ROTATION AND BRAKING STRATEGIES TO PERFORM A SUCCESSFUL CUTTING MANEUVER

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This study aimed to reveal principle movement strategies during successful 90° cutting maneuvers (CMs). Investigation of the pelvis rotation angle showed that subjects mainly use two strategies: one with most of the 90° cutting angle already realized within the body rotation *prior* to the transition step or one with the rotation executed after transition. These different turning strategies also impacted the way subjects deflected their COM velocity. Pre-rotation results in a more effective movement and less injury risk while post-rotation is suggested to occur in unanticipated cutting maneuvers.

KEYWORDS: Change of direction, mechanics, rotation, deflection, performance

INTRODUCTION: A successful cutting maneuver (CM) requires the deflection of the center of mass (COM) velocity along with a body rotation into the new movement direction (Jindrich, Smith, Jespers, & Wilson, 2007). However, it remained unclear how external forces, reactions and segment orientations interact to meet these two major requirements.

To understand the whole movement process GRFs, COMs and COPs before, during and after the transition step have been investigated. Recently, preparatory strategies prior to the transition step were investigated and a pre-rotation towards the new movement direction as well as backwards leaning was reported (Donnelly et al., 2012). However, subjects using rearfoot striking were *less* pre-rotated than those using a forefoot technique (David, Peters, Komnik, & Potthast, 2016). The ability to turn by using the limb motion for rotational impulse is given pre- or post-transition as the outside limb needs to be accelerated to rotate the body. This suggests either a pre-transition (PRE) rotation strategy or a post-transition (POST) rotation strategy. Due to the reported pre-rotations and postures, GRFs, which are aligned with the global coordinate system, are inappropriate to explain the mechanics of the multi-segmented body. Rather, a GRF transformation into the individual segment coordinate systems is required to fully understand GRF impact (Glaister, Orendurff, Schoen, & Klute, 2007). Additionally, it would be possible to interpret the forces acting on each body segment when the movement is not translational.

Consequently, the aim of this study was to reveal mechanical movement strategies within a heterogeneous sample which performed anticipated cutting maneuvers. It was hypothesized, that due to the high mechanical demands during the turning step, the rotation of the body might be realized before or after the turning step. The rotational impulse might then be realized through acceleration of the free segments of the lower body or through a rotation of the shoulder and pelvis axis which is then followed by the lower body.

METHODS: Fast CMs of 90° were investigated using a 14 camera optoelectronic motion capture system (200 Hz, VICON^{TM}, Oxford, UK) and two force plates (FP) (1000 Hz, Kistler Instrumente AG, Winterthur, Switzerland) to determine cutting kinematics and kinetics using an inverse dynamic approach. GRFs were recorded of the transition step and the first acceleration step of the CM. In total, 52 reflecting markers were attached to defined bony landmarks to create a 15-segment rigid model. All 61 subjects with different age, sex and sportive background were free of injury and pain. After warm up and several CMs to control whether the testing procedure was understood, participants had to perform five valid trials of 90° CMs to their dominant side with maximum effort. A trial was defined to be valid if 90° were negotiated, which was controlled by eyesight and each FP was struck by one foot only. All participants wore the same non-studded indoor soccer shoe (Under Armour Speed Force ID). In order to calculate inertial properties, whole-body anthropometrics were measured to adjust the inverse dynamic model accordingly. The study was approved by the Ethical

Committee of the German Sport University Cologne and all participants provided their informed written consent to participate.

Inverse dynamic calculations were carried out with an anatomic-landmark-scaled Lower-Body-Model (Lund, Andersen, Zee, & Rasmussen, 2015) of the AnyBody™ Modeling System (Version 6.0, AnyBody Technology, Aalborg, Denmark). The model anthropometry was adapted according to Hanavan's antropometric model (Hanavan, 1964) to cover the participants' individual properties. 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, 2012) For final data analysis Matlab (2014a, Mathworks, Natick, USA) was used.
Statistical parametric mapping (SPM) (Friston, Ashburner, Kiebel, Nichols, & Penny, 2007) were used to compare the time series of knee, hip and ankle angles and moments prior, during and after transition, as well as shoulder, pelvis and foot orientation relative to the global coordinate system. For comparison of discrete values, students' t-test was used. The alpha level was set to be 0.05 for all tests. For the analysis the CM movement was divided into four parts: (i) braking step before transition (ii) transition step until the intersection between anterior-posterior and medio-lateral velocity (iii) transition step after the intersection between anterior-posterior and medio-lateral velocity until TO (iv) acceleration step after the transition step (Figure 1).

