European Journal of Sport Science
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t714592354

The influence of soccer-specific activity on the kinematics of an agility sprint

Matt Greig [a]
[a] Sport and Physical Activity, Edge Hill University, Ormskirk, UK

Online Publication Date: 01 January 2009

European Journal of Sport Science, January 2009; 9(1): 23–33

Routledge
Taylor & Francis Group

ORIGINAL ARTICLE

The influence of soccer-specific activity on the kinematics of an agility sprint

MATT GREIG

Sport and Physical Activity, Edge Hill University, Ormskirk, UK

Abstract

The aim of this study was to investigate the influence of soccer-specific fatigue on the kinematics of an agility sprint. Ten male professional soccer players (age 24.7±4.4 years, body mass 77.1±8.3 kg) completed an intermittent treadmill protocol replicating the activity profile of match-play, comprising two 45-min halves separated by a 15-min passive half-time interval. Pre-exercise and at 15-min intervals each player completed an agility sprint that consisted of a 180° cutting manoeuvre. Knee joint kinematics in the frontal and sagittal planes were determined for both the support and turning leg using a nine-camera automated motion analysis system operating at 200 Hz. During the penultimate foot contact, knee kinematics were characterized by joint flexion and increased varus alignment. Knee flexion at touchdown decreased significantly ($P<0.05$) as a function of exercise duration from 57.4±15.5° before exercise to 37.0±5.9° at the end of the second half. The range of joint movement during the knee flexion phase increased significantly during the first half ($T_{45}=66.6\pm18.2°$) and remained elevated during the second half ($T_{75}=66.4\pm18.1°$; $T_{90}=65.7\pm20.4°$; $T_{105}=70.2\pm19.4°$) relative to pre-exercise values (51.8±18.8°). During the final foot contact, knee kinematics were also characterized by flexion and increased varus alignment. Knee flexion at touchdown decreased during each half, with the knee angle at the end of the first half (30.6±7.0°) significantly ($P=0.02$) straighter than before exercise (39.5±6.3°), and significantly straighter at the end of the second half (30.2±2.9°) than after the half-time interval (37.7±7.8°) or before exercise. The range of knee flexion during ground contact increased significantly during each half. The range of knee varus during flexion changed from a varus displacement during the first 15 min to a valgus displacement thereafter. Peak valgus observed at the end of each half ($T_{45}=4.7\pm7.9°$; $T_{105}=6.9\pm7.4°$) was significantly ($P<0.05$) greater than before exercise. The range of valgus movement during knee extension was greatest following the passive half-time interval ($T_{60}=6.2\pm7.3°$), and tended to increase throughout the second half. Prolonged exposure to soccer-specific intermittent exercise therefore induced changes in knee kinematics that may have implications for injury incidence. The increased varus alignment and time-dependent decrease in knee flexion at touchdown represent two potential mechanisms for increased injury risk.

Keywords: *Fatigue, soccer, cutting, sprinting, biomechanics*

Introduction

In an audit of injuries in professional football, Hawkins and colleagues (Hawkins, Hulse, Wilkinson, Hodson, & Gibson, 2001) reported that ligament strains were a prominent type of injury. The mechanism of ligamentous injury has been described as consisting of a sudden deceleration in preparation for a landing or change in direction (Garrett, 2005). The cutting or side-stepping manoeuvre satisfies this mechanism (Boden, Dean, Feagin, & Garrett, 2000), and is arguably more representative of soccer activity than single-legged hopping tasks for example (McLean, Lipfert, & van den Bogert, 2004). The functional relevance of the cutting movement to the incidence of anterior cruciate ligament injury has previously attracted research directed at identifying differences between the sexes (Sigward and Powers, 2006). However, this research focus offers little insight into the mechanisms of injury contributing to the temporal pattern of injury incidence observed during soccer match-play (Hawkins *et al.*, 2001).

Running has been identified as a primary injury mechanism in professional football (Hawkins *et al.*, 2001). Woods and colleagues (Woods, Hawkins, Hulse, & Hodson, 2003) suggested that this injury

Correspondence: M. Greig, Sport and Physical Activity, Edge Hill University, St. Helens Road, Ormskirk L39 4QP, UK. E-mail: matt.greig@edgehill.ac.uk

ISSN 1746-1391 print/ISSN 1536-7290 online
DOI: 10.1080/17461390802579129

risk is exacerbated when running involves a change in direction. The cutting action has been described as commonly incorporating a sudden deceleration phase on impact, accompanied by a rapid change in speed and/or direction (McLean *et al.*, 2004). In addition to the deceleration involved in cutting tasks, Hewett *et al.* (2005) suggested that the lateral pivoting during this motion is thought to increase knee joint loading and the risk of injury. There is increasing evidence in the literature that impaired or abnormal neuromuscular control of the knee joint is a major contributor to the injury mechanism (Hewett *et al.*, 2005).

Fatigue has been shown to impair sprinting mechanics (Pinniger, Steele, & Groeller, 2000), muscular strength (Rahnama, Reilly, Lees, & Graham-Smith, 2003), and joint stability (Nyland, Shapiro, Stine, Horn, & Ireland, 1994). The combined influence of such factors is likely to predispose players to injury during tasks that impose a high mechanical demand. The temporal pattern of joint sprain injuries in soccer match-play suggests that ligamentous injuries increase during the latter stages of a match (Woods *et al.*, 2003). The ligaments play a passive role in maintaining joint stability. The temporal pattern of muscle strain injuries also suggests a fatigue effect, and it should be acknowledged that muscles play an active role in joint stabilization (Woods *et al.*, 2004). Fatigue-induced changes in the active and passive joint-stabilizing mechanisms would create the change in neuromuscular control of the knee joint previously described as contributing to injury (Hewett *et al.*, 2005).

There is, however, little literature on the effect of fatigue on the performance of high-risk, sport-specific movements such as the side-step cutting movement. Furthermore, where fatigue has been considered, the exercise protocol used to induce fatigue has not been representative of the stresses imposed by competition (Nyland, Shapiro, Caborn, Nitz, & Malone, 1997). The importance of accurately reflecting the game environment has been highlighted by McLean *et al.* (2004), which has previously been replicated using unanticipated execution of side-stepping tasks (Besier, Lloyd, & Ackland, 2003). The aim of the present study was to investigate the influence of soccer-specific activity on knee joint kinematics during an agility movement representative of soccer activity. Specifically, the agility sprint is characterized by a complete reversal of direction, as opposed to a graded directional cut, thereby imposing deceleration and lateral pivoting on both legs.

