WHY IS THE LEFT KNEE RATHER PRONE TO INJURY DURING TEAM HANDBALL-SPECIFIC SIDE-CUTTING MANEUVERS TO THE RIGHT?

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The purpose of this study was the biomechanical inter-leg evaluation in three team handball-specific side-cutting maneuvers. This should help to gain a better understanding how different movement executions potentially produce harmful demands to one or both knee joints. Therefore, eight competitive handball player performed the three most common side-cutting maneuvers to the right side (side-cutting maneuver was performed with alternating or simultaneous steps) in a game-like setting in a movement laboratory. Movement data were collected with a 3D motion capture system and two linked 3D force plates. The analysis of the side-cutting maneuvers revealed increased vertical and medio-lateral ground reaction force components on the left leg, which initiated the side-cutting maneuver. The peak knee abduction moments in the weight acceptance phase did not differ between the left and the right leg in all three side-cutting maneuvers. However, higher peak knee valgus angles occurred at the left leg, which increased with increasing stance time. The results of this study indicate that during the performance of handball-specific side-cutting maneuvers to the right, the left knee joint has a greater risk to get injured. Consequently, athletes and coaches should place special focus on the movement execution of the cutting initiating leg to reduce the risk of knee injuries. Furthermore, leg explosive strength and core stability should be in major focus in training exercises to prepare the athlete for the demands in such high intensity movements.

KEYWORDS: Sport-specific feints, sport-specific analysis, injury biomechanics, performance analysis.

INTRODUCTION: Team handball is characterized by high physical demands, associated with a high injury incidence quantified by 63.4 injuries per 1000 athletes in Sweden (Åman et al., 2016). Severe injuries occur most frequently at the knee joint, with a high incidence of anterior cruciate ligament (ACL) injuries (Laver et al., 2018; Myklebust et al., 2003; Seil et al., 2016). Due to the important function of the ACL for knee joint stability and functionality, injuries of the ACL can lead to a long-term drop out from competitive playing and require an intense rehabilitation program to regain full knee joint stability and functionality (Myklebust et al., 2003). The majority of ACL tears occurs in team handball in non-contact situations, typically during sidestep cutting maneuvers and in landing situations (Laver et al., 2018; Olsen et al., 2004). Handball-specific side-cutting maneuvers are characterized by abrupt changes of the movement direction while acting with very high movement velocity (Bencke et al., 2013). Due to flexed knee joint position, accompanied with high valgus and rotational stress, these cutting movements bear a high potential for severe knee injuries (Bencke et al., 2013; Kristianslund et al., 2014; Mok et al., 2018). Especially the so called plant-and-cut faking movement at the initiation of the side-cutting maneuvers bears the highest risk for an ACL injury (Olsen et al., 2004).
The purpose of this study was (1) to quantify the ground reaction force components between the legs and (2) the frontal plane angles and moments between the knee joints in three handball-specific side-cutting maneuvers. Therewith, it should be evaluated, which leg is at higher risk to get overstressed and has a higher potential of a knee injury.

METHODS: Eight male competitive [4.8 ± 1.5 hrs per week; playing experience: 14.9 ± 4.8 yrs] team handball players [23.4 ± 2.1 yrs; 1.84 ± 0.07 m; 80.6 ± 9.1 kg] performed the three most frequently performed side-cutting maneuvers (alternating or simultaneous foot planting) in a movement analysis laboratory. The general characteristics of the side-cutting maneuvers are illustrated in Figure 1. All subjects were right-handed throwers and all side-cutting maneuvers were orientated to the right.

For a realistic performance of the side-cutting maneuver, the subjects were instructed to use a three to four step run-up, held a ball as if playing, and should perform the cuts with game-like intensity. The run-up velocity was controlled by light barriers. Full body kinematics and ground reaction forces (GRFs) (1000Hz; AMTI Inc., Watertown, MA) were collected synchronously using a marker-based motion capture system (11 MX-13 cameras, 200Hz, Vicon, Oxford, UK) to perform biomechanical modeling. 42 spherical reflective markers were placed on subject's anatomical landmarks according to the ALASKA Dynamicus protocol (Härtel & Hermsdorf, 2006; Willwacher et al., 2017). For calculating the forces of each leg separately, each subject had to step on one of two separated force plates (Figure 1). After recording and pre-processing (gap-filling of trajectories; filtering of kinematics and kinetics with a 15 Hz fourth-order low-pass Butterworth filter) of the data, inverse dynamics modeling was computed. By this procedure vertical, anterior-posterior, and medio-lateral GRF components, as well as frontal plane knee joint kinematics and external moments were computed and subsequently analyzed.

