# A LOCAL APPROACH TO IDENTIFY THE IMPACT OF SUBJECT SPECIFIC MOVEMENT STRATEGIES ON THE LOCAL FORCES DURING CUTTING MANEUVERS

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During multidirectional movements the body is not aligned with the global coordinate system (CS), complicating the interpretation of forces and moments. To overcome these issues, the global ground reaction force (GRF) was transformed into the CS of each segment and the orientation of the segments relative to the global CS were expressed in Euler angles (EA). Principle component analysis (PCA) was used to discriminate the wave forms of the local GRF and the EAs. The first three PC Eigenvectors of the EA and local GRF were correlated to determine the impact of the segment’s orientation on the GRF. An upright position of the shank and thigh segment increased the force acting medially on the knee. This potentially increases the risk of a varus movement, whereas a frontal tilt increased a laterally directed force that potentially stabilized the leg axis.

**KEY WORDS:** Force, Coordinate system transformation, Injury prevention, Change of direction

**INTRODUCTION:** Many research attempts were pursued in order to understand the biomechanics of fast and safe cutting maneuvers (CMs). Studies that tried to correlate biomechanical parameters and the CM performance identified ankle joint power, pelvis and trunk orientation and ground contact time as performance relevant parameters but the correlations were only moderate (Marshall et al., 2014). However, studies that investigated the impact of leg force and ground reaction force (GRF) generation showed contradicting results (Nimphius, Callaghan, Bezodis, & Lockie, 2018). The missing plausibility may be based the definition of performance parameters in general, but also on an insufficiant understanding of the CM mechanics. Supposing that leg force or GRF generation are as linked to the performance of multidirectional maneuvers as they are in straight sprinting, neglects the nature of the movement task: Athletes need to change their body’s orientation during running. This includes, that the segments’ coordinate systems (CS) are not aligned with the global reference frame (Glaister, Orendurff, Schoen, & Klute, 2007). This results in a body that changes the position relative to the GRF vector in each time step, which may lead to a misinterpretation of the global GRF. Investigating the joint angles and forces instead of global GRF also does not allow identifying the impact of movement strategies on joint loading or performance as they are expressed in the segments CS which covers the position of the segments relative to the global CS.
Therefore, the aim of this investigation was to investigate the forces during fast 90° CMs from the segments perspective. It was hypothesized, that this approach is able to identify the impact of the subject specific movement execution on the GRF vector.

**METHODS:** Fifty-nine athletes were investigated in a complex 3D movement analysis setup consisting of 14 infrared cameras (200 Hz, F40, Vicon, Oxford, UK) and two force plates (1000 Hz, Kistler, Winterthur, Switzerland) that recorded the transition ($STEP_{Trans}$) and first acceleration step ($STEP_{Acc}$) of an athlete while performing maximal 90° CMs. 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 (2014a, Mathworks, Natick, USA) was used.

To analyse the GRF from a local perspective, the local CS for the foot, shank, thigh, pelvis and trunk segments and the COM were defined according to the ISB recommendations (Wu et al., 2002). To transform the global GRF into the local CS a rotation matrix **R** was defined:

$$\mathbf{R} = \begin{bmatrix} & {}^{\mathrm{Local}}\mathbf{CS}^{-1} & & -d_1 \\ & & & -d_2 \\ & & & -d_3 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (1)$$

Then, the rotation matrix **R** of each segment was applied to the global GRF:

$$^{\mathrm{Local}}\mathbf{GRF} = {}^{\mathrm{Global}}\mathbf{GRF}\ \ \mathbf{R} \qquad (2)$$