Methods

Subjects

Ten male professional soccer players were recruited for the present study (mean $\pm s$: age 24.7 ± 4.4 years, body mass 77.1 ± 8.3 kg). All participants provided written informed consent in accordance with departmental and university ethical procedures.

Experimental design

Each participant performed all exercise sessions between 15:00 and 17:00 h to account for the effects of circadian variation and in accordance with regular competition time (Reilly & Brooks, 1986). Each player completed an intermittent treadmill (LOKO S55, Woodway GmbH, Steinackerstraße, Germany) protocol designed to replicate the activity profile of soccer match-play (Bangsbo, 1994). The soccer-specific intermittent protocol comprised the varying exercise intensities inherent to match-play, based on notational analysis, which categorized eight modes of activity (Bangsbo, 1994). To provide a 15-min activity profile, the frequency of each mode of exercise evident during match-play was divided by six. The data set was arbitrarily distributed to provide the 15-min activity profile (Figure 1), which was repeated six times in the test (i.e. 90 min), as described by Greig and colleagues (Greig, McNaughton, & Lovell, 2006). The short duration of the high-speed movements excluded consecutive stationary and sprint modes of activity. The maximum treadmill acceleration of 2 m s^{-2} was applied for transition to and from all modes of exercise with the exception of the transition from walk to stationary (or vice versa) where an acceleration of 1 m s^{-2} was used. The 15-min activity profile resulted in a distance of 1.62 km being covered, giving a total distance covered of 9.72 km. A constant treadmill incline of 2% to reflect the energetic cost of outdoor running was also applied (Jones & Doust, 1996). There was a 15-min half-time interval, during which the participant remained seated and stationary. Each participant completed a minimum of three familiarization trials on the treadmill protocol on previous laboratory visits, comprising a minimum of 120 min. During these familiarization sessions, the players also completed trials of the cutting manoeuvre, both before and after exercise.

Before exercise, and following each 15-min bout of activity, each player completed a single maximal-effort trial of an agility sprint. The sprint comprised a maximal-effort 180° cutting manoeuvre (i.e. a reversal of direction) considered to be representative of the nature of competitive soccer match-play. The

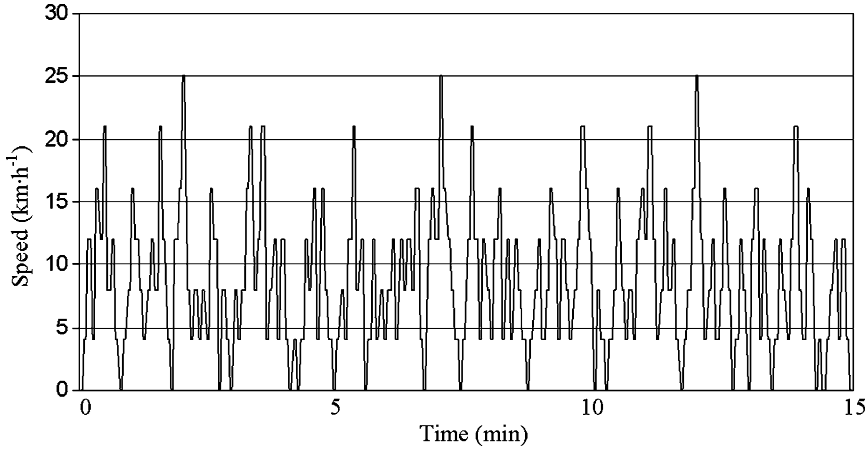

Figure 1. The soccer-specific intermittent treadmill protocol.

distance over which the sprint was completed was also selected so as to be representative of this type of activity in competition (Bangsbo, 1994). The movement was initiated from a standing start 3.5 m from a target zone, which was clearly marked on the floor. The player was required to execute the turn on his right (dominant, as defined by preferred kicking leg) foot within the designated target area. The player approached the target area at maximal speed, planted the right foot within the target area, and then pivoted about this foot to achieve a 180° cutting movement. The player then accelerated out of the turn along the same path as the entry into the turn. This cutting manoeuvre replicates previous protocols (e.g. McLean *et al.*, 2004; Sigward and Powers, 2006) with the degree of cut changed to 180° in the present study to replicate functional soccer movements. The starting point and the designated target area in which to plant the right foot and perform the turn, plus verbal reinforcement as to the demands of the task, were the only constraints imposed upon movement strategy.

Analysis was constrained to the period from the penultimate foot contact (left foot contact during entry stride) to the first exit stride out of the turn (right foot contact during exit stride). Figure 2 provides a representation of selected instants during the agility sprint. The linear approach to the turn (a) is initially arrested by the planting of the left foot (b) and ultimately with the right foot plant (c). Following the pivot about the planted right foot, acceleration out of the turn is initiated by replanting the left foot (d) so that the exit stride (e) achieves a 180° cutting movement. Although the player "turned" on his right foot, Figure 2 illustrates the role of the left leg in decelerating the movement and subsequently aiding recovery out of the turn. Following the turn, the player was required to sprint back past the starting position along the same path in an attempt to enforce a standardized reversal of direction.

The movement volume was created to enable data collection of the final approach stride and the first stride out of the turn. Data were collected using nine high-speed ProReflex MCU1000 digital cameras (Qualisys, Sweden) operating at 200 Hz for real-time three-dimensional optical motion capture. The movement volume was calibrated by moving a 750-mm wand throughout the movement volume.

