KNEE KINEMATICS AND KINETICS OF SPORT-SPECIFIC FAKE-AND-CUT MANEUVERS OF VARYING COMPLEXITY IN FEMALE HANDBALL PLAYERS

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The purpose of this study was to 1) compare knee joint kinematics and kinetics of fake-and-cut tasks of varying complexity in 51 female handball players and 2) present a case study of one athlete who ruptured her ACL three weeks post data collection. External knee joint moments and knee joint angles in all planes at the instance of the peak external knee abduction moment (KAM) as well as moment and angle time curves were analyzed. Peak KAMs and knee internal rotation moments were substantially higher than published values obtained during simple change-of-direction tasks and, along with flexion angles, differed significantly between the tasks. Introducing a ball reception and a static defender increased joint loads while they partially decreased again when anticipation was lacking. Our results suggest to use game-specific assessments of injury risk while complexity levels do not directly increase knee loading. Extreme values of several risk factors for a post-test injured athlete highlight the need and usefulness of appropriate screenings.

KEYWORDS: injury prevention, screening, ACL.

INTRODUCTION: The majority of anterior cruciate ligament (ACL) injuries in team sports are non-contact injuries while female handball players have been shown to be at higher risk than their male counterparts (Kobayashi et al., 2010). In a prospective study, Hewett et al. (2005) identified the peak external knee abduction moment (KAM) as a risk factor for non-contact ACL injuries. However, screening athletes based on peak KAMs alone might be insufficient, as a combination of valgus loading and tibial internal rotation has been observed in ACL injury situations (Koga et al., 2010) and shown to strain the ACL substantially more than either one alone (Shin et al, 2011). Furthermore, Markolf et al. (1995) have shown *in vitro* that the impact of internal rotation moments (KIRMs) on ACL loading is especially high at small knee flexion angles. To identify high-risk athletes, screenings that typically involve change-of-direction tasks have been suggested and applied in various setups. However, these tasks are usually not designed to simulate game play, and the role of sport specificity and added complexity (e.g. catching a ball, faking a defender) in ACL screening programs hence remains unknown. Therefore, the main purpose of the study was to compare knee joint angles and external joint moments at the instance of the peak KAM in all planes during three sport-specific fake-and-cut tasks in female handball players. We hypothesized that knee joint loading increases with increasing task complexity. Three weeks post data collection, one of the athletes reported that she suffered a non-contact ACL tear during practice. Therefore, the second purpose was to compare the data of the injured athlete (IA) to the data of the whole cohort.

METHODS: The study was approved by the Regional Ethics Committee. Fifty-one female (mean ± SD: 66.9 ± 7.8 kg, 1.74 ± 0.06 m, 19.2 ± 3.4 years) handball players from various Norwegian handball divisions volunteered after informed consent was obtained. Full-body kinematics and ground reaction forces were captured with a marker-based tracking system (24 cameras, Qualisys AB, 200 Hz) and force plates (AMTI, 1000 Hz) during three standardized fake-and-cut tasks. In all tasks, athletes accelerated for 6 meters and arrived at an angle of ~35° to the long axis of the simulated handball court. Athletes were instructed to perform the fake-and-cut maneuvers with match-like intensities. In Task 1, a simple pre-planned fake and sidestep cut was performed. In Task 2, athletes caught a pass, performed a fake, and cut in front of one static defender. The cutting leg for Tasks 1 and 2 was determined based on the players' team positions. In Task 3, athletes caught a pass before faking three variably moving opponents and performing a sidestep cut. The middle and one randomly alternating outside defender moved towards the athlete during the catch, forcing a cut away from them, resulting in an unanticipated cut. Task 3 was therefore performed on both the right and left leg. However, only the same leg as in Tasks 1 and 2 was considered for the initial analysis. The task order was randomized, and a minimum of five valid trials per task was recorded.
Marker trajectories and ground reaction forces were filtered with a recursive 4^{th} order low-pass Butterworth filter with a 20 Hz cut-off frequency (Mai & Willwacher, 2019). The knee joint center was defined as the midpoint between the medial and lateral femoral condyle markers. Segment inertial properties were calculated based on anthropometric data derived from de Leva (1996). Resultant external knee joint moments were determined with inverse dynamics (Hof, 1992; Willwacher et al., 2016) using a rigid body model of the lower extremities and normalized to body weight. To test for differences in external knee joint moments and joint angles in all planes at the instance of the peak KAM between tasks, repeated-measures ANOVAs were applied. Moment and angle time curves of the first 100 ms of stance in all planes were compared using repeated-measures ANOVAs of statistical parametric mapping (SPM, v.M0.4.8, www.spm1d.org). Data were tested for normality, and the level of significance was set to α = .05. Post hoc tests for discrete parameters were performed with Bonferroni correction. Decile ranks for IA were calculated to compare these data to the uninjured athletes. All calculations were performed using a custom-made MATLAB script (R2021a, The Mathworks, Natick, USA).

