

THE EFFECTS OF A 90-MINUTE SIMULATED SOCCER MATCH-PLAY ON KNEE AND HIP KINEMATICS

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Abstract

Knee and hip extension are two proposed mechanisms of non-traumatic anterior cruciate ligament (ACL) injury. This study aimed to investigate the changes of the hip extension angles following exertion induced by an overground simulated soccer match-play. Fifteen male recreational players consented to this study and were required to complete a 90 minutes of simulated soccer match-play. Knee and hip angles were measured at initial contact during 45° anticipated side-cutting tasks performed prior to the simulation (time 0 min), at the end of the first half (time 45 min) prior to the second half (time 60 min) and at the end of the soccer match simulation (time 105 min). A two (group: dominant, nondominant) × four (time: 0 min, 45 min, 60 min and 105 min) mixed between- and within- subjects ANOVA was utilized. Results revealed that both knee and hip extension angles were significantly altered over time (knee: $F_{3,102} = 4.464$, $p = 0.005$, $\eta^2 = 0.116$; hip: $F_{3,102} = 9.998$, $p = 0.000$, $\eta^2 = 0.227$), however no significant differences were observed between dominant and nondominant sides (knee: $F_{1,34} = 0.026$, $p = 0.872$, $\eta^2 = 0.001$; hip: $F_{1,34} = 0.225$, $p = 0.638$, $\eta^2 = 0.007$). Pairwise comparisons indicated that the knee and hip is more during the second half of the simulation (time 60 min and time 105 min), compared to pre-exertion (time 0 min) ($p < 0.05$). The more erect knee and hip landing postures observed suggested a greater risk of ACL injury during the latter stage of each halves of match-play, supporting epidemiological observations. Further interrogations of the kinematic differences in the knees and hips across limb dominance are warranted for a more comprehensive understanding of the changes in a multiplanar perspective following soccer specific fatigue development.

Keywords: Anterior Cruciate Ligament, injury, soccer, limb dominance, biomechanics

Introduction

Soccer match-plays have witnessed numerous accounts of non-traumatic Anterior Cruciate Ligament (ACL) injuries; and interestingly, the predisposition of injury incidence rates appears to favor the later stages of soccer match-play as compared to the initial stages of the match (Ekstrand, Hägglund, & Waldén, 2011; Hawkins, Hulse, Wilkinson, Hodson, & Gibson, 2001). Most episodes of non-traumatic ACL injuries would demonstrate an extended knee and hip with a planted foot on the ground while pivoting for a change in direction in mid-run; which is very much what is represented during an side-cutting maneuver (Alentorn-Geli et al., 2009; Boden, Dean, Feagin, & Garrett, 2000; Cochrane, Lloyd, Butfield, Seward, & Mcgivern, 2007; Silvers & Mandelbaum, 2007; Waldén, Hägglund, Magnusson, & Ekstrand, 2011). An extended orientation of the knee and hip has been proven to increase the strain in the ACL (Donnelly et al., 2012; Hashemi et al., 2011; Mclean, Huang, & Van Den Bogert, 2005; Pandey & Shelburne, 1997; Yu & Garrett, 2007) and the strain reduces as the knee and hip moves into a more flexed orientation (Hashemi et al., 2011; Yu & Garrett, 2007). Hawkins et al. (2001) reported that injury incidence rates in soccer are highest at the final 15 minutes of both the first half and the second half of the match. this finding coincides with the study by Mohr, Krstrup, and Bangsbo (2003) which found reductions in physical performances over time in matches. These findings have brought about the speculations of a biomechanical induction mechanism of non-traumatic ACL injury from fatigue development through physical exertion by utilizing the side-cutting maneuver to recreate the biomechanical loading of the ACL in a soccer-specific task execution to enable a better understanding of the biomechanical limits of the ACL (Greig, 2009; Raja Azidin, Sankey, Drust, Robinson, & Vanrenterghem, 2015; Sanna & O'connor, 2008) specifically to match soccer match-play demands.