The pre-test warm-up comprised 3-min of treadmill running at a constant velocity of 12 km h^{-1}, followed by 7 min of treadmill running on an intermittent protocol similar to but not replicating the test protocol and without the highest running speed. The player was then allowed 10 min of free running exercises to incorporate dynamic flexibility and functional movement patterning including graded cutting manoeuvres. Following the warm-up period and three familiarization trials of the cutting manoeuvre, the participant was prepared for motion analysis. A static standing model was created for each player with passive retro-reflective markers (Qualisys, Sweden) of 20 mm diameter placed so as to define the pelvis (anterior superior iliac spine, posterior superior iliac spine, and each greater trochanter), each thigh (lateral knee, medial knee, and a plate-mounted four-marker cluster), each shank (lateral ankle, medial ankle, and a plate-mounted four-marker cluster), and each foot (calcaneus, fifth metatarsal head, fifth metatarsal base, and first metatarsal). Each player wore an indoor soccer training shoe (deemed appropriate by the researcher during familiarization trials), to which the foot markers were attached. The marker configuration was reduced for the dynamic model. To enable tracking of each segment during the running trials, the thigh and shank clusters remained, in addition to the posterior and anterior superior iliac spine markers to track the pelvis, and the calcaneus, fifth metatarsal head and base, and the lateral ankle markers to define each foot segment. Data were

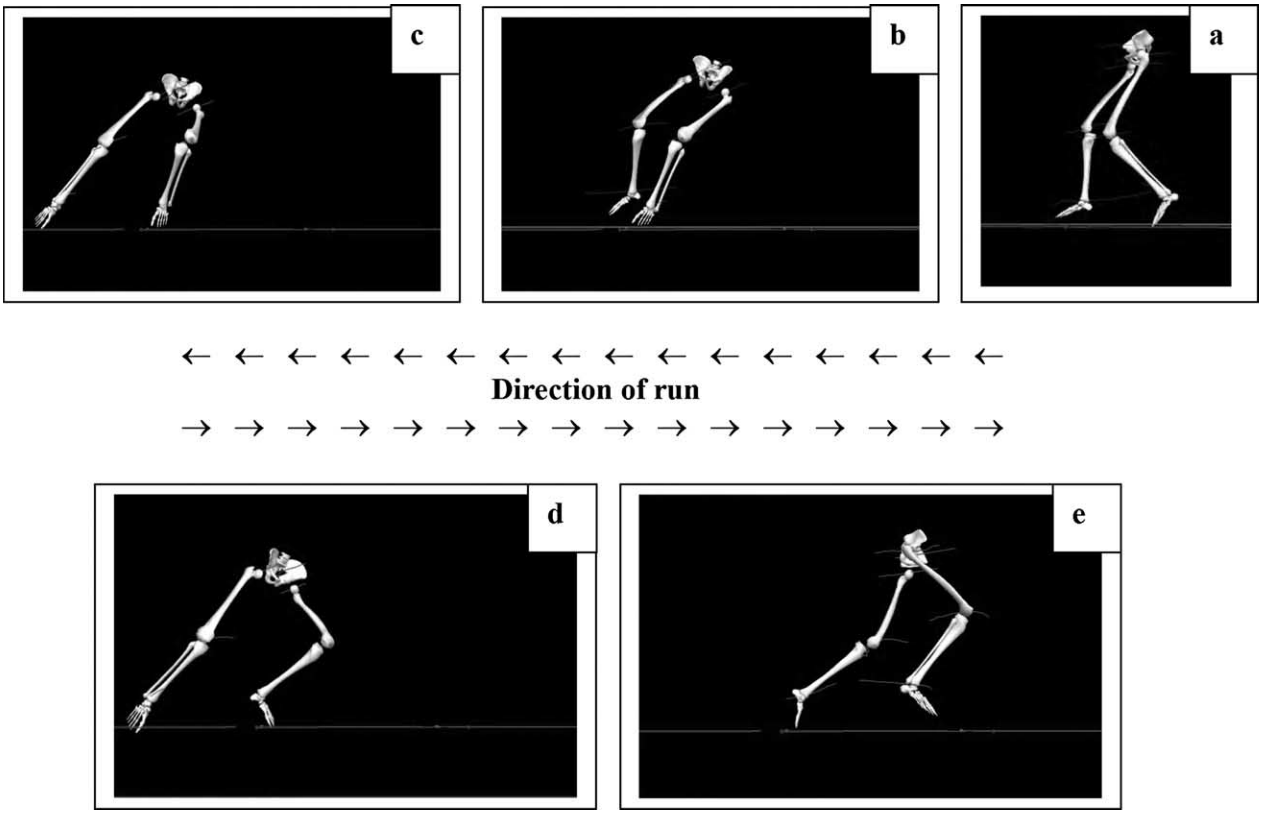

Figure 2. Temporal representation of the agility sprint: (a) linear approach, (b) pivot – left foot plant, (c) pivot – right foot plant, (d) pivot – left foot re-plant, (e) exit.

captured and tracked using Qualisys Track manager software (Qualisys, Sweden), and exported in c3d format to Visual3D software (C-Motion, MD, USA) for analysis.

Data analysis

In Visual3D (C-Motion, MD, USA), a model template was created for each player. A pelvis segment was defined using the anterior and posterior superior iliac spine markers plus individual-specific anthropometric data (height and weight). The thigh segments were defined using the medial and lateral knee and ankle markers from the static model plus the four marker clusters that were tracked throughout each kick. The feet were defined using the medial and lateral ankle markers, and the first and fifth metatarsal heads, from the static model. The four tracking markers for each foot comprised the calcaneus, the head and base of the fifth metatarsal, and the lateral ankle.

Knee joint kinematics were calculated for both the left and right leg contacts at 15-min intervals throughout the exercise protocol. Although the same analysis variables were applied to each knee, a comparison of left and right knee kinematics was not the purpose of this study given the technical requirements of the turn. The duration of ground contact was sub-divided into a flexion (from touch-down to maximum knee flexion) and extension (from maximum knee flexion to take-off) phase. In most instances, the left foot was lifted from the floor during the right foot contact, and then re-planted to initiate the sprint out of the turn. During these trials, the flexion phase was analysed during the initial contact of the left foot providing the pivot for the turn, and the extension phase analysed from the re-planted ground contact phase providing the acceleration away from the turn. In trials where the left foot maintained ground contact throughout the duration of the right foot pivot, the flexion and extension phases of the left knee were sequential, and maximum knee flexion clearly defined.

Knee joint angle was defined in varus–valgus and flexion–extension at touchdown, maximum flexion, and take-off. The range of motion was subsequently determined during both the flexion and extension phases, defined as the change in knee angle over the duration of either the flexion or extension phase. The knee joint angle was defined in each plane as the orientation of the shank segment relative to the thigh segment. The agility sprint was also quantified with respect to stride parameters. The stride length and stride angle (measured relative to the running direction) were calculated for the final approach stride (left foot contact to right foot contact) and the first exit stride following the turn (left foot contact to right foot contact).