RESULTS: Task 2 produced the highest (1.73 ± 0.61 Nm/kg) and Task 1 the lowest peak KAMs (1.52 ± 0.54 Nm/kg). Values for Task 1 were significantly lower than for Tasks 2 and 3 ($p_{posthoc}$ = .003 and .020, respectively; Table 1).

Table 1: Means ± SD of external knee joint moments and knee joint angles at the instance of the peak external knee abduction moment. Numbers in parentheses represent means for the injured athlete. Superscripts indicate significant differences to the respective tasks.

Task	Sagittal plane	Frontal plane	Transverse plane
	External knee joint moments at peak KAM [Nm/kg]		
1	-1.96 (-0.65) ± 0.79	1.52 (2.41) ± 0.54^{*2,3}	-0.35 (-0.94) ± 0.31
2	-1.84 (-1.54) ± 0.81	1.73 (3.60) ± 0.61^{*1}	-0.43 (-1.01) ± 0.29^{**3}
3	-2.09 (-1.53) ± 0.77	1.64 (2.69) ± 0.56^{*1}	-0.31 (-0.94) ± 0.28^{**2}
	Knee joint angles at peak KAM [°]		
1	43.8 (29.4) ± 11.8^{*2}	-14.1 (-10.2) ± 4.7	5.9 (-5.2) ± 6.5
2	39.8 (23.3) ± 10.7^{*1,3}	-14.7 (-16.0) ± 4.9	6.4 (2.3) ± 6.2
3	44.1 (32.9) ± 11.2^{*2}	-14.9 (-13.8) ± 5.1	7.0 (0.3) ± 7.3

*****$p_{posthoc}$ < .05; ******$p_{posthoc}$ < .001

Task 2 also produced the highest KIRMs at peak KAM (-0.43 ± 0.29 Nm/kg) and differed significantly ($p_{posthoc}$ < .001) from Task 3 (-0.31 ± 0.28 Nm/kg). Moreover, Task 2 produced significantly smaller knee flexion angles at peak KAM (39.8 ± 10.7°) than Tasks 1 (43.8 ± 11.8°, $p_{posthoc}$ = .021) and 3 (44.1 ± 11.2, $p_{posthoc}$ = .014). Sagittal plane moments and frontal and transverse plane angles at peak KAM remained unaffected (p > .05; Table 1). Significant (p < .05) differences were found for joint moment (Figure1 A–C) and angle time curves within the first 100 ms of stance (Figure 1D–F) in all planes.

For IA, values within the tenth decile were found for peak KAMs and KIRMs at peak KAM in all tasks. In Task 2, IA showed the highest magnitudes of all athletes for these parameters across all tasks. For knee flexion angles, values within the first (Tasks 1 and 2) and second decile (Task 3) were found. In Task 2, IA produced the second smallest knee flexion angles of all subjects across all tasks (Table 1). The time curve analysis shows higher KAMs (Figure 1B) and KIRMs (Figure 1C) within the first 45 ms and higher knee external rotation angles (Figure 1F) within the first 100 ms of stance compared to the whole cohort.

