TESTING INJURY RISK IN ACL-RECONSTRUCTED FOOTBALL PLAYERS ON THE FIELD: A PRACTICAL TOOL TO ASSESS CUTTING BIOMECHANICS THROUGH WEARABLE SENSORS

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The aim of the present study was to inspect differences between healthy and ACLR football players through a kinematic on-field assessment of cut manoeuvres. 62 (47 healthy, 15 ACLR) were enrolled. The players performed planned 90° changes of direction and unplanned football-specific changes of direction. Kinematics was collected through 8 wearable inertial sensors (MTw Awinda, Xsens). Healthy and ACLR players differed in hip and knee rotation during the entire cut phase ($p<0.045$), in hip and knee flexion at initial foot contact ($p<0.001$), and pelvis-trunk tilt and rotation ($p<0.036$). A tool to determine the risk of knee loading based on the dangerous movement patterns emerged was provided. Differences between healthy and ACLR players persisted after RTS clearance, the tool provided can support clinicians in RTS through objective on-field measurements.

KEYWORDS: ACL, biomechanics, wearables, injury prevention, ecological dynamics, change of direction.

INTRODUCTION: Movement biomechanics has become crucial in the rehabilitation and return to sport (RTS) after anterior cruciate ligament (ACL) injury in football (soccer). Recent studies have identified clear injury risk patterns that could be identified in association with an ACL injury (Della Villa et al., 2020). These patterns involve whole-body mechanics and are likely induced by either mechanical, neurocognitive perturbation, or both. Tools to testing cut manoeuvres are therefore important to detect dangerous biomechanical patterns.
Cutting movements such as the ones occurring during pressing, deceiving actions, and decelerations from sprinting in football are considered the movements at higher risk of inducing overload in the knee joint and onto the ACL (Della Villa et al., 2020; Di Paolo et al., 2022). Despite a great effort has been put into the introduction of sport-specific unanticipated elements while testing players in a standard laboratory environment, these kinds of information may lack context and ecological validity. Data collected in ecological environments has been therefore advocated to improve injury risk pattern detection. It has been shown that differences related to the context (lab vs field) exist during cut manoeuvres in healthy female football players (Di Paolo et al., 2023). When testing players during and after the RTS phase after an ACL injury, the investigation of players' biomechanics in a context as close as possible to reality might be of great help to inspect residual asymmetries and dangerous patterns. In particular, the movement of healthy and ACL-reconstructed (ACLR) players might differ in sport-specific cut manoeuvres.
So far, no studies presented the differences between healthy and ACLR players in football-specific tasks captured on the field. The aim of the present study was to (I) inspect differences between healthy and ACLR football players through a kinematic on-field assessment of cut manoeuvres and (II) provide a practical tool for the assessment of ACL injury risk during the RTS.

METHODS: 62 competitive football (soccer) players were enrolled: 47 were free from musculoskeletal injuries (age 15.9 ± 2.4, 27 males) and 15 (age 16.9 ± 4.2, 11 males) were ACLR players. All the ACLR players were cleared for RTS (>14 months after ACL surgery). Each player's parent/tutor signed informed consent and agreed to their own child's performance data acquisition and treatment for research purposes. The team coach was present and supervised all the data acquisition phases. This study obtained approval from the *Blinded for submission*.