Statistical analysis

Each kinematic parameter was determined at 15-min intervals throughout the exercise protocol. Analysis of variance (ANOVA) was used to examine the influence of exercise duration on each parameter. Significant differences between means were identified using a least-squares difference *post-hoc* test. All results are reported as means ± standard deviations. Statistical significance was set at $P < 0.05$.

In what follows, the performance measures are classified according to the time during the protocol, with testing conducted every 15 min throughout the simulated game. The pre-test score would therefore be allocated the time subscript "00". The time classification is cumulative and includes the passive half-time interval. The end of the first half would be specified as "45", the start of the second half as "60", and the end of the game as "105".

Results

Left knee kinematics

Figure 3 shows the amount of knee flexion during the penultimate ground contact phase of the turn. Knee flexion is quantified at first contact with the ground, at the point of maximum flexion, at maximum flexion following the re-planting of the foot, and at take-off. At the instances of peak knee flexion and take-off, ANOVA revealed no significant main effect for exercise duration. However, at touchdown a significant main effect for time was obtained ($P < 0.05$), with knee flexion decreasing throughout each half. Knee flexion at T_{00} (57.39 ± 15.46°), T_{15} (53.23 ± 17.89°), and T_{60} (52.33 ± 19.86°) was significantly ($P < 0.05$) greater than at T_{90} (37.65 ± 8.91°) and T_{105} (37.03 ± 5.87°).

With the exception of the resting trial, the duration of the knee flexion phase tended to increase during the first half and remained elevated throughout the second half. The shortest duration of flexion at T_{15} (0.18 ± 0.06 s) was considerably ($P < 0.10$) less than at T_{75}, T_{90} and T_{105} (0.25 ± 0.05 s). The range of joint movement during the knee flexion phase (Figure 4) tended to increase during the first half, and remained elevated during the second half. The range of knee flexion at the end of the first half (T_{45}: 66.6 ± 18.2°) and throughout the second half (T_{75}: 66.4 ± 18.1°; T_{90}: 65.7 ± 20.4°; T_{105}: 70.2 ± 19.4°) was significantly greater than before exercise (T_{00}: 51.8 ± 18.8°).

Left knee kinematics revealed that increased varus alignment was present throughout the period of ground contact, ranging from approximately 8° at touchdown to 17° in maximum flexion. However, no significant main effect for exercise duration was observed for knee varus at touchdown, maximum flexion or take-off.

Right knee kinematics

Figure 5 shows the amount of flexion in the right knee during the turn at touchdown, maximum flexion, and take-off. Knee flexion at touchdown tended to decrease during the first half with the joint angle at T_{45} (30.57 ± 6.99°) significantly ($P = 0.02$) straighter than at T_{00} (39.50 ± 6.31°). A similar trend was observed during the second half, with the knee significantly more flexed at T_{60} (37.71 ± 7.80°) than at T_{105} (30.21 ± 2.90°).

Although ANOVA revealed no significant main effect for exercise time in the duration of either flexion or extension, the range of knee flexion tended to increase as a function of exercise duration (Figure 6). The range of flexion at T_{00} (28.17 ± 9.31°) was

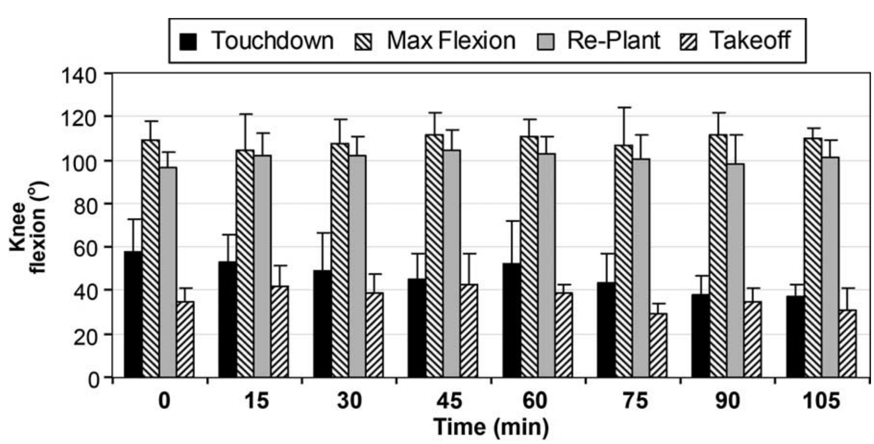

Figure 3. Time history of changes in left knee flexion during the turn (flexion represents the phase from touchdown to maximum knee flexion).

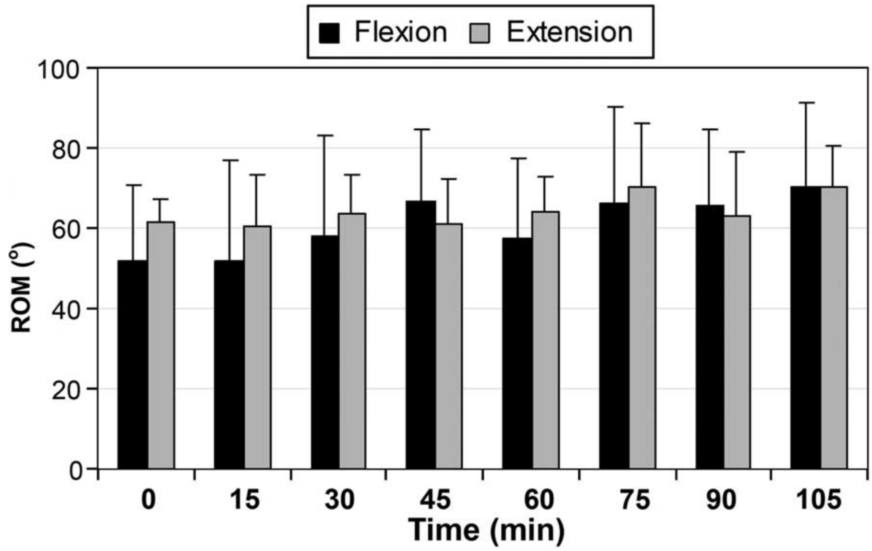

Figure 4. Time history of changes in range of left knee flexion and extension during the turn (flexion represents the phase from touchdown to maximum knee flexion, extension represents the phase from maximum knee flexion to take-off).

significantly less than at $T_{15–45}$, and the range of flexion at the start of the second half (T_{60}: 30.18 ± 10.70°) was significantly less than at $T_{75–105}$.