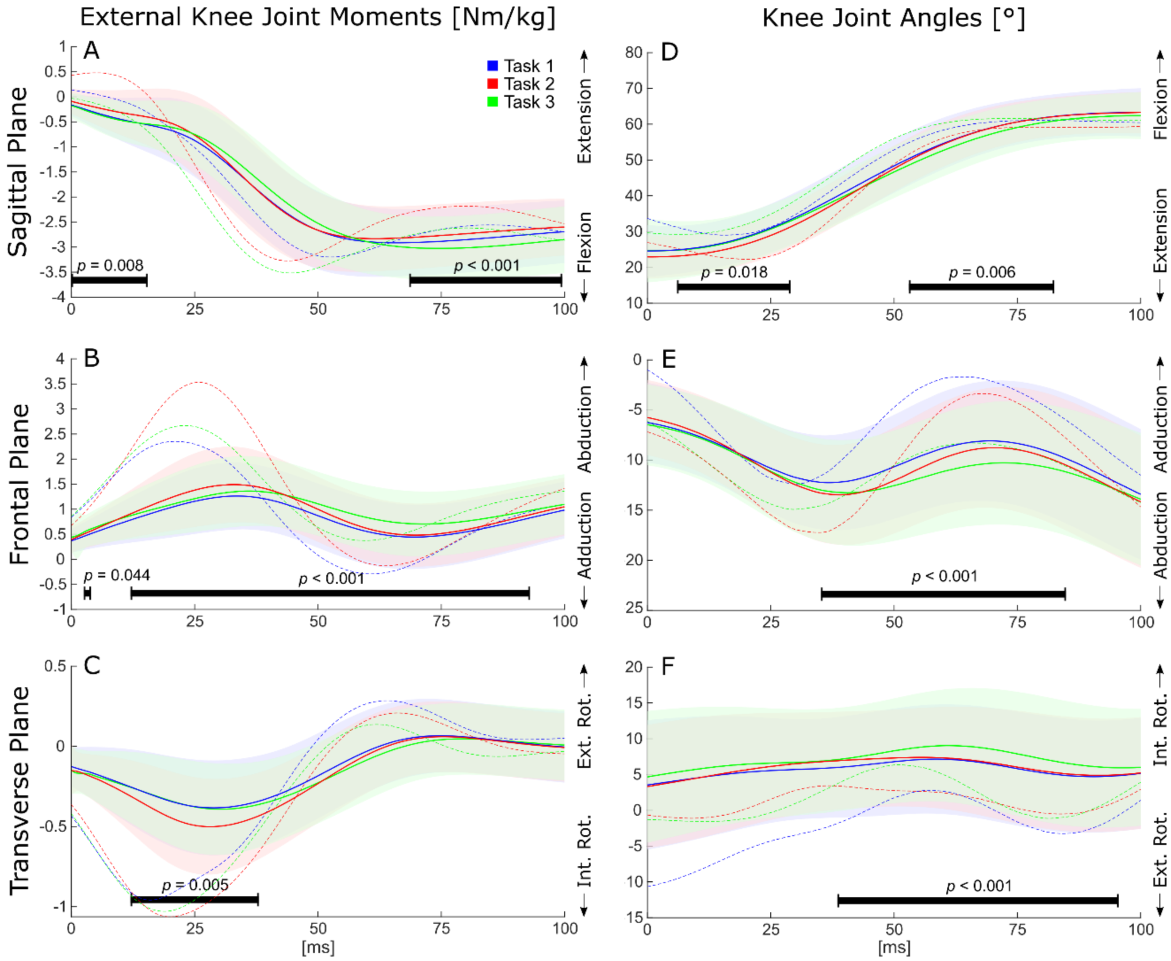

Figure 1: Knee joint angles and external joint moments in each plane and task. Solid lines represent the means for all 51 athletes, shaded areas represent standard deviations, dashed lines represent means for the injured athlete. Black horizontal bars indicate significant task complexity effects within the spanned time frames.

DISCUSSION: All three tasks independent of the complexity level produced higher values for peak KAMs than those published in previous research (e.g., up to ~1.2 Nm/kg or ~226% higher than males in Besier et al., 2001). Task 2 produced the highest peak KAMs, highest KIRMs at peak KAM (~0.11 Nm/kg or ~34% higher than peak values in Besier et. al, 2001), and the smallest knee flexion angles at peak KAM, all of which have been suggested as contributors to ACL loading. Since Task 2 produced on average higher frontal and transverse plane moments than Task 3, we infer that increasing the task complexity beyond its optimal threshold decreases knee joint loading, possibly attributable to smaller cut angles (-10°), slower execution speeds (-0.18 m/s), and lessened intensities of the faking maneuvers due to the lack of anticipation.