RESULTS: Due to the significantly different orientation of the pelvis and shoulder segments, it was possible to group the 61 subjects into a PRE group (18 subjects) and a POST group (43 subjects). The PRE group showed a rotation of 41.3° (± 9.7) prior to transition, 18.7° (±8.6) during transition and 29.9° (± 5.8) after transition. In contrast, the POST group showed a turning strategy where most of the 90° rotation was done during the stance phase after the turn. The turning maneuver was therefore executed with a pre-rotation of 24.9° (± 8.3), while the turning stance phase was characterized merely by a slight rotation of 19.7° (± 7.8) followed by the acceleration step where 42.5° (± 8.4) of the rotation were generated (Figure 1). For the last step before transition, no differences were detected either in kinematics or COM velocity but PRE subjects were already rotated towards the new movement strategy during the braking step. Therefore, PRE seemed to initiate the rotation through upper body rotation.

Path speed at touch down (TD) or take off (TO) (p=0.2, p=0.7) was not different which suggests that the choice of rotation strategy had no impact on the cutting performance. However, the investigation of the different phases of the CM revealed differences in the velocity deflection strategy of the two groups. At TD the pre-transition group showed already a higher COM velocity towards the new movement direction ($p<0.001$, PRE: 0.6 m/s ± 0.3 POST: 0.3 m/s ± 0.3).

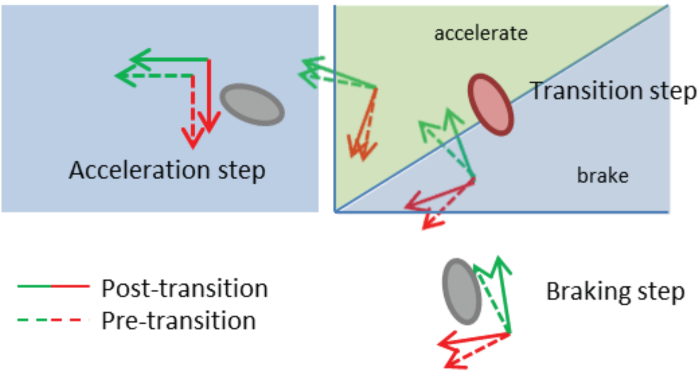

Figure 1 COM orientation relative to the global coordinate system of PRE (dashed coordinate systems) and POST (solid coordinate systems). Red and grey ellipsoids show the average position of the planted feet relative to the COM during the braking step (first grey foot) the transition step on the first force plate (red foot) which is divided into the braking (blue) and acceleration (green) phase and the acceleration step (second grey foot) on the second force plate (rectangles).

The straight position of the POST subjects allowed for a more rapid deceleration until the intersection than for the PRE group ($p<0.002$, mean PRE: 1.6 m/s ± 0.3 POST: 1.3 m/s ± 0.2) whereas the PRE group showed a higher velocity towards the new movement direction ($p<0.001$, mean PRE: 1.6 m/s ± 0.3 POST: 1.3 m/s ± 0.2). The deceleration of the horizontal COM velocity was generated by higher knee and hip flexion angles in the POST group (p=0.001, p=0.001, Figure 2) but reduced ankle dorsiflexion angles (p=0.005) and a longer contact time ($p<0.001$, mean PRE: 55.5 ms ± 13.2, mean POST: 68.1 ms ± 12.9). The different position of the segments resulted in longer lever arms for POST for the knee in the sagittal plane (p=0.011). No differences in the knee flexion moment were detected, which suggests a high workload for the knee stabilizing muscles for the POST group. The subjects of the POST group showed higher knee adduction moments during the braking phase of the transition step which was generated by longer lever arms in the frontal knee plane p=0.02).
In addition, the POST group was able to generate a higher horizontal COM velocity during the acceleration phase (p=0.005, mean PRE: 1.05 m/s ± 0.2, mean POST: 1.3 m/s ± 0.3). In contrast, the POST group showed less additional deceleration in the medio-lateral velocity compared to the pre-transition group ($p<0.001$, mean PRE: -0.5 m/s ± 0.2, mean POST: -0.4 m/s ± 0.1). Apart from higher flexion angles, the knee flexion angle showed a shift in the time series after transition as the POST group executed the main part of the 90° rotation after transition. Since the peak flexion angle was reached at the same time, POST generated a higher flexion angular velocity in comparison to PRE (p=0.003 (Figure 2).
The PRE group showed a larger curve radius compared to post-transition. This resulted in a more constant path speed for the PRE group (p= 0.001) when an already pre-rotated body and less change in velocity over the whole transition time were combined.

