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Original research

Prolonged running increases knee moments in sidestepping and cutting manoeuvres in sport

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ABSTRACT

Objectives: To investigate how knee kinematics, kinetics and loading changes during sidestepping tasks following a prolonged running protocol performed in a laboratory setting.
Design: All participants performed sidestepping, and crossover cutting tasks in a randomised order before and after a 60 min running protocol on a non-motorised treadmill that simulated an AF game.
Methods: Eight healthy male participants who partook in semi-professional and amateur Australian Football undertook a series of straight line runs, sidestepping (SS), and crossover cutting (XO) tasks before and after a simulated game of Australian football. Kinematic data were analysed at initial foot contact of the SS and XO manoeuvres and kinetic data were analysed during the weight acceptance phase of the stance.
Results: The knee was significantly more flexed at foot contact following fatigue compared to pre-fatigue states. Fatigue was also a factor contributing to significant increases in internal knee extension moments. Significant differences were also observed between SS and XO trials with flexion/extension moments, with notable differences in varus/valgus and internal/external rotation moments.
Conclusions: Acute angles of knee flexion at foot strike in a fatigued state may place the joint at an increased risk of injury. Increases in knee extension moments in the fatigued state suggests the knee joint must withstand significantly high stresses once fatigued.

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1. Introduction

Anterior cruciate ligament (ACL) injuries are a devastating soft tissue injury which frequently occur in sports that are characterised by a sudden change in direction or rapid deceleration.[1,2] ACL injuries are a common costly injury in sport[3] with reconstructive surgical costs in the USA alone amounting to USD$2 billion[4,5] with annual costs in Australia ranging between AUD$1.5–$2 billion.[6] Arguably, Australian Football (AF) has the highest rate of injuries of all sports in Australia, of which the majority (26%) is comprised of knee, lower limb and ankle injuries.[3,6,7] A thorough understanding of associated injury mechanisms is necessary as it may provide relevant knowledge to prevent further injuries.

Mechanisms of ACL rupture can be categorised as either contact or non-contact.[3] Non-contact mechanisms, involving no direct physical encounter with another player or object, constitute between 56%[7] to 65%[3] of ACL injuries in AF. Additionally, most non-contact ACL ruptures occur during dynamic sporting manoeuvers including sidestepping.[2,8,9] Ultimately, if a load applied to the ACL exceeds its strength, the ligament will rupture.[10]

Cadaveric studies have shown that combined coronal and transverse loads can elevate the strain experienced through the ACL.[11] Anterior tibial forces with internal rotation moments induce high ACL loading when the knee is close to full extension, while anterior tibial forces with valgus moments create high ACL loading with the knee flexed between 20° to 40°.[9,11,12] Internal rotation and valgus moments are applied while the quadriceps are extending the knee[1,2,11] during the weight acceptance phase of sidestepping. A forceful combination of these factors cause the knee collapse, which appears to be the main injury mechanism during sidestep and cutting manoeuvres.[9,13] Furthermore, high peak valgus knee moments during landing has been suggested to predict subsequent ACL injury.[14] Taken together, this leads to the conclusion that the combined loading of quadriceps knee extension with applied val-

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gus and internal rotation knee moments at 10°–40° of knee flexion are critical biomechanical variables associated with ACL injury.[11] Fatigue may also influence risk of ACL injuries. Research into soccer and rugby union has shown that ACL rupture occurs more frequently toward the end of the first and second halves of the game suggesting that fatigue may be a factor in injury risk.[15,16] Muscular fatigue is inevitable in team sports, therefore the level of fatigue experienced whilst playing sport is of particular importance, especially as this has previously been demonstrated to alter knee kinematics in relation to ACL injury risk.[17] The definition of fatigue differs immensely across different scientific fields, including biomechanics, physiology, psychology and neurophysiology.[18] For the purpose of the current study, fatigue can be classified as an intrinsic factor that affects both the neurological and musculoskeletal system.[19]

Increased forces in addition to other kinetic parameters such as flexion/extension and varus/valgus moments, have further been demonstrated to change with the onset of neuromuscular fatigue.[20] If knee musculature is compromised as a result of fatigue, the chances of sustaining high moments around the knee joint may be increased,[17] possibly as optimal technique deteriorates. Athletes demonstrating quadriceps and hamstring fatigue have previously demonstrated reduced peak extension moments of the quadriceps and reduced peak flexion moments of the hamstrings during sidestepping and crossover cutting tasks.[17,21,22] Further, previous research, which fatigued only a specific muscle group i.e., hamstrings or quadriceps, found that; the knee flexion, extension and internal rotation moments are altered depending on the muscle group that has been fatigued.[22] For example, hamstring fatigue decreases knee flexion moments and increases internal tibial rotation, while quadriceps fatigue decreased knee extension moments. These torque changes in fatigue have also demonstrated altered timings of kinetic variables while performing a side-step manoeuver.[20] Therefore, the aim of this study was to assess the impact of a prolonged running protocol, designed to simulate a game of AF, on knee kinematics and kinetics and joint loading patterns in sidestepping tasks.