IA's ranking in the highest deciles for peak KAM and KIRM at peak KAM, and lowest deciles for knee flexion angle at peak KAM suggests high ACL loading. Further, IA produced her highest peak KAMs as well as highest KIRMs and smallest knee flexion angles at peak KAM in Task 2, highlighting the loading placed on the knee during that task. It needs to be noted that IA's injury occurred post data collection to the leg initially not analyzed. Therefore, a secondary analysis of the KAM of the injured leg during Task 3 was performed, revealing even higher KAMs than in the uninjured leg (2.87 vs. 2.69 Nm/kg), and the highest values among all athletes. However, although still well above loading levels previously published, average peak KAMs for all athletes decreased for the leg initially not analyzed compared to the initially analyzed leg in Task 3 (1.33 vs. 1.64 Nm/kg), possibly due to further decreased cut angles due to the angled inrun relative to the simulated handball court's long axis.

CONCLUSION: All tasks produced substantially higher knee joint loading than tasks designed in previous research and, therefore, may be better suited as screening tasks than tasks lacking game specificity. A combination of high KAMs, high KIRMs and low knee flexion angles might put athletes at higher risk of injury than high KAMs alone. Adding key game elements to a sport-specific pre-planned fake and cut task increases knee joint loading more than in an unanticipated cut, indicating an optimal task complexity for screenings. Our results provide valuable insight into knee biomechanics, external factors influencing knee joint loading, and the design of screening tasks.

REFERENCES

Besier, T. F., Lloyd, D. G., Cochrane, J. L., & Ackland, T. R. (2001). External loading of the knee joint during running and cutting maneuvers. *Medicine and science in sports and exercise*, *33*(7), 1168-1175. http://doi.org/10.1097/00005768-200107000-00014

de Leva, P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. *Journal of biomechanics*, *29*(9), 1223-1230. http://doi.org/10.1016/0021-9290(95)00178-6

Hewett, T. E., Myer, G. D., Ford, K. R., Heidt Jr, R. S., Colosimo, A. J., McLean, S. G., ... & Succop, P. (2005). Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: a prospective study. *The American journal of sports medicine*, *33*(4), 492-501. http://doi.org/10.1177/0363546504269591

Hof, A. L. 1992. "An Explicit Expression for the Moment in Multibody Systems." *Journal of Biomechanics* 25 (10): 1209–11. https://doi.org/10.1016/0021-9290(92)90076-D.

Kobayashi, H., Kanamura, T., Koshida, S., Miyashita, K., Okado, T., Shimizu, T., & Yokoe, K. (2010). Mechanisms of the anterior cruciate ligament injury in sports activities: a twenty-year clinical research of 1,700 athletes. *Journal of sports science & medicine*, *9*(4), 669.

Koga, H., Nakamae, A., Shima, Y., Iwasa, J., Myklebust, G., Engebretsen, L., ... & Krosshaug, T. (2010). Mechanisms for noncontact anterior cruciate ligament injuries: knee joint kinematics in 10 injury situations from female team handball and basketball. *The American journal of sports medicine*, *38*(11), 2218-2225. http://doi.org/10.1177/0363546510373570

Mai, P., & Willwacher, S. (2019). Effects of low-pass filter combinations on lower extremity joint moments in distance running. *Journal of biomechanics,* *95*, 109311. http://dx.doi.org/10.1016/j.jbiomech.2019.08.005

Markolf, K. L., Burchfield, D. M., Shapiro, M. M., Shepard, M. F., Finerman, G. A., & Slauterbeck, J. L. (1995). Combined knee loading states that generate high anterior cruciate ligament forces. *Journal of orthopaedic research*, *13*(6), 930-935. http://dx.doi.org/10.1002/jor.1100130618

McLean, S. G., Huang, X., & Van Den Bogert, A. J. (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.

Shin, C. S., Chaudhari, A. M., & Andriacchi, T. P. (2011). Valgus plus internal rotation moments increase anterior cruciate ligament strain more than either alone. *Med Sci Sports Exerc*, *43*(8), 1484-1491. http://dx.doi.org/10.1249/MSS.0b013e31820f8395

Willwacher, S., Kurz, M., Menne, C., Schrödter, E., & Brüggemann, G. P. (2016). Biomechanical response to altered footwear longitudinal bending stiffness in the early acceleration phase of sprinting. *Footwear Science,* *8*(2), 99-108. http://dx.doi.org/10.1080/19424280.2016.1144653