Several studies have focused on biomechanical changes in gait and posture that follow soccer match-play exertions. In a shuttle-run-based simulation, Sanna and O'connor (2008) noted a more extended knee alignment at initial contact (IC) during a side-cutting maneuver post-fatigue compared to pre-fatigue among female athletes. Using a match-play simulation on a treadmill, Greig (2009) observed similar changes occurring among male athletes. However, due to the differences in the nature of the testing procedures (i.e. participants' gender, match-play simulation), another study by Raja Azidin et al. (2015) emerged comparing the changes occurring in the lower limbs from a treadmill match-play simulation to that of an overground match-play simulation and found no differences in knee kinematic changes between the two protocols. The study by Raja Azidin et al. (2015) did, however, note significant differences in physiological responses to the different match-play simulations proposed to be the result of multidirectional utility movements utilized in the overground match-play simulation. In another study, Raja Azidin (2015) also found that the hip angles are noticeably more extended (more erect) at the end of full time match-play simulation (90 minutes) compared to at the beginning of the simulation (0 minute).

According to Hashemi et al. (2011), a more extended orientation of the knee and hip at IC is proposed to be a contributing factor to increased anterior translational force acting on

the proximal tibia. This force acts upon the ACL that holds the proximal tibia to the distal femur. At full knee extension, the tensions acting on the knee increase from both external tension from the translational force and internal tension from the increased length of the ACL (Li, Defrate, Rubash, & Gill, 2005; Neumann, 2015). The ACL is also reported to be elevated thus which has been reported to increase amplify the translational or shear force from the quadriceps contraction running through the patellar tendon towards the proximal tibia (Blackburn & Padua, 2008).

The current understanding of kinematic changes in the knee has been explored arguably in detail, however, to our knowledge, present studies have emphasized more on the dominant limb as it was reported to be more prone to ACL injury as compared to the nondominant limb among males (Brophy, Silvers, Gonzales, & Mandelbaum, 2010). Whether or not the nondominant limb kinematics are as adversely affected by fatigue as the dominant limb is yet to be uncovered. Hence this study attempts to delve into the investigation on comparing the kinematic changes of the dominant and nondominant limbs throughout the development of fatigue induced by soccer match-play exertions.

Methods

Participants

Eighteen recreationally trained male athletes consented to this study. Their mean age, height, and mass are 23 ± 5 years' old, 1.7 ± 0.7 m, and 70 ± 10 kg respectively. All participants attended to at least 1 training day per week, with 1 to 2 training hours per session. Participants were inquired and admitted to have not suffered any ACL injury or any other injury on the lower limbs since the previous 6 months. A written informed consent was obtained from all participants as required by the university ethics committee for ethical approval to conduct this study.

Experimental design

In a single group, repeated measures design, all participants were instructed to attend to two separate laboratory sessions. For the first session, the participants attended to a familiarization session which consisted of a 15-minute simulated soccer match-play simulation and side-cutting tasks. The actual testing session takes place at least 48 hours after the familiarization session where the participants were instructed to avoid alcohol, caffeine and vigorous exercise within 24 hours before the testing. The testing procedure is preceded by a 15-minute dynamic warm-up session followed by 10 minutes of passive rest as according to the Fédération Internationale de Football Association (FIFA) standard match-play procedures. Participants were then required to complete an overground soccer match-play simulation for 90 minutes interceded by a 15-minute half-time interval. Before the simulation (0 minute), at the end of the first half (45 minutes), before the second half (60 minutes) and at the end of the second half (105 minutes) of the simulation, participants were assessed for knee and hip kinematic markers of ACL injury risk using 5 trials of side cutting tasks on both the dominant and nondominant limbs.

During the testing session, all participant was instructed to wear tight-fitting compression suits and standardized indoor footwear. All participants were required to wear a heart rate monitor (Polar Heart Rate System, Electro, Finland) and reported ratings of perceived exertion (RPE, 20-point Borg Scale) for physiological responses monitoring. During the 15-minute, passive half time period, the participants were allowed to drink water.