2. Methods

Eight healthy male AF players who were free of disease and injury participated (age: 19.4 + 1.6 years, height: 1.83 + 0.05 m, mass: 79.4 + 10.0 kg). The participants competed in various levels of AF ranging from senior community to semi-professional leagues. All experimental procedures were approved by The University of Western Australia Human Research Ethics Committee (RA/4/1/1448) and all participants provided their written informed consent prior to testing.

Participants performed sidestepping (SS), and crossover cutting (XO) tasks before and after a prolonged running protocol on a non-motorised treadmill that simulated an AF game. Knee kinematics and kinetics were measured for SS and XO tasks to determine the changes in the risk of ACL injury after completing a protocol which simulated a game of AF.

Participants attended a familiarization session 7 days prior to the main testing trial to become accustomed with running on the non-motorised treadmill and to identify individual maximum running speed. After completing a suitable treadmill warm up, participants completed 2 × 5 s maximal sprints with 5 min walking/jogging recovery between each sprint. During these sessions data were collected to identify individual peak sprint speeds and to create a specific fatiguing protocol for the subsequent main trial.

The main testing session was performed on a Woodway non-motorised treadmill (model Force 3.0 TNT, Fitness Technology, Skye, South Australia, Australia), which consisted of four continuous 20 min quarters (including standing, walking, jogging, fast running, and sprinting efforts), each followed by 5 min rest. These quarter and rest durations were chosen as they represent a typical Western Australia Amateur Football League (WAAFL) AF game. The speed of running efforts was determined from familiarization session data based on a percentage of individual maximum sprinting speed. The duration and frequency of these efforts were based on previous research that has characterised player movements in a typical game of AF[23,24]; based on those player movement data a running protocol was devised to simulate a game of AF similar to previous researchers.[25,26] Defined movement patterns (and relative speeds) include: stand (0% max), walk (20% max), jog (35% max), fast run (65% max), maximal sprint (max speed). At each change in effort the participant received audio and visual cues to increase or decrease their running speed.

Participants performed sidestepping and cutting tasks immediately before and after the prolonged running protocol to assess knee biomechanics during these manoeuvers.[1,27] The laboratory surface consisted of a rubberised flooring suitable for conducting sports activities on. Participants each wore their own running shoes for the duration of the testing. The UWA lower limb marker set[28] was used to measure the participants' kinematics and kinetics. Kinematic data were collected using a 12 camera Vicon MX System (Vicon, West Way, Oxford, UK) and kinetic data were collected from an AMTI in-ground force plate (model BP12001200-4K, AMTI, Watertown, Massachusetts, USA).

The cutting trials involved the participants running approximately 30m, to reach a velocity equivalent to that of a fast jog (or 60% maximum running speed), before contacting the in-ground force plate. Upon contact, participants would either cut 45° to the left; or cut 45° right, pivoting off their preferred leg.[1,27] SS tasks were performed toward the opposite direction as the pivot leg and XO tasks were defined as changing direction to the same side as the pivot leg.[1,27] Tasks were completed in a randomised order with visual cues provided by the Kinematic Measurement System (Fitness Technology, Skye, South Australia, Australia) prior to the approach run. This system also monitored the running speed of the participants to ensure a consistent speed was maintained for all participants and trials of $4.5\ \mathrm{m\ s^{-1}}$. All running and cutting tasks were anticipated, with the system indicating the direction and type of task required, whereby the participant received the visual cues prior to the approach run. Prior to the simulated fatiguing protocol rest intervals comprised of 1 min, with post-trial rest intervals matching 45 s. To ensure a level of fatigue was maintained during the post-trial measures, participants ran on a motorised treadmill at a speed that maintained the heart rate acquired at the end of trial. Five successful trials from each manoeuver (SS and XO) were collected during pre- and post-fatiguing simulation protocol.

Rating of perceived exertion (RPE) scores were collected prior to and after each simulated 20-min quarter of the prolonged running protocol to indicate participant fatigue levels. To further quantify the fatigue levels, heart rate (HR) was monitored (Polar model RS400, Oulu, Finland) throughout the running protocol with values recorded before and after each quarter. Additionally, HR was recorded immediately prior to the cutting trials in both the pre- and post-fatigued states.

The three-dimensional kinematic and kinetic data were filtered using a low pass, zero-lag, 4th order Butterworth filter with a cut-off frequency of 15 Hz. Cut off frequencies were determined via residual analysis of kinematic and kinetic pilot data. Knee axes and hip centers were established using custom written software in Matlab (Natick, MA, USA) based on data collected in calibration trials.[28] The filtered kinematic and kinetic data from the running, SS, and XO trials were processed using the UWA lower body model,[28] which calculated 3D joint angles and moments of the ankle, knee and hip joints. These data were further processed using custom written

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