Soccer-specific Fatigue Decreases Reactive Postural Control with Implications for Ankle Sprain Injury

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To quantify the influence of soccer-specific fatigue on reactive dynamic balance, ten male professional soccer players (age 24.7 ± 4.4 yr, body mass 77.1 ± 8.3 kg, VO₂max 63.0 ± 4.8 ml·kg·min⁻¹) completed an exercise protocol replicating the activity profile of match-play. Pre-exercise, and at 15 min intervals, players completed three balance tasks requiring response to a system perturbed to induce either plantar flexion of the ankle or inversion of the ankle (by rotation or translation). ANOVA revealed a significant main effect for exercise duration in each task, with both reaction time and total centre of gravity displacement tending to increase during each half. In all three trials there was a significant increase in medio-lateral and anterior-posterior displacement, the planar perturbation of the platform evoking a multi-angular response. Dynamic balance performance decreased as a function of time during each half, suggesting a greater risk of injuries at these specific times, in accord with epidemiological observations of ankle sprain injury.

KEYWORDS fatigue, soccer, proprioception, ligamentous injury

INTRODUCTION

Joint sprains are a primary injury type in sport, with a multifaceted aetiology, and accounting for approximately 20% of all soccer injuries (Hagglund, Walden, & Ekstrand, 2004). In an audit of injuries in English professional
football (Hawkins, Hulse, Wilkinson, Hodson, & Gibson, 2001), knee and ankle joints accounted for 34% of all injuries, with the most common injury type being a joint sprain injury. Epidemiological research has also examined the time pattern of injury incidence during soccer match-play. Ekstrand, Hagglund, and Walden (2011) reported that the increased injury risk toward the end of each half was evident for the total of traumatic injuries and for the injury subtype of sprains. Previously, Woods, Hawkins, Hulse, and Hodson (2003) reported that 48% of ankle sprain injuries were sustained in the last 15 minutes of each half of matches. The same pattern has been observed in elite youth soccer (Cloke, Spencer, Hodson, & Deehan, 2009). In the fatigued state a joint may fail to produce those appropriate muscular responses that have a protective function in maintaining joint stability (Rozzi, Yuktanandana, Pincivero, & Lephart, 2000). Aetiological risk factors associated with joint sprain injury include impaired proprioceptive capacity and postural stability (Hewett, Lindenfeld, Riccobene, & Noyes, 1999; Murphy, Connolly, and Beynnon, 2003).

The influence of fatigue on the performance of balancing tasks has been justified on the basis that such tasks require that the adaptive control system responds appropriately to demands raised by the task and the environment. This is a complex process comprising both static (ligaments, articular surfaces) and dynamic (neuromuscular system) contribution (Reimann & Lephart, 2002). Muscular fatigue might induce a change in balance strategy specific to the locality of fatigue (Adlerton, Moritz, & Moe-Nilssen, 2003).

The aim of the current study was to examine the influence of soccer-specific fatigue on balance performance. Single-legged dynamic balance is considered most appropriate to the requirements of soccer, and forms part of many intervention and pre-habilitation programmes. Soccer-specific fatigue has been shown to impair single legged balance performed on a wobble board apparatus over 30 s (Greig & Walker-Johnson, 2007), which is arguably not representative of the mechanism of ankle sprain incidence. In the present study a series of balance tasks was devised that requires the player to react to sudden perturbations in the system, which is more representative of the mechanics of ankle sprain. Specifically, the three balance tasks comprise trials inducing ankle plantar flexion, ankle inversion by lateral rotation of the platform, and ankle inversion by medial translation of the platform.

**MATERIALS AND METHODS**

Ten male professional players (age 24.7 ± 4.4 yr, body mass 77.1 ± 6.3 kg, VO$_{2\text{max}}$ 63.0 ± 4.8 ml·kg·min$^{-1}$) participated in this study. Participants were tested between 15:00 and 17:00 h in accord with regular training or competition times, and to account for the effects of circadian variation (Reilly &...
Brooks, 1986). Participants attended the laboratory in a 3-hour post-absorptive state, having performed no vigorous exercise in the 24 h prior to testing, and with diet standardised for 48 h preceding each test. Players were required to consume 500 ml of water 2 h prior to testing to ensure euhydration.

Players completed an intermittent treadmill protocol, designed to replicate the activity profile of soccer match-play (Greig, McNaughton, & Lovell, 2006). Acknowledging that the treadmill protocol fails to reflect the multidirectional nature of match-play, the same exercise protocol has been shown to induce a fatigue affect in balance strategy (Greig & Walker-Johnson, 2007). The 15 min activity profile (Figure 1) was completed six times in total, with a passive 15 min half-time interval.

Pre-exercise, and at 15 minute intervals throughout the exercise protocol each player completed balance tasks administered using the SMART EquiTest (NeuroCom International, Portland, Oregon, USA). Single-legged dynamic balance was quantified using three trials, with the player responding to perturbation of the system so as to maintain balance. The system perturbation was 8° anterior rotation over 0.2 s for the plantar flexion trial, 8° lateral rotation over 0.2 s for ankle inversion by rotation, and 3 cm medial translation over 0.3 s for ankle inversion by translation. The visual surround remained fixed in the upright position with no feedback, and movement of the force plate was initiated with a zero time delay such that no data were collected prior to movement of the support surface.