Soccer match simulation

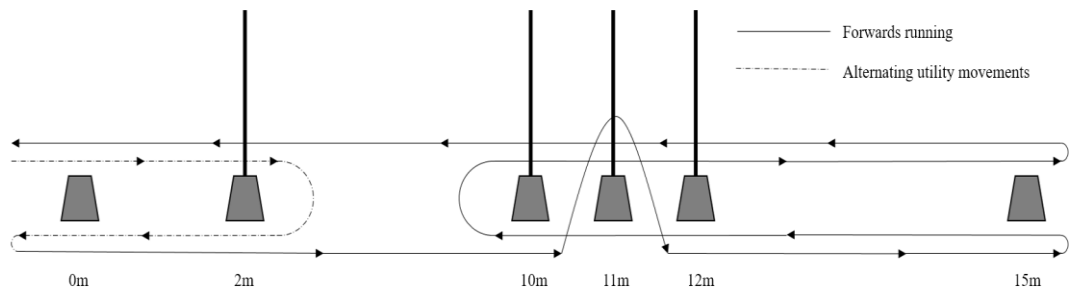


Figure 1: The overground simulated soccer match-play. Adapted from Raja Azidin et al. (2015).

The soccer match simulation used in this study is a multidirectional overground soccer match simulation by Raja Azidin et al. (2015). This overground soccer match simulation protocol has been proven to be more representative of an actual soccer match-play in both the physical loading (Barreira et al., 2016) and the physiological loading aspects (Raja Azidin et al., 2015; Small, Mcnaughton, Greig, & Lovell, 2010). Further description of the protocol has been published elsewhere (Raja Azidin et al., 2015) and illustrated in Figure 1.

Side-cutting tasks

The side cutting tasks utilized were anticipated in nature and consists of a 45° change of direction. Cones were placed at 45° of deviation from the runway to apart from floor markings placed to represent a target gate for exiting the 45° side cutting task. The dominant limb was defined as the preferred limb to be used when kicking a ball, and this procedure was standardized for all participants. Side cutting tasks were selected for this study because of its maneuvers that reflect most reported kinematics and demands of the lower limb during ACL injury occurrence (Faunø & Wulff, 2006; Hawkins et al., 2001; Mclean, Huang, Su, & Van Den Bogert, 2004). Further reports on the reliability of side cutting kinematics have also been published elsewhere (Sankey et al., 2015).

Data collection

All side cutting tasks were performed inside a 0.15 × 0.15 m box marked on the ground with two high-speed cameras (Exilim ZR-800, Casio, USA) set at 240 frames per second (fps) and a pixel resolution of 512 × 384 placed at perpendiculars to both sides (sagittal plane) of the side cutting box. The height and distance of the cameras were adjusted

accordingly to fit the full model of the markers into the recorded display in order to ensure that the markers were all visible for processing.

Biomechanical model

10 reflective markers were placed on both sides of the participants' selected body bony landmarks (acromion process, greater trochanter, lateral femoral epicondyle, lateral malleolus and lateral side of the fifth metatarsal) to enable visual access for the observer to process the recorded data.

Data and statistical analysis

Paired t-tests were used to compare the pretest (time 0 min) knee and hip angles between dominant and nondominant limbs to assess the baseline assumption of similar pretest angles between the two limbs. A 2 (limb: dominant, nondominant) \times 4 (time: 0 min, 45 min, 60 min, 105 min) split-plots analysis of variance (SPANOVA) was conducted for each dependent variable using the Statistical Package for Social Sciences (SPSS v. 23, IBM, New York, USA). The alpha level was set at 0.05.

Results

Physiological response

The mean heart rates during the simulated soccer match-play exertion (time 5 min to 105 min) was 153 ± 10 beats \cdot min⁻¹. Heart rates were elevated over time throughout the simulation ($F_{5,3,89,2} = 23.1, p = 0.000, \eta^2 = 0.576$) (Figure 11a). Likewise, the mean RPE (time 5 min to 105 min) was 12 ± 2 . Rate of perceived exertions were also elevated over time ($F_{3,9,66,2} = 31.9, p = 0.000, \eta^2 = 0.652$).