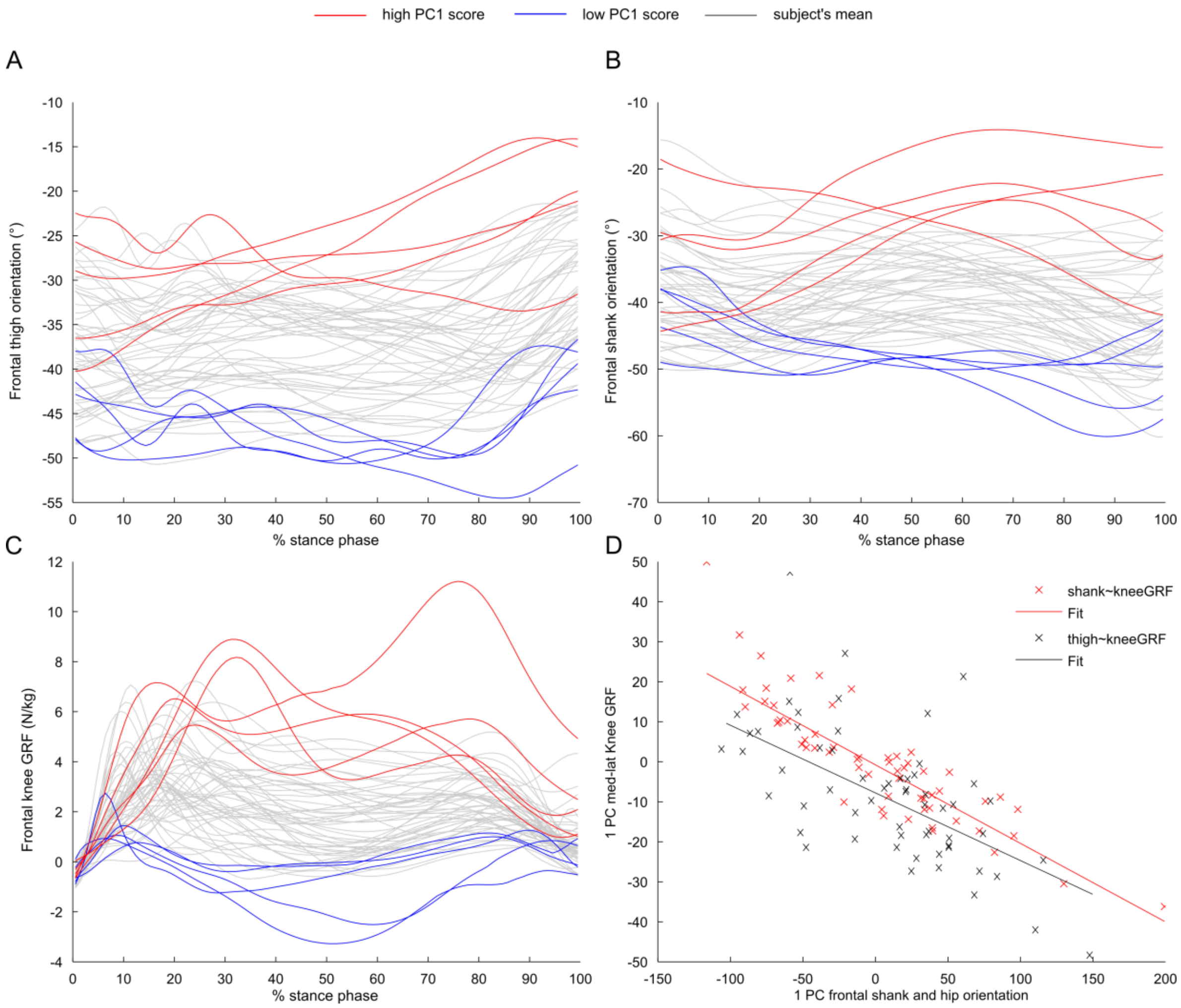


**Figure 1: A-B) Orientation of the thigh and shank segment in the respective segment's frontal plane for each subject (grey). Negative values indicate a frontal tilt of the segment towards the new movement direction. C) Transformed GRF in the frontal knee plane. Positive values indicate a force that acts to the lateral side of the knee. Negative values indicate a force that acts to the medial side. The red and blue curves show the subject's with the highest (red) and lowest (blue) PC1 scores. D) Correlation of the PC1 of the knee (red crosses) and thigh Euler angles (black crosses) with the PC1 scores of the medio-lateral knee GRF.**