Dependent t-tests ($p \leq 0.05$) were computed to detect potential differences in frontal knee angles and moments as well as GRF components between the legs in each side-cutting maneuver. Additionally, the effect size Cohen's *d* was computed between the legs.

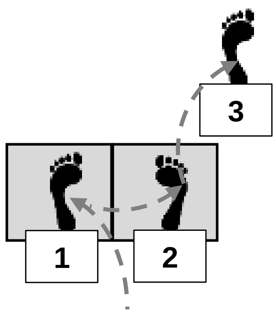
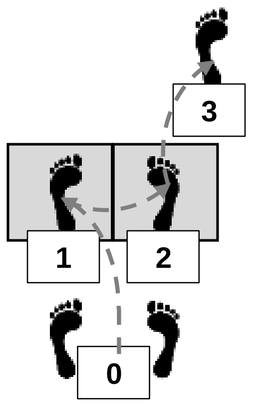
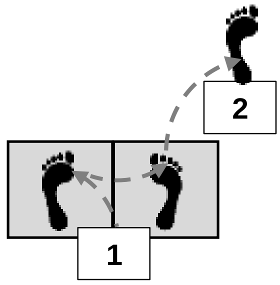
<table>
<tr><th>Type of Sidestep Cutting Maneuver</th><th>Three Step Side-Cutting: Normal Run-up (3S)</th><th>Three Step Side-Cutting: Following 'Zero'-Step (3Z)</th><th>Side-Cutting with Simultaneous Parallel Steps: Normal Run-up (2S)</th></tr>
<tr><td>Step Sequence</td><td>
</td><td>
</td><td>
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Figure 1: Foot placement during the different types of tested side-cutting maneuvers: 3S is characterized by three consecutive alternating steps for the side-cutting maneuver after a normal run-up; 3Z is characterized by three consecutive alternating steps for the side-cutting maneuver following a 'zero-step' situation, where both feet are simultaneously placed parallel before the side-cutting maneuver is performed as in 3S; 2S is characterized by parallel simultaneous foot placement ('zero-step') during the side-cutting movement. After foot placement, the side-cutting maneuvers is performed by shifting the body's main load firstly to the left leg and subsequently to the right leg. Footprints on grey squares represents the steps on the force plates. The dashed line in dark grey represents the center of mass trajectory.

RESULTS:

All three side-cutting maneuvers did not differ in the run-up velocity (3S: 2.8 m/s ± 1.0 m/s; 3Z: 2.3 m/s ± 1.0 m/s; 2S: 2.5 m/s ± 1.0 m/s).

In all three different side-cutting maneuvers, peak vertical and peak medio-lateral GRF components were significantly increased in the left legs compared to the right legs (Table 1). The anterior-posterior directed peak GRF strongly differed between the left and the right leg (Table 1). The left leg had to withstand the largest portion of the braking forces (posteriorly directed), while the right leg generated most of the propulsion force (anteriorly directed) into the new movement direction (Table 1).

Table 1: Mean Values (MV) and Standard Deviations (SD) of Peak GRF Components in the Three Tested Side-Cutting Maneuvers.

GRF Component	Sidestep Cutting Maneuver	Left Leg GRF [N] (MV ± SD)	Right Leg GRF [N] (MV ± SD)	Inferential Statistics
Vertical	3S	2086.4 ± 156.6	1510.9 ± 315.3	$p = .001$; $d = 1.95$
	3Z	1911.8 ± 322.5	1444.0 ± 228.9	$p = .005$; $d = 1.53$
	2S	2421.8 ± 579.0	1140.9 ± 230.1	$p < .001$; $d = 2.15$
Medio (+) / Lateral (-)	3S	930.3 ± 146.6	310.8 ± 151.0	$p < .001$; $d = 3.90$
	3Z	991.1 ± 242.4	300.4 ± 153.7	$p < .001$; $d = 3.19$
	2S	1085.0 ± 314.4	97.5 ± 43.1	$p < .001$; $d = 4.45$
Anterior (+) / Posterior (-)	3S	- 563.2 ± 190.3	566.3 ± 152.2	$p < .001$; $d = 6.16$
	3Z	- 330.0 ± 106.0	538.4 ± 116.3	$p < .001$; $d = 7.31$
	2S	- 461.6 ± 67.2	490.8 ± 126.3	$p < .001$; $d = 8.46$

External peak knee abduction moments showed no significant difference between the left and the right leg in the weight acceptance phase in the three side-cutting maneuvers (Table 2).

Table 2: Mean Values (MV) and Standard Deviations (SD) of the Peak External Knee Abduction Moments (PEKAM) in the Three Tested Side-Cutting Maneuvers.