Kinematic response

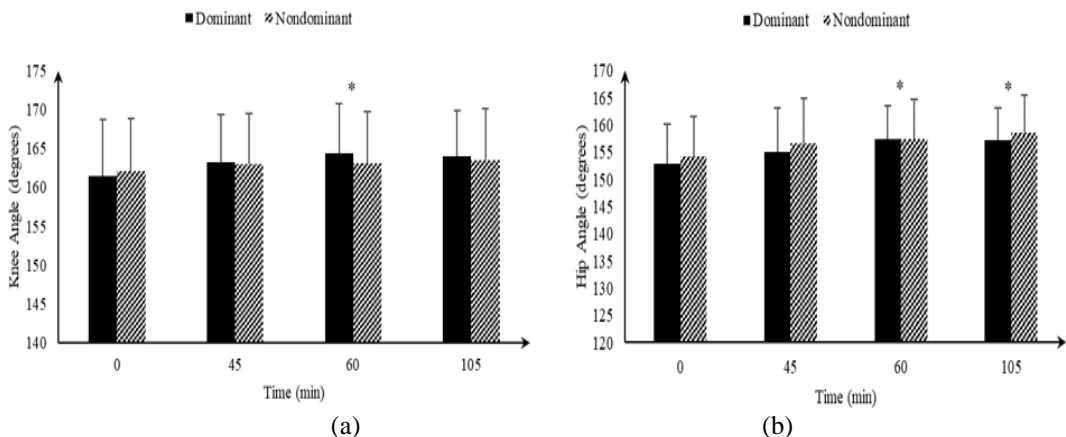


Figure 1: Heart rate (a) and RPE (b) changes over time during simulated soccer match-play.

* Denotes a significant difference compared to 0 min.

A “split-plots” analysis of variance determined that there were significant changes in the knee and hip extension angles over time (knee: $F_{3,102} = 4.464$, $p = 0.005$, $\eta^2 = 0.116$; hip: $F_{3,102} = 9.998$, $p = 0.000$, $\eta^2 = 0.227$), however the changes were not influenced by limb dominance (knee: $F_{3,102} = 0.810$, $p = 0.491$, $\eta^2 = 0.023$; hip: $F_{3,102} = 0.334$, $p = 0.801$, $\eta^2 = 0.010$). There were no significant differences in the knee and hip extension angles between the dominant and nondominant limbs (knee: $F_{1,34} = 0.026$, $p = 0.872$, $\eta^2 = 0.001$; hip: $F_{1,34} = 0.225$, $p = 0.638$, $\eta^2 = 0.007$). Post-hoc tests using Bonferroni correction procedures revealed that the knee is more extended after a 15-minute passive half time rest ($p = 0.025$). The hip is also observed to be more extended after a 15-minute passive half time rest ($p = 0.000$) and at the end of the second half of the simulation ($p = 0.001$). Therefore, we can speculate that the nondominant limb may be just as similarly susceptible to ACL injury as the dominant limb following the development of fatigue from soccer match-play.

Discussion

The primary findings of the present study show that the changes that occur in the knee and hip extension angles were similar across the dominant and nondominant limbs. All joints appear to be more erect at IC following fatigue. A 15-minute passive half-time interval did not influence reductions in the knee and hip extension angles. This finding coincides with existing literature on the increased risks of ACL injury over the development of fatigue. However, the aim of this study was to investigate the kinematic changes of the knee and hip extension angles across limb dominance and will be discussed in the subsections that follow.

Physiological responses

Heart rate response appeared to increase as a function of exercise duration, suggesting an overall effect of physiological loading. The mean heart rate response in the simulated soccer match-play was 153 ± 10 beats \cdot min⁻¹. A soccer player’s average heart rate during match play has been shown to range from 156 to 167 beats.min⁻¹ depending on the level of the players (Bangsbo, Nørregaard, & Thorsoe, 1991; Mohr et al., 2003; Thatcher & Batterham, 2004; Van Gool, Van Gerven, & Boutmans, 1988). However, the data presented by these studies were based on the work-rates of professional soccer players during actual match-play. Since our participants were recreationally trained, their activity profiles consisted lesser amount of time performing high-intensity activities, and totaling to the lesser distance covered throughout the match-play simulation.

The rate of perceived exertion was in line with heart rate response during the simulation. The mean RPE during the simulated soccer match-play was 12 ± 2 . This result is slightly lower than previous studies (Nicholas, Nuttall, & Williams, 2000; Raja Azidin et al., 2015) and we attribute this discrepancy to the lesser amount of lesser amount of time performing high-intensity activities and distance covered by our participants as compared to other studies.

