This means that the athletes are exposed either to a positive or negative FM although executing the same movement task (Figure 2). Investigation of those trials with the highest PC scores for the first eigenfunction revealed a low preorientation of the foot and a slight external rotation of the segment during midstance. Conversely, trials with the lowest PC scores show a comparably higher amount of preorientation of the foot segment and a slight internal rotation during mid stance (Figure 2).

An analogous behaviour is observed for the pelvis segment, where high scores are related to less preorientation. The progression of the pelvis rotation during stance might be directly linked to the FM. Athletes with a high amount of preorientation are exposed to a negative FM moment. This is one possible explanation why they do not show a considerable increase in pelvis rotation during midstance. By reaching the peak FM (~30% of stance), the pelvis rotation of the pelvis segment reaches a plateau with almost no further rotation. In contrast, athletes that are exposed to a positive rotation FM show a strong increase in the pelvis rotation angle (Figure 2).
It was hypothesized that the FM will also affect lower limb joint loading and therefore contribute to the injury risk that was linked to specific movement strategies. The identification of high and low scoring trials with regards to the internal rotation moment at the knee joint supports this idea, because a positive FM is associated with an internal rotation moment at the knee joint (Figure 2) which is by its function increasing the load on the ACL.

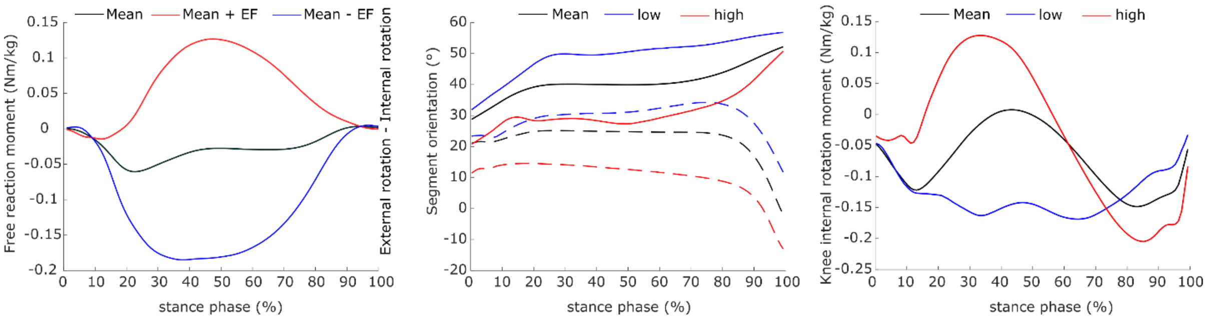

Figure 2: Results of the first eigenfunction (EF, variance explained: 62%) of the FPCA analysis of the FM. The overall mean (black) and the respective representative mean values for high (red) and low (blue) PC scores for the FM, the pelvis (solid lines) and foot orientation (dashed lines) and the knee internal rotation moment are displayed from left to right.

DISCUSSION: The investigation of the FM by using FPCA identified the characteristics of the FM across all trials of the 52 subjects. Interestingly, the execution of the same task resulted in FMs with different orientation (Figure 2). By linking the FPCA scores of the FM to lower limb segment orientations and knee joint moments, it was possible to understand that a negative FM that was reported for athletes that use a movement strategy with a high preorientation will decelerate the rotation of the body. This is likely to be mechanically advantageous. Jindrich, Besier, and Lloyd (2006) discussed the function of braking forces during 45° and 60° cutting maneuvers and argued, that these braking forces prevent the athlete from over rotation. Their model calculation showed, that without these braking forces the rotation angle would have been 1.4 – 3 times higher.
Going one step further, it can be assumed, that an early rotation of the body is a top-down strategy to change direction during running. As the generated FM seems to limit further rotation of the body that was initialized before touch down. In contrast to that, without preorientation, the FM might initiate the rotation of the body. This can be described as a bottom-up strategy. Although this was only reported for forces and the impact of the FM is likely to be much smaller, it was interesting to observe, that the two different orientations occur during the same task.
As Wannop et al. (2010) already reported, this FM is transferred to the shank segment and causes a change in the knee joint moment. Without preorientation, the FM resulted in an internal rotation of the tibia, therefore increasing the load on the ACL.