Sidestep Cutting Maneuver	Left Leg PEKAM [Nm/kg] (MV ± SD)	Right Leg PEKAM [Nm/kg] (MV ± SD)	Inferential Statistics
3S	0.41 ± 0.31	0.37 ± 0.38	$p = .72$; $d = 0.12$
3Z	0.54 ± 0.44	0.32 ± 0.17	$p = .09$; $d = 0.48$
2S	0.32 ± 0.18	0.29 ± 0.24	$p = .82$; $d = 0.12$

Associated to these frontal knee moments, analysis revealed in average knee valgus angles (3 S: 1.9° ± 1.0°; 3Z: 2.4° ± 1.0°; 2S: 2.5° ± 1.4°) in the left knee over the stance phase compared to neutral or slight varus position (3S: 3.0° ± 0.9°; 3Z: 3.0° ± 1.2°; 2S: 3.2° ± 0.9°) in the right knee (3S: $p < .01$; $d = 2.02$; 3Z: $p < .01$; $d = 2.11$; 2S: $p < .01$; $d = 1.43$). Additionally, the knee valgus angles increased in the left leg from heel strike (HS) to toe-off (TO) in 3S (HS 1.8° ± 1.7°, TO 4.0° ± 2.5°; $p = .01$; $d = 0.91$), 3Z (HS 1.6° ± 2.4°, TO 4.5° ± 2.7°; $p < .01$; $d = 1.14$), and 2S (HS 0.9° ± 2.5°, TO 4.5° ± 2.8°; $p = .01$; $d = 1.38$). In the right leg, the knee joint showed a varus position in the knee joint, which decreased in 3S (HS 3.8° ± 3.3°, TO 0.7° ± 1.0°; $p = .01$; $d = 0.84$) and 3Z (HS 4.4° ± 3.6°, TO 0.8° ± 1.3°; $p < .01$; $d = 0.97$), but not in 2S (HS: 2.6° ± 4.0°, TO 1.3° ± 1.7°; $p = .29$; $d = 0.33$) over the stance time.

DISCUSSION: In this study, knee joint mechanics of male handball players were analyzed during three handball-specific side-cutting maneuvers to detect potential harmful knee joint alignment and loadings with respect to knee injuries. The side-cutting maneuvers were performed under standardized settings with a game-like intensity.

When comparing both knee joints in regards to higher biomechanical demands, which could contribute to a higher risk of knee injuries, it emerged that in side-cutting maneuvers to the right side, the left leg has to withstand higher vertical forces and shear forces. Furthermore, the left leg has to accept almost the whole amount of the braking forces, and shows in the transition phase to the right side, increasing knee valgus angles accompanied with peak knee abduction moments (Bencke et al. 2013). Although these frontal plane loads are not higher than those at the right leg, the detected knee valgus position and knee abduction moments increase the stress to the knee joint's structures, as for instance the ACL. The detected frontal plane moments are in accordance with other studies and show that high valgus stress is produced during this side-cutting maneuvers (Bencke et al., 2013). Additionally, high valgus loads are widely described and accepted as a major risk factor for ACL injuries (Bencke et al., 2013; Bahr & Krosshaug 2005; Krosshaug et al., 2006; Olsen et al., 2004). Due to the fact that the right knee joint is in a slight varus position during the whole stance phase, this knee joint

is in a safer position to avoid collapsing into valgus. Additionally, as the knee abduction moments in the left knee joint occurred especially in the weight acceptance phase, this moment induces high valgus stress. If the athlete cannot withstand this external abduction moment, the knee joint could rather collapse into full valgus, which would make a knee injury more likely. These findings clearly contribute the findings of Olsen et al. (2004) and show that the leg, which is used to perform the change of direction after the run-up phase has a potential increased risk to suffer from an knee injury.
Furthermore, the shear forces acting over the left knee joint are rather increased compared to the right knee joint, which also contribute to negative stress to the knee joint's structures.

CONCLUSION: These biomechanical measures show that right-handed team handball players potentially have to withstand higher loads in their left knee joint compared to their right knee joint while performing handball-specific side-cutting maneuvers to the right side. The findings indicate a higher risk of the side-cutting initiating leg for knee joint injuries.
Due to the knowledge of the results of this study with a relatively small sample, it is absolutely necessary to enlarge the scope of the study by increasing the sample size. Furthermore, as increases of medio-lateral GRF, as well as increases of knee flexion and valgus angles in side-cutting maneuvers with a defensive player were observed, studies in a more sport-specific setting should be taken under consideration (McLean et al., 2004). Furthermore, as practical implication, athletes and coaches should place special focus on the movement execution of the cutting initiating leg to reduce the risk of knee injuries during side-cutting maneuvers in team handball. To address that, leg explosive strength and core stability training should play a major role in the purpose of team handball-specific training. This would help to increase the strength capacities of the athletes, which are necessitated to withstand the demands in such high explosive movements.

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