Effects of simulated soccer match-play on knee and hip extension angles

Within-subjects main effects ANOVA findings of this study suggests that the knee and hip extension angles are aligned in a more erect posture over time compared to a pre-fatigue condition (knee: $F_{3,102} = 4.464$, $p = 0.005$, $\eta^2 = 0.116$; hip: $F_{3,102} = 9.998$, $p = 0.000$, $\eta^2 = 0.227$). Furthermore, the changes that occur over time were not influenced by limb dominance as indicated in the interaction effects results (knee: $F_{3,102} = 0.810$, $p = 0.491$, $\eta^2 = 0.023$; hip: $F_{3,102} = 0.334$, $p = 0.801$, $\eta^2 = 0.010$). These findings coincide with observations of the similar manner by Greig (2009) and Raja Azidin et al. (2015). In their studies, Raja Azidin et al. (2015), used a similar 45° side-cutting task, however, the nature of the movement was unanticipated compared to our study which utilized an anticipated side-cut which was similar to that being used by Sanna and O'connor (2008). However, Sanna and O'connor (2008) did not integrate multidirectional movements in their simulation as compared to the overground soccer match-play simulation. The study by Greig (2009) used a 180° agility sprint instead of a 45° side-cut and moreover utilized a treadmill protocol simulation which only consisted of forwards running.

An extended knee at IC may be caused by the reductions in muscular torque-velocity relations as speculated by Spendiff, Longford, and Winter (2002) and potentially increase the intrinsic tension of the ACL (Markolf et al., 1995). Studies by Dai, Herman, Liu, Garrett, and Yu (2012) and Li et al. (2005) reported a more elevated and deviated ACL angle in an extended knee, and the mechanism is observed by Yu and Garrett (2007) to be a factor contributing to increases of ACL strain. This condition combined with an increased patellar tendon insertion angle and a decreased hamstrings insertion angle (Blackburn & Padua, 2008) could limit the hamstrings' ability to neutralize the shear forces (Pandy & Shelburne, 1997) and cause increases in the tibial anterior translation forces (Nunley, Wright, Renner, Yu, & Garrett Jr, 2003; Yu & Garrett, 2007).

At the point of contact, the quadriceps and hamstrings synchrony in activation is supposed to act as a protection mechanism towards the knee (Wojtys, Ashton-Miller, & Huston, 2002) by reducing the ACL loading at most extension angles (McClean et al., 2005; Pandy & Shelburne, 1997) which has been observed to have reduced force outputs from soccer match-play exertions and fatigue (De Ste Croix, Priestley, Lloyd, & Oliver, 2015; Greig, 2008; Raja Azidin, Pykett, Scanlon, Bradburn, Robinson, & Vanreenterghem, 2014; Raja Azidin et al., 2015; Raja Azidin, Sankey, Robinson, & Vanreenterghem, 2013) and has been coined to contribute to an increase in injury risk (Hashemi et al., 2011). Furthermore, an extended knee has also been associated with increased knee valgus and knee adductor moments (Dai et al., 2012) which has been prospectively studied and identified as biomechanical risk factor for ACL injury (Hewett, Myer, Ford, Heidt, Colosimo, McClean, Van Den Bogert, Paterno, & Succop, 2005).

The extended knee and an erect hip orientation may expose the ACL to detrimental conditions such as increased anterior translation forces leading to ACL rupture (Hashemi et al., 2011; Markolf et al., 1995). An extended hip at initial is sought to shift the body's center of mass posterior the knee and encouraging a dysynchrony in knee and hip extensions which leads to a higher tibial anterior translation force from the overwhelming

ground reaction forces upon IC (Hashemi et al., 2011; Koyanagi, Shino, Yoshimoto, Inoue, Sato, & Nakata, 2006; Shimokochi, Yong Lee, Shultz, & Schmitz, 2009). The dysynchrony in the knee and hip extension extensions have been proven to be associative to the shear forces during landing (Shultz, Nguyen, Leonard, & Schmitz, 2009) and contribute to the failure of the ACL.

Effects of simulated soccer match-play on dominant and nondominant knee and hip extension angles

Between-subjects ANOVA findings from our study showed no significant differences in dominant and nondominant limbs for both knee and hip extension angles (knee: $F_{1,34} = 0.026$, $p = 0.872$, $\eta^2 = 0.001$; hip: $F_{1,34} = 0.225$, $p = 0.638$, $\eta^2 = 0.007$). All limb extension angles significantly changed over time and towards a more extended orientation. The extended knee and hip orientation have been attributed to increases in ACL injury risk as discussed in the previous section.