Right knee kinematics were characterized by increased varus alignment throughout the turn. However, no significant main effect for exercise duration was observed for knee varus at touchdown, maximum flexion or take-off (Figure 7).

The range of knee varus during the flexion phase showed a change from a varus displacement during the first 15 min to a valgus displacement thereafter (Figure 8). Peak valgus displacement during knee flexion was observed at the end of each half (T_{45}: 4.7 ± 7.9°; T_{105}: 6.9 ± 7.4°), which was significantly ($P < 0.05$) different to the varus displacement observed at $T_{00–15}$. The range of valgus movement at the knee during the extension phase was greatest following the passive half-time interval (T_{60}: 6.2 ± 7.3°), and tended to increase as a function of exercise time during the second half.

Stride parameters

Analysis of variance revealed no significant main effect of exercise duration in the length of either the final approach stride (~0.70 m) or in the exit stride (~0.80 m). The approach angle was observed to peak following the half-time interval (T_{60}: 17.5 ± 6.6°), and increased gradually during the second half (T_{105}: 16.6 ± 7.3°). The exit stride angle tended to increase during the first half and decrease during the second half (T_{00}: 34.1 ± 10.4°; T_{45}: 40.4 ± 6.8°;

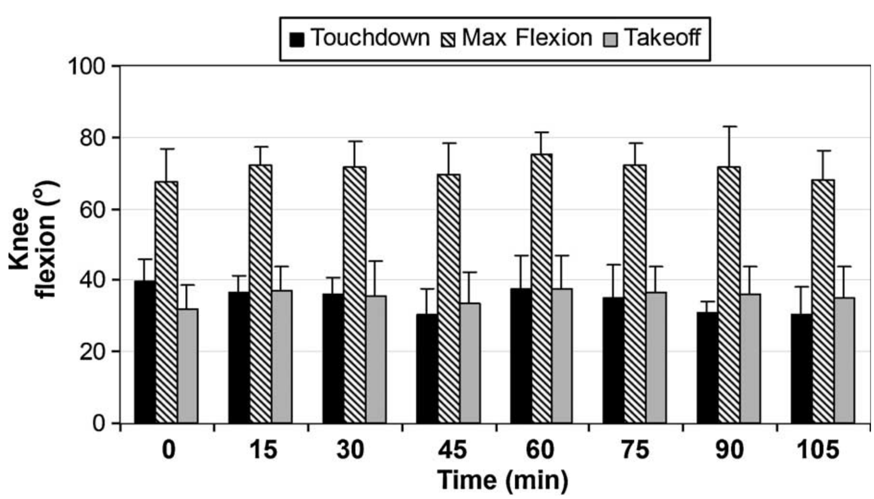

Figure 5. Time history of changes in right knee flexion during the turn (flexion represents the phase from touchdown to maximum knee flexion).

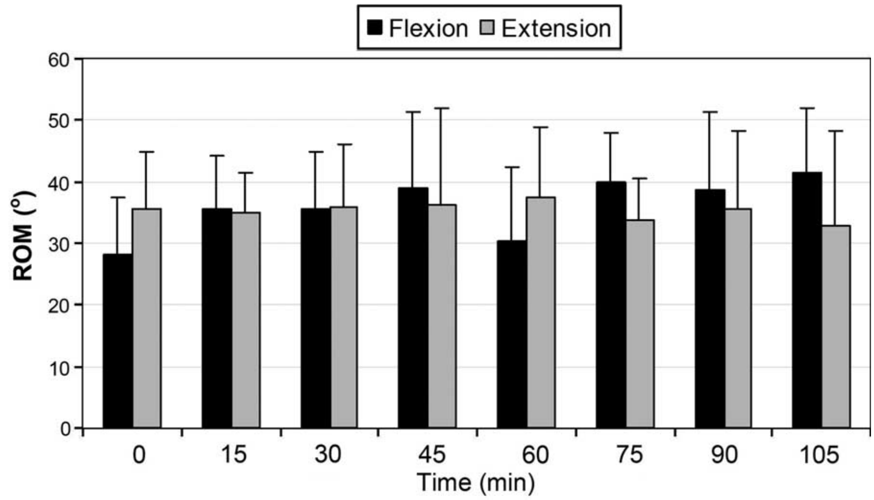

Figure 6. Time history of changes in range of right knee flexion and extension during the turn (flexion represents the phase from touchdown to maximum knee flexion, extension represents the phase from maximum knee flexion to take-off).

T_{105}: 33.3 ± 10.3°). At all instants, the exit stride was at a significantly greater angle than the approach stride (Figure 9).

Discussion

The aim of this study was to investigate the temporal pattern of kinematic alterations in the performance of an agility sprint during prolonged exposure to soccer-specific intermittent activity. The mechanics of cutting movements have been considered in considerable detail, primarily due to their functional relevance to the incidence of anterior cruciate ligament injury and their relation to sporting activities (e.g. Boden *et al.*, 2000; McLean *et al.*, 2004). However, no consideration has been given to the influence of prolonged exposure to sport-specific activity on the performance of such movements. Nyland *et al.* (1997) considered the influence of fatigue on crossover cutting, but fatigue was induced by isokinetic trials and at a speed of only 30° s^{-1}, which arguably lacks functional relevance to the mechanisms of soccer injuries. Spendiff and colleagues (Spendiff, Longford, & Winter, 2002) suggested that the nature of muscle fatigue is likely to be specific to the movement pattern of the exercise, a proposal adopted in the design of the present study.

The knee joint kinematics of the support leg during the penultimate foot contact were characterized by two mechanisms thought to contribute to knee injury. The knee joint at touchdown was characterized by knee joint flexion and varus at touchdown. The amount of knee flexion at touchdown tended to decrease as a function of exercise duration during each half, reducing the potential to provide a protective mechanism for knee joint stability (Hewett *et al.*, 2005). A lack of knee flexion during such tasks has consistently been highlighted as a risk factor in female athletes (e.g. Hewett *et al.*, 2005). With the knee approaching fuller extension at