The investigation of the FM has the positive aspect of not being related to any model calculations. Therefore, measurements between studies should be comparable. However, other factors affecting the FM have to be taken into consideration as well: Shoe-surface traction is highly dependent on the area of the foot that is in contact with the floor. Athletes with an eversion of the foot, might not generate high FMs. Another factor is the design of the sole, that usually provides high traction values only in some directions. This might have biased the outcome of this study.

CONCLUSION: The findings of this study add valuable detail to our current understanding of the causes of knee joint overloading in athletes, that are using a movement strategy without considerable preorientation of the foot and trunk segments. Additionally, this understanding can help to design footwear and especially cleats configurations, that modify the FM where needed. However, the most important finding is that we should not group athletes based on global characteristics. The findings of this study displayed, that the same movement can be achieved by opposite directed forces. Therefore, within subject variation and the between subject differences should be considered when grouping athletes.

REFERENCES:

David, S., Komnik, I., Peters, M., Funken, J., & Potthast, W. (2017). Identification and risk estimation of movement strategies during cutting maneuvers. *Journal of Science and Medicine in Sport, 20*(12), 1075–1080.

Dempsey, A.R., Lloyd, D.G., Elliott, B.C., Steele, J.R., & Munro, B.J. (2009). Changing sidestep cutting technique reduces knee valgus loading. *The American Journal of Sports Medicine, 37*(11), 2194–2200.

Havens, K.L., & Sigward, S.M. (2015). Joint and segmental mechanics differ between cutting maneuvers in skilled athletes. *Gait & Posture, 41*(1), 33–38.

Hootman, J.M., Dick, R., & Agel, J. (2007). Epidemiology of collegiate injuries for 15 sports: summary and recommendations for injury prevention initiatives. *Journal of Athletic Training, 42*(2), 311–319.

Jindrich, D.L., Besier, T.F., & Lloyd, D.G. (2006). A hypothesis for the function of braking forces during running turns. *Journal of Biomechanics, 39*(9), 1611–1620.

Luo, G., & Stefanyshyn, D. (2011). Identification of critical traction values for maximum athletic performance. *Footwear Science, 3*(3), 127–138.

McLean, S.G., Walker, K.B., & van den Bogert, A.J. (2005). Effect of gender on lower extremity kinematics during rapid direction changes: An integrated analysis of three sports movements. *Journal of Science and Medicine in Sport, 8*(4), 411–422.

Mclean, S.G., Huang, X., Su, A., & van den Bogert, Antonie J. (2004). Sagittal plane biomechanics cannot injure the ACL during sidestep cutting. *Clinical Biomechanics, 19*(8), 828–838.

Mclean, S.G., Huang, X., & van den Bogert, A.J. (2008). Investigating isolated neuromuscular control contributions to non-contact anterior cruciate ligament injury risk via computer simulation methods. *Clinical Biomechanics (Bristol, Avon), 23*(7), 926–936.

Mclean, S.G., Huang, X., van den Bogert, A.J., & Mclean, S.G. (2005). Association between lower extremity posture at contact and peak knee valgus moment during sidestepping: implications for ACL injury. *Clinical Biomechanics, 20*(8), 863–870.

Robinson, M.A., & Donnelly, C. (2017). An exploratory analysis correlating force plate free moments and multi-component knee moments during sidestepping. In *ISB Proceedings Archive* . Brisbane.

Wannop, J.W., Worobets, J.T., & Stefanyshyn, D.J. (2010). Footwear traction and lower extremity joint loading. *The American Journal of Sports Medicine, 38*(6), 1221–1228.

Willwacher, S., Goetze, I., Fischer, K.M., & Brüggemann, G.-P. (2016). The free moment in running and its relation to joint loading and injury risk. *Footwear Science, 8*(1), 1–11.

Acknowledgement

Special thanks go to Under Armour who sponsored the shoes for this project.