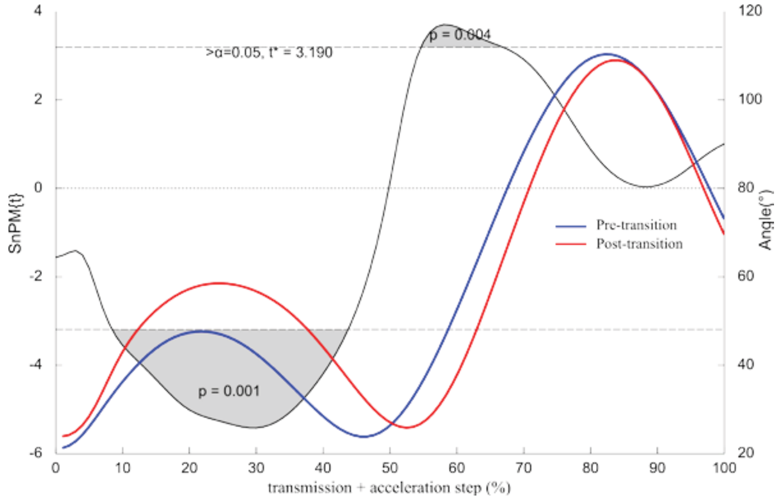

Figure 2 : Time series of SPM (black) and Knee flexion angle of PRE (blue) and POST (red) group showing higher knee flexion angles for the POST group and also a right shift meaning a shorter time period to flex the knee after transition indicating higher knee flexion angular velocity. The grey shaded areas highlight areas of significant differences between the groups.

DISCUSSION: Two different turning strategies were detected among the 61 subjects. One strategy includes subjects with body rotation prior to transition, the other strategy was body rotation after transition. From an energetic point of view, the PRE strategy is preferable since less horizontal velocity needs to be decelerated by means of absorption and therefore less velocity needs to be reaccelerated after transition. As already reported, a straight body position at TD was associated with an increased risk of ACL relevant load (David et al., 2016). This was additionally supported by the longer lever arms in the frontal knee plane.
POST generated a higher flexion angular velocity in comparison to PRE (p=0.003).which supported the hypothesis that a post-transition rotation requires an acceleration of the lower limb segments (Figure 2).

The detected strategies also showed, that a strict description of the braking and acceleration part of the movement, as reported by other authors (Glaister, Orendurff, Schoen, Bernatz, & Klute, 2008; Jindrich et al., 2007) was not possible. Subjects of the PRE group did not show a sharp deflection angle and therefore did not need to decelerate to the same extend as the POST subjects. The movement of the PRE group was therefore comparable to curve running.

Unfortunately, it was not possible to test unanticipated CM due to space restrictions. Subjects were asked to perform the turning maneuvers with maximum effort, so we did not standardize the run-up speed. However, this had the advantage to reveal the aforementioned strategies which otherwise would have been masked by controlled speeds. Although, it was not possible to detect the GRF of the breaking step immediately before the turn, the TD and TO of the braking step could be detected, which allowed for investigation of joint angles and COM velocity.

CONCLUSION: The rotation and braking strategy gives insight into the subject specific CM mechanics. The results showed that pre-transition rotation results in a more continuous path speed and less sagittal joint flexion. It is therefore concluded, that the pre-transition strategy is more effective compared to the post-rotation strategy. At the same time, less pre-rotation during the braking phase is associated with an increased risk of ACL relevant loads. Therefore, the pre-transition strategy should be favored over the post-transition strategy, but it has to be mentioned, that body rotation before transition could be prohibited through gaming situations and short preparation time in unanticipated CM.

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