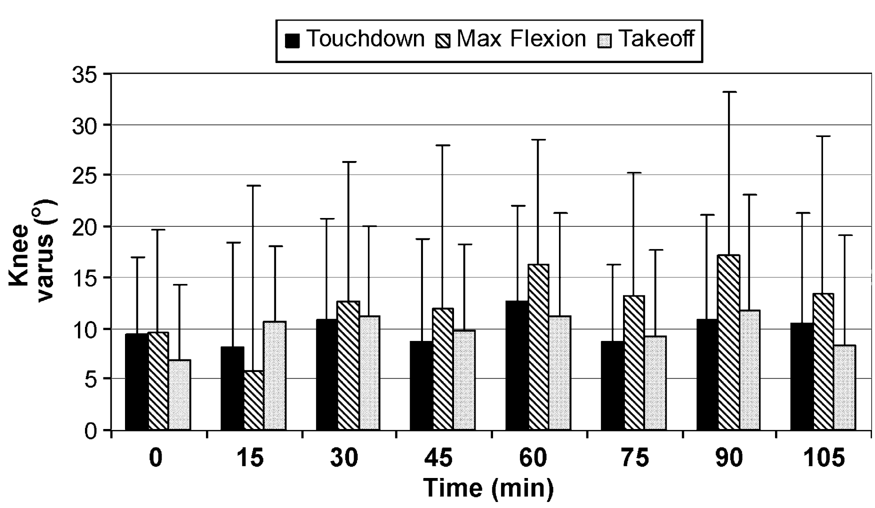

Figure 7. Time history of changes in right knee varus displacement during the turn.

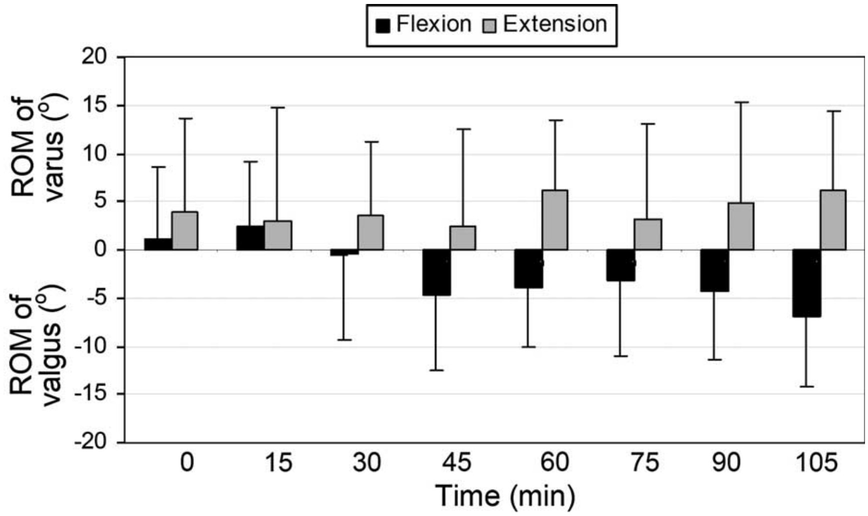

Figure 8. Time history of changes in range of right knee varus and valgus during the turn (flexion represents the phase from touchdown to maximum knee flexion, extension represents the phase from maximum knee flexion to take-off).

touchdown as a function of exercise duration, the quadriceps are increasingly placed at a mechanical advantage for knee extension and produce the most stretch on the anterior cruciate ligament. However, the fatigue-induced reduction in knee flexion places the hamstrings at a mechanical disadvantage, and furthermore the quadriceps contract eccentrically and therefore with great force. This eccentric contraction of the quadriceps can overpower the antagonistic hamstrings, which may subsequently displace the tibia anteriorly and increase ligamentous strain. With increased duration of exposure to the intermittent activity profile, the players in the present study progressively lost the exhibited characteristics of a "soft" landing which can help reduce injury risk (Garrett, 2005). Although it is not possible to establish a causal relationship, the fatigue-induced reduction in knee flexion at touchdown and the subsequent increase in injury risk support the temporal observations of Hawkins *et al.* (2001) that most soccer injuries occur during the latter stages of each half.

The subsequent flexion of the left knee following touchdown was observed to increase in duration throughout the exercise protocol. The range of knee flexion increased in the last 15 min of the first half and remained elevated during the second half, with the exception of the final trial. The increased joint flexion might be indicative of a fatigue effect in controlling the sudden deceleration required to perform the turn. Any compromise in knee joint stability might be attributed to impaired passive stabilization provided by the ligamentous structures and/or active stabilization provided by the knee musculature.

The increased varus alignment of the knee at touchdown was evident throughout the trial, and although not affected by exercise duration, has been

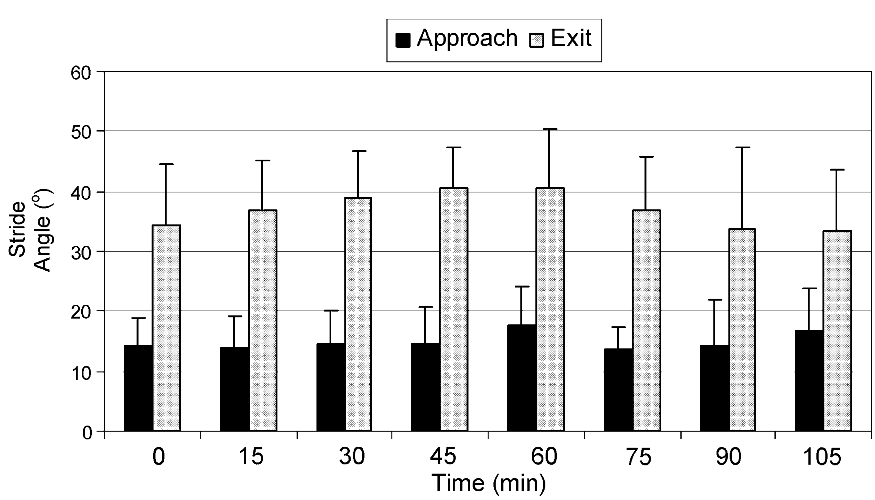

Figure 9. Time history of changes in stride angle during the turn.

related to ligamentous injury (Wind, Bergfeld, & Parker, 2004). This varus alignment of the knee joint places greater stress on the ligamentous structures and on the musculature, providing dynamic joint stabilization. The observation of knee varus at touchdown in elite male soccer players is supported by the research of Yu *et al.* (2005), who observed a change in knee angle from valgus to varus in male soccer players after the age of 12 years. The influence of age in landing mechanics has received much more attention in female athletes (e.g. Hewett, Myer, & Ford, 2006), but the observations of Yu *et al.* suggest an influence of prolonged exposure to soccer activity in male players. Drawer and Fuller (2001)reported a prevalence of osteoarthritis in the knee joints of retired male professional players, with the knee being the most common site of both acute and chronic injuries that lead to early retirement. Ligament and cartilage damage were the most commonly reported types of career-ending injury. The increased varus alignment observed in the present study in male professional players is in contrast with the often reported knee valgus in female athletes, and has been related to an increased risk of ligament injury (Wind *et al.*, 2004).