The rotation of the ${}^{Local}$**CS** relative to the ${}^{Global}$**CS** was extracted as quaternions by using the 'qGetQ' function and then transferred into Euler angles by using the 'quat2eul' function in Matlab (The MathWorks, Natick, Massachusetts). In order to determine the impact of segment orientation on the local, principle component analysis was used to discriminate the wave forms of respective parameters. The PC Eigenvectors of the Euler angles where than correlated with the local GRF.

**RESULTS:** The orientation of the shank and the thigh segment are used as an example to show the advantage of the presented local approach. To interpret the first PC Eigenvectors, the five highest and lowest values were identified and the respective wave forms of the Euler angles and local knee GRF were plotted (figure 1 A-C).
High PC1 scores of the shank and thigh Euler angles coded for in decrease of frontal tilt towards the new movement direction, whereas low values coded for a stronger frontal tilt at initial touch down with a slight increase during the stance phase. High PC1 scores of the medio-lateral knee GRF indicated laterally directed GRF with overall higher peak GRF while low values indicated medially directed GRF. There was a strong correlation of the shank's and thigh's orientation in the frontal plane of the segment ($r= -.87$ and $r= -.62$, $p<0.001$) and the medio-lateral force that acted on the knee joint (figure 1 D). The orientation of the shank and the thigh segment in the frontal plane showed a high cross-correlation ($r= .72$, $p>0.001$).

**DISCUSSION:** The presented results underline the importance of local approaches in multidirectional movements. During multidirectional movements the segment position relative to the global reference frame is changing constantly (Glaister et al., 2007). Additionally, a high variety of subject specific movement strategies was reported recently and linked to injury risk (David, Komnik, Peters, Funken, & Potthast, 2017; Dempsey et al., 2007) but also performance relevance (Green, Blake, & Caulfield, 2011; Marshall et al., 2014). Therefore the body's orientation relative to the global reference frame is supposed to be different between subjects as well. The interpretation of forces is essential in order to understand both, an athlete's potential to accelerate the body after transition, but also when trying to identify potential risk factors of a movement. By investigating the local force that acted in the frontal plane on the knee it was possible to identify the frontal tilt of the leg axis as a major contributor in order to decrease the varus loading associated with anterior cruciate ligament injuries (Hootman, Dick, & Agel, 2007; Mclean, Huang, van den Bogert, & Mclean, 2005). A frontal tilt of the leg axis (low PC 1 score, Figure A and B) by means of curve leaning was associated ($r= -.87$ and $r= -.062$) to a laterally acting force (high PC 1 score, Figure 1 C) which counteracted a varus movement of the knee joint. The frontal tilt of the leg axis is supposed to result in a medialization of the global GRF vector relative to the knee joint as large masses (e.g the trunk) were moved towards the new movement direction. However, it can be assumed that the frontal tilt of the body is strongly dependent on the movement velocity as curve leaning might not be possible after a slow approach.
Multivariate correlation was declined as there was a high cross-correlation between the shank and thigh PC scores ($r= .72$). However, high cross-correlation values might identify specific movement strategies. Recent studies already showed that specific foot strike pattern are associated with body posture (David et al., 2017; Dempsey et al., 2007) but it was not possible to separate each segment's impact on the investigated parameter. By transforming the global GRF into each segments local coordinate system and using PC analysis, the relationship between segment orientation and respective forces was identified. This directly showed the impact of the orientation of the segment.

**CONCLUSION:** In order to increase the mechanical understanding of multidirectional movements such as fast cutting maneuvers, it is important to analyse the forces that act locally on the segments. This approach enables us to understand the impact of segment orientation on GRF. This understanding can then be used to identify movement strategies that decrease injury risk or improve the athlete's performance. Future investigations should also take the movement velocity into account, as curve leaning might depend on the approach speed.

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