Data collection was held in a football pitch equipped with artificial turf. The players performed a planned 90° changes of direction within the Agility T-test and unplanned football-specific changes of direction (FS deceiving action). The agility T-test is one of the most common tests in football and multidirectional sports to investigate sprint and agility performance. The test was performance (time)- oriented and did not include any other player/element, as the players were pushed to sprint at their maximum and complete the drill in the shortest time possible. Two trials per side were collected for each player. The football-specific changes of direction consisted of a cut with an opponent in ball possession, to simulate a football-specific defensive pressing pattern. The players were instructed to ‘‘sprint to take the ball away from the opponent’’ as if they were in a real game. The players were unaware of the direction of the change chosen by the opponent. The opponent made the move into the new direction only when the player involved in the test was approaching the cone, in order to simulate a deceiving action. Lower limbs and trunk kinematics were collected through 8 wearable inertial sensors (MTw Awinda, Movella Xsens). The sensors were positioned as follows: foot dorsum, shin, thigh, pelvis (L5), and trunk (C7). Two experienced users carried on the sensor placement for all the player and dynamic calibration (Walk + N Pose) was performed according to the manufacturer’s instructions. The output sample frequency was 100Hz. The system has been previously validated against marker-based motion capture for the kinematics assessment of high-dynamics movements adopted in RTS from ACL injury with excellent agreement on sagittal plane, fair-to-excellent agreement on frontal plane, and poor-to-fair agreement on transverse plane on both lower limbs and trunk joints (Di Paolo et al., 2021).

Joint kinematics for ankle, knee, hip, pelvis, and trunk in the three anatomical planes was computed for each trial in the company’s proprietary software and extracted for post-processing to a custom Matlab script. The identification of the cut stance phase was performed through the pelvis vertical velocity according to (Milner & Paquette, 2015). Data were normalized to include the deceleration and acceleration phase of the cut: the 0% and 100% were respectively 25ms before the beginning and 25ms after the end of the stance phase of the foot contact in which the players changed their direction.

The two-tailed Student’s t-test within the Statistical Parametric Mapping was used to inspect the differences ($p<0.05$) in joint kinematic waveforms between healthy and ACLR players (injured limb).

RESULTS: Healthy and ACLR players differed in hip and knee rotation during the entire cut phase (hip rotation mean diff. 7.5° - ACLR external hip rot., $p<0.045$), in hip and knee flexion with a stiffer strategy at initial foot contact (knee flexion mean diff. at IC=27.3° - ACLR lower knee flexion, $p<0.001$), and in pelvis and trunk tilt (entire cut phase, mean diff. trunk tilt=5.9° - ACLR more contralateral tilt, $p<0.007$) and rotation (initial foot contact, mean diff trunk rotation=7.6° - ACLR ipsilateral rotation, $p<0.036$).

A tool to determine the risk of knee loading based on dangerous movement patterns was provided (Figure 1). The tool simultaneously includes multiple biomechanical risk factors based on quantitative thresholds belonging to three areas (dynamic valgus collapse, sagittal knee loading, and trunk-pelvis imbalance). The detailed description of the risk factors and relative thresholds is based on the current literature and is presented in Table 1 (Di Paolo et al., 2022). A movement is overall considered at risk if at least 4/8 risk factors are simultaneously present in the movement. Regarding the single areas, the presence of a specific risk is determined by the presence of 2/2 or 3/3 risk factors for that specific area. This tool therefore indicates the presence of a movement performed with a dangerous pattern and is able to describe the macro-areas of risk – and therefore to be assessed for improvement.

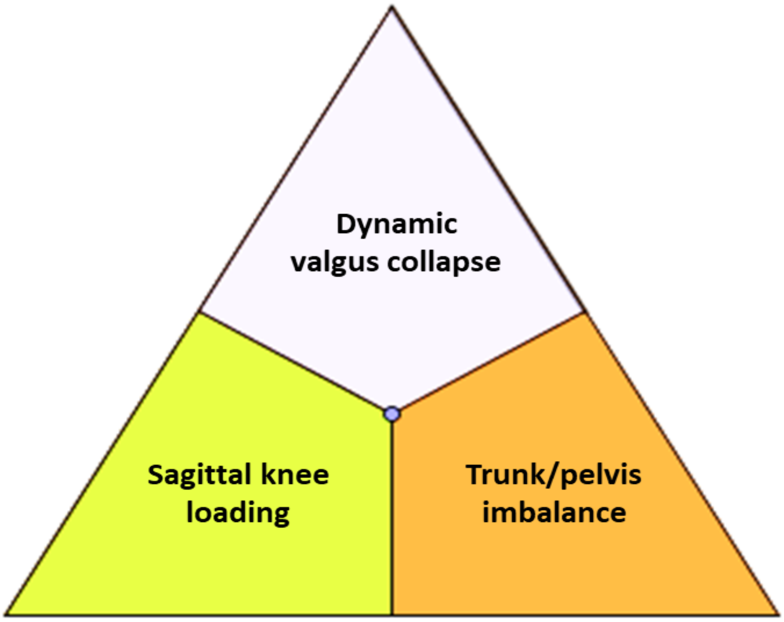

Figure 1: General example of the tool to inspect the presence of dangerous patterns for ACL injury. The parameters for the three areas and relative thresholds are reported in Table 1.