The potentially damaging varus displacement of the left knee during the penultimate foot contact prior to the turn might be attributed to the strategy used in the approach. The angle of the final approach stride relative to the direction of running was approximately 15°, the left foot planted outside the running line to create this angle. The two agility manoeuvres most commonly considered in the literature are the step-over cut and the side-stepping cut (Houck, 2003). To perform these cutting manoeuvres, it is proposed that the individual approaches along a straight line and then deviates to the left or to the right respectively from the plant foot. This technique is not a realistic reactive movement in soccer match-play, and in experimental conditions this restraint has produced a reduction in the speed of approach (Besier *et al.*, 2003; McLean *et al.*, 2004). The present study used professional players with a considerable training history and exposure to soccer activities. The self-selected strategy of laterally displacing the penultimate (left) foot contact increases the stability during the turn compared with the case where the final stride is made parallel to the running direction. The lateral placement of the penultimate (left) foot predisposes the knee to varus displacement.

The left foot plant is made in preparation for the turn, attempting to provide a stable base for the turn performed on the right leg, which is forced to complete the deceleration and initiate the change in direction of the movement. The right knee therefore flexes in an attempt to arrest the momentum of the body. The knee joint at touchdown was again characterized by knee joint flexion and varus at touchdown. As with the previous contact, the amount of knee flexion at touchdown tended to decrease as a function of exercise duration during each half, potentially negating the influence of this protective mechanism (Hewett *et al.*, 2005) and increasing the risk of ligamentous injury. The potentially damaging varus displacement at touchdown was greatest following the passive half-time interval and remained elevated during the latter stages of the second half. This might suggest an increased risk of injury during the initial stages of the second half, supporting epidemiological observations (Hawkins *et al.*, 2001; Rahnama *et al.*, 2003). While pre-match warm-ups are well established in professional soccer, this finding might advocate the use of re-warm-up strategies during the half-time interval.

The range of knee flexion was greatest during the latter stages of each half, possibly indicative of increased mechanical load and decreased joint stability as a function of exercise duration. The increased range of knee flexion also had implications for the alignment of the knee. For the first 15 min of the protocol, the right knee was displaced in the varus direction during flexion, but thereafter the knee was displaced in the valgus direction. Knee valgus has consistently been implicated as a risk factor for injury in female athletes (Hewett *et al.*, 2006). With right knee valgus displacement during the flexion phase, the extension phase was associated with varus displacement. The range of varus displacement during knee extension increased after the passive half-time interval and during the latter stages of the second half. Although it is not possible to determine a cause-and-effect relationship, this temporal pattern of changes in knee joint kinematics supports epidemiological observations of injury in professional football with the incidence of injuries greatest during the latter stages of each half (Hawkins *et al.*, 2001) and during the initial stages of the second half (Rahnama *et al.*, 2003).

The greater knee valgus and smaller knee flexion angles adopted by female soccer players during cutting and landing tasks have previously been associated with greater quadriceps activity and less hamstring activity (Malinzak, Colby, Kirkendall, Yu, & Garrett, 2001). Prolonged exposure to the same exercise protocol used in the present study has previously been shown to increase the loading on the hamstring musculature (Greig *et al.*, 2006). This fatigue effect of the running protocol might induce a change in the muscle contribution during dynamic tasks analogous to the modified strategies used by female athletes, shown to increase the risk of injury (Garrett, 2005). Greig and Walker-Johnson (2007) showed that the same exercise protocol as used in the present study impaired dynamic balance performance in a similar sample of professional players, although the mechanism of this change was not clear.

Following the right footed turn, the left foot is re-planted to accelerate the exit from the turn. At every time point, the angle of the exit stride was greater than the approach stride. The exit stride angle decreased throughout the second half, with potential implications for performance, since accelerating from a stationary position would be enhanced by shorter, wider strides that would tend to increase this stride angle. The gradual reduction in this exit angle might further reflect impaired joint stability, the kinematic changes therefore having potential implications for both performance and injury risk.

The fatigue effect observed in knee joint kinematics, and the associated risk of injury, might be considered in the design of functional tests used to determine readiness for return to sporting activity following injury. While joint integrity might be maintained during the performance of functional tasks in the rested state, the prevalence of injuries during the latter stages of match-play and the observation of fatigue-induced changes in mechanics suggest that joint integrity might be compromised when performing the same task in a fatigued state. Practitioners might therefore be advised to consider the adoption of a graded fatigue test when considering the readiness of a player to return to competition, particularly in light of the considerable impact of re-injuries on injury incidence (Hawkins *et al.*, 2001).

Although the observed changes in knee joint kinematics mirror the temporal observations of injury incidence during match-play (e.g. Hawkins *et al.*, 2001), it is not possible to determine a causal relationship. The implications of the observed changes in knee joint kinematics would be greatly enhanced if the data collection were extended to include kinetic analyses. Performing the turn on a force platform would enable the use of inverse dynamic analysis to calculate segmental kinetics during the agility sprint. Incorporating electromyographic analysis would further enhance the current study by providing a measure of muscular fatigue specific to the knee joint kinematic analysis. It should also be noted that the findings of the present study are specific to both the exercise protocol and the cutting manoeuvre. Treadmill-based running protocols have an inherent limitation in that there is limited scope to replicate the utility modes of locomotion such as backward running, jumping, and side-stepping. Furthermore, the exercise protocol used in the present study fails to replicate any involvement with either the ball or other players. Free running protocols may be better placed to replicate the multi-factorial demands of soccer match-play, assuming they provide a valid representation of activity profile. However, the exercise protocol used in the present study does provide a model with which to examine many facets of performance. Future consideration might be given to optimizing half-time re-warm-up strategies, or the influence of ergogenic aids on the physical response to soccer-specific activity. The agility sprint used in the present study might be replaced with other functional tasks, related either to skilled technical performance (e.g. shooting accuracy) or injury prevention. If sufficient notational data were available, the present study could also be replicated for youth or female players.