Previous researchers have placed much emphasis on the dominant limb kinematics (Bossuyt, García-Pinillos, Raja Azidin, Vanrenterghem, & Robinson, 2016; Cortes, Greska, Kollock, Ambegaonkar, & Onate, 2013; Cortes, Quammen, Lucci, Greska, & Onate, 2012; Lucci, Cortes, Van Lunen, Ringleb, & Onate, 2011; Quammen et al., 2012; Raja Azidin, 2015; Sanna & O'connor, 2008) following fatigue onset. This was possibly due to findings from epidemiological studies suggesting that the dominant limb being more prone to injury than the nondominant limb especially among male athletes (Brophy et al., 2010). The study by Greig (2009) did look into the kinematics of the nondominant limb during a 180° agility cut, however, the nature of the observation is arguably crude as it was observed in the perspective of a supporting limb only and not as the pivoting limb. Existing literature that did observe the nondominant limb kinematics (Borotikar, Newcomer, Koppes, & Mclean, 2008; Chappell et al., 2005; Dingenen et al., 2015a; Dingenen et al., 2015b; Mclean et al., 2007; Mclean & Samorezov, 2009; Padua et al., 2015; Paterno et al., 2010) presented discrepancies in data collection methodologies thus may in explaining the mechanics.

Our findings were similar to the study by Borotikar et al. (2008) who observed no difference in knee extension angles between the dominant and nondominant limbs. They did report differences in knee internal rotations between the two limbs while another study by Mclean et al. (2007) reported that significant differences in peak knee internal rotation across the two limbs are following fatigue as a main effect of gender. The nature of our side cutting tasks used during this study was anticipated; whilst Mclean and Samorezov (2009) highlighted that the fatigue-induced alterations beyond the biomechanical parameters would be more pronounced in unanticipated maneuvers which is more likely to be observed as in match-play situations. Therefore, it is important to note, that based on the findings of this study, we speculate that unlike the proposed limb dominance role presented by Brophy et al. (2010), the nondominant limb is actually just as susceptible to acquiring non-traumatic ACL injury as the dominant limb, nevertheless this speculation should be looked into with great caution and should not be considered as a rejection of the existing proposal.

Practical implications

The findings from this study prove that the knees and hips are exposed to increasing risks of ACL injury over time. With the addition of this study to the existing knowledge, clinical physicians can prompt for a more cost-effective, field-based approach to injury screening for athletes prior to team selection. This study also supports the notion that injury screening procedures should include a sport-specific exertion protocol in between two tests to observe the nature of the changes in the biomechanical parameters of injury risks to gain added value and crucial data for more comprehensive interpretations as well as integrations with proper injury prevention or return to play assessment procedures.

Limitations

The current study revealed that fatigue development from match-play exertions might cause impairments in the knee and hip extensions during dynamic, pivoting movements which may lead to increases in ACL injury risk. This study also revealed that the kinematic changes in the knee and hip extension angles were not influenced by limb dominance status of the legs. Only the sagittal plane was observed in this study, therefore the question of whether multidirectional soccer match-play exertions would influence different changes on the dominant and nondominant limbs cannot be justified solely from this study. Furthermore, although the current study investigated a full-time match simulation of 90 minutes excluding the passive half-time interval, FIFA-standard match durations have repeatedly been extended into two additional extra-time halves summing up to 120 minutes of soccer match-play time, and the effects of additional exertions from the added durations are yet to be uncovered.

Conclusion

The findings of the current study have shown that a more erect and extended landing posture in the knees and hips may be observed throughout the development of fatigue from simulated soccer match-play exertions (knee: $F_{3,102} = 4.464$, $p = 0.005$, $\eta^2 = 0.116$; hip: $F_{3,102} = 9.998$, $p = 0.000$, $\eta^2 = 0.227$). The extended knees and hips do not, however, reveal differences between dominant and nondominant limbs (knee: $F_{1,34} = 0.026$, $p = 0.872$, $\eta^2 = 0.001$; hip: $F_{1,34} = 0.225$, $p = 0.638$, $\eta^2 = 0.007$), suggesting that unlike the current consensus, the nondominant limbs are actually as much affected as the dominant limbs from the development of fatigue, with greater fatigue leading to increasing of ACL injury risk. However further observations are warranted to provide a more comprehensive understanding of the kinematic impairments in the knees and hips following fatigue development from a multiplanar perspective.

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