Table 1: Detailed description of the risk factors included in the tool to inspect the presence of dangerous patterns for ACL injury. IC=initial contact in cut foot stance; MKF= maximum knee flexion angle frame.

Risk Factor	IC	MKF
Sagittal Knee Loading		
Hip/knee ratio	> 1.5	> 1.5
Knee flexion	<20.1	<46.2
Ankle plantarflexion	<−8.5	<0.1
Knee Valgus Collapse		
Knee valgus	>5.3	>5.1
Hip abd/adduction	<0.4; >19.0	<−2.7; >19.7
Hip internal rotation	>15.1	>13.0
Trunk/Pelvis Imbalance		
Trunk ipsilateral bending	>14.5	>22.9
Trunk contralateral rotation	>5.8	>11.9

DISCUSSION: The present study aimed at describing the potential differences in motion patterns between healthy and ACL injured players that have been cleared for RTS (minimum 14 months after surgery) in a set of football-specific movement tasks and to provide a practical tool to detect the injury risk patterns related to ACL injury. The movements were performed on the field and included the presence of football-specific elements such as the ground, cleat shoes, ball, and opponent performing a deceiving action.

Interesting differences emerged between the healthy and ACLR players. ACLR players adopted a stiffer strategy at lower limbs at initial foot contact and showed greater rotations at the hip and tilt at the pelvis and trunk compared to the healthy players. These aspects could contribute to increasing the load on the operated knee joint: a stiffer strategy is indeed addressed as one of the major points of interest during the RTS phase to dissipate through the muscles the vertical forces and sagittal plane moments that would otherwise occur at the joint level. The presence of both hip, pelvis, and trunk rotation on the frontal and transverse plane further indicates that these players induce also torsional moments at the knee joint level and get closer to an ACL injury pattern compared to their non-injured counterparts (Della Villa et al., 2020).

Despite an acceptable timing after ACL surgery, the absence or the limited commitment to neuromuscular training during the rehabilitation phase could have left the players with biomechanical imbalances from either before or after surgery, with the latter as an intrinsic compensation to avoid the load on the operated leg.

A practical tool to inspect the risk of occurrence of dangerous patterns related to the risk of ACL injury was presented based on the statistical and clinically-significant differences emerged on the present study cohort's data comparison and on threshold extracted from the current literature. The presence of quantitative literature-based criteria for the assessment of whole-body biomechanics both at initial foot contact and maximum knee flexion angle offers the chance to inspect the biomechanics due to the approach of the player to the cut and his kinematical response to the loads occurring during the contact to the ground. In lab tools to detect dangerous patterns have already been demonstrated to be able to detect high knee abduction moment, the most adopted metrics to define the risk of ACL injury in prospective studies (Hewett et al., 2015). Moreover, the present tool allows to distinguish among different areas of interest for dangerous biomechanical patterns, leading to an immediate chance to start a targeted corrective program both in primary and secondary ACL injury prevention. The adoption of a multi-joint/multi-planar kinematics approach allows to minimize the errors in identification of differences between healthy and ACLR players potentially caused by to the assessment of a single feature or waveform for separate joint angles as well as accounting for the limited accuracy of IMUs in some joint angle (e.g., knee transverse plane).

CONCLUSION: Differences were identified between healthy and ACLR players in on-field football-specific movement even after RTS clearance. The tool here proposed can support clinicians in boosting the rehabilitation and RTS programs after ACL injury through objective on-field measurements.

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