Conclusions

The soccer-specific intermittent running protocol was observed to induce a temporal change in the kinematics of the agility sprint. Knee flexion at touchdown tended to reduce as a function of exercise duration, reducing the protection provided by this mechanism. In the penultimate foot contact, knee varus increased throughout the first half and remained elevated thereafter, with a marked increase in knee varus displacement following the passive half-time interval. The latter stages of each half and the period immediately after the half-time interval might therefore pose an increased risk of injury, supporting epidemiological observations. In the final foot contact, the knee displacement changed from varus to valgus as exercise continued. Malalignment of the knee joint is a primary risk factor for injury and is indicative of impaired joint stability, with implications for both the passive ligamentous and active muscular contributions. Although no cause-and-effect relationship can be assumed, the temporal pattern of kinematic changes to agility sprinting mechanics supports epidemiological observations of injury incidence during soccer match-play.

References

Bangsbo, J. (1994). *Fitness training in football – a scientific approach*. Bagsvaerd, Denmark: Ho+Storm.

Besier, T. F., Lloyd, D. G., & Ackland, T. R. (2003). Muscle activation strategies at the knee during running and cutting maneuvers. *Medicine and Science in Sports and Exercise*, *35*, 119–127.

Boden, B. P., Dean, G. S., Feagin, J. A., & Garrett, W. E. (2000). Mechanisms of anterior cruciate ligament injury. *Orthopaedics*, *23*, 573–578.

Drawer, S., & Fuller, C. W. (2001). Propensity for osteoarthritis and lower limb joint pain in retired professional soccer players. *British Journal of Sports Medicine*, *35*, 402–408.

Garrett, W. E. (2005). The anterior cruciate ligament: The big picture. In *International football and sports medicine: Caring for the* *soccer athlete worldwide* (pp. 235–242). Rosemont, IL: American Orthopaedic Society for Sports Medicine.

Greig, M. P., McNaughton, L. R., & Lovell, R. J. (2006). Physiological and mechanical response to soccer-specific intermittent activity and steady-state activity. *Research in Sports Medicine*, *14*, 1–24.

Greig, M. P., & Walker-Johnson, C. J. (2007). The influence of soccer-specific fatigue on functional stability. *Physical Therapy in Sport*, *8*, 185–190.

Hawkins, R. D., Hulse, M. A., Wilkinson, C., Hodson, A., & Gibson, M. (2001). The association football medical research programme: An audit of injuries in professional football. *British Journal of Sports Medicine*, *35*, 43–47.

Hewett, T. E., Myer, G. D., & Ford, K. R. (2006). Anterior cruciate ligament injuries in female athletes: Part 1, mechanisms and risk factors. *American Journal of Sports Medicine*, *34*, 299–311.

Hewett, T. E., Myer, G. D., Ford, K. R., Heidt, R. S., Colosimo, A. J., McLean, S. G., et al. (2005). Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: A prospective study. *American Journal of Sports Medicine*, *33*, 492–501.

Houck, J. (2003). Muscle activation patterns of selected lower extremity muscles during stepping and cutting tasks. *Journal of Electromyography and Kinesiology*, *13*, 545–554.

Jones, A. M., & Doust, J. H. (1996). A 1% treadmill grade most accurately reflects the energetic cost of outdoor running. *Journal of Sports Sciences*, *14*, 321–327.

Malinzak, R. A., Colby, S. M., Kirkendall, D. T., Yu, B., & Garrett, W. E. (2001). A comparison of knee joint motion patterns between men and women in selected athletic tasks. *Clinical Biomechanics*, *16*, 438–445.

McLean, S. G., Lipfert, S. W., & van den Bogert, A. J. (2004). Effect of gender and defensive opponent on the biomechanics of sidestep cutting. *Medicine and Science in Sports and Exercise*, *36*, 1008–1016.

Nyland, J. A., Shapiro, R., Caborn, D. N. M., Nitz, A. J., & Malone, T. R. (1997). The effect of quadriceps femoris, hamstring and placebo eccentric fatigue on knee and ankle dynamics during crossover cutting. *Journal of Orthopaedic, Sports and Physical Therapy*, *25*, 171–184.

Nyland, J. A., Shapiro, R., Stine, R. L., Horn, T. S., & Ireland, M. L. (1994). Relationship of fatigued run and rapid stop to ground reaction forces, lower extremity kinematics, and muscle activation. *Journal of Orthopaedic, Sports and Physical Therapy*, *20*, 132–137.

Pinniger, G. J., Steele, J. R., & Groeller, H. (2000). Does fatigue induced by repeated dynamic efforts affect hamstring muscle function? *Medicine and Science in Sports and Exercise*, *32*, 647–653.

Rahnama, N. T., Reilly, T., Lees, A., & Graham-Smith, P. (2003). Muscle fatigue induced by exercise simulating the work rate of competitive soccer. *Journal of Sports Sciences*, *21*, 933–942.

Reilly, T., & Brooks, G. A. (1986). Exercise and the circadian variation in body temperature measures. *International Journal of Sports Medicine*, *7*, 358–368.

Sigward, S. S., & Powers, C. M. (2006). The influence of gender on knee kinematics, kinetics and muscle activation patterns during side-step cutting. *Clinical Biomechanics*, *21*, 41–48.

Spendiff, O., Longford, N. T., & Winter, E. M. (2002). Effects of fatigue on the torque–velocity relation in muscle. *British Journal of Sports Medicine*, *36*, 431–435.

Wind, W. M., Bergfeld, J. A., & Parker, R. D. (2004). Evaluation and treatment of posterior cruciate ligament injuries. *American Journal of Sports Medicine*, *32*, 1765–1775.

Woods, C., Hawkins, R., Hulse, M., & Hodson, A. (2003). The Football Association Medical Research Programme: An audit of injuries in professional football – an analysis of ankle sprains. *British Journal of Sports Medicine*, *37*, 233–238.

Woods, C., Hawkins, R. D., Maltby, S., Hulse, M., Thomas, A., & Hodson, A. (2004). The Football Association Medical Research Programme: An audit of injuries in professional football – analysis of hamstring injuries. *British Journal of Sports Medicine*, *38*, 36–41.

Yu, B., McClure, S. B., Onate, J. A., Guskiewicz, K. M., Kirkendall, T. K., & Garrett, W. E. (2005). Age and gender effects on lower extremity kinematics of youth soccer players in a stop-jump task. *American Journal of Sports Medicine*, *33*, 1356–1364.