Balance was performed on the dominant limb, based on epidemiological data that has consistently reported significantly more injuries to the dominant leg (Hawkins et al., 2001). All subjects completed familiarisation trials of the balance tasks on a minimum of three previous laboratory visits. From familiarisation trials, the test–retest reliability of all performance measures were
categorised as good (Portney & Watkins, 1983), with intra-class correlation coefficients ranging from 0.76 to 0.88.

Time-history of the centre of gravity coordinates in reaction to perturbation of the system was sampled at 100 Hz. Response time and total, anterior-posterior, and medio-lateral displacement of the centre of gravity were quantified. The pre-testing score is allocated the time subscript ‘00’, the end of the first half as ‘45’, and the end of the game as ‘105’.

A significant main effect for exercise duration was investigated using ANOVA. Significant differences between means were identified using a least-squares difference post-hoc test, all results reported as the mean ± standard deviation, with significance accepted at $P < 0.05$.

RESULTS

Figure 2 shows the time history of the total distance travelled ($d$) in responding to the system perturbation. The ANOVA revealed a significant ($P < 0.01$) main effect for time during each trial, with the centre of gravity displacement generally increasing as a function of exercise duration.

In plantar flexion the influence of exercise duration was evident in both halves, with $d_{45}$ (5.53 ± 0.83 cm) significantly greater than $d_{00-30}$, and $d_{105}$ (6.38 ± 0.85 cm) significantly greater than $d_{00-75}$. The same pattern was evident in lateral rotation, with $d_{45}$ (2.98 ± 0.60 cm) significantly greater than $d_{00-30}$, and $d_{105}$ (3.52 ± 0.57 cm) significantly greater than $d_{00-75}$. In medial translation the same fatigue effect was observed with $d_{45}$ (2.45 ± 0.19 cm) significantly greater than $d_{00}$ and $d_{15}$, and $d_{105}$ significantly greater than $d_{00}$-$d_{45}$, and $d_{75}$.

**FIGURE 2** Time history of changes in total centre-of-gravity displacement ($d$).
Figure 3 shows the time history of the response time \( t \) to the system perturbation. The ANOVA revealed a significant main effect for exercise time in all trials.

The resting response time \( t_{00} \) (0.81 ± 0.16 s) was significantly faster than \( t_{75-105} \) in plantar flexion trials. In lateral rotation the response pre-exercise \( t_{00} = 0.90 ± 0.29 \) s was significantly faster than at the end of each half \( t_{45} = 1.24 ± 0.26 \) s; \( t_{105} = 1.13 ± 0.15 \) s). Similarly, in medial translation the response was significantly slower at the end of the each half \( t_{45} = 0.81 ± 0.23 \) s; \( t_{105} = 0.69 ± 0.09 \) s) than at rest \( 0.61 ± 0.09 \) s), and with \( t_{105} \) significantly slower than \( t_{45} \).

Figure 4 shows the time history of movement amplitude in the medio-lateral direction (ΔML) during each trial.

The ANOVA revealed a significant \((P < 0.01)\) main effect for exercise time in each trial. In plantar flexion, medio-lateral displacement increased significantly after the half-time interval, with ΔML_{60} (9.70 ± 2.88 mm) significantly greater than ΔML_{00-45}. During the second half ΔML increased as a function of exercise duration, such that ΔML_{105} (14.61 ± 6.17 mm) was significantly greater than ΔML_{75-90}. In lateral rotation medio-lateral displacement generally increased during each half, with ΔML_{45} (23.81 ± 6.30 mm) significantly greater than ΔML_{00-15}, and in the second half ΔML_{90} (29.49 ± 6.14 mm) and ΔML_{105} (30.04 ± 4.70 mm) were significantly greater than ΔML_{00-75}.

Similarly, in medial translation displacement increased progressively with exercise duration in each half such that ΔML_{30} (20.90 ± 4.02 mm) and ΔML_{45} (21.23 ± 3.36 mm) were significantly \((P = 0.01)\) larger than ΔML_{00} (15.35 ± 3.57 mm), and ΔML_{105} (26.75 ± 4.87 mm) was significantly \((P < 0.01)\) larger than at all points during the first half and ΔML_{75}. 

![Figure 3](image_url) 
**FIGURE 3** Time history of changes in response time \( t \).
The ANOVA also revealed a significant ($P < 0.01$) main effect for exercise time for displacement in the anterior-posterior direction during each trial (Figure 5).

In anterior rotation, ΔAP increased as a function of exercise time in each half. At the end of the first half $ΔAP_{45}$ (47.86 ± 7.36 mm) was significantly greater than at all preceding times. The half-time interval had a significant ($P = 0.03$) improvement on performance ($ΔAP_{60} = 40.50 ± 5.54$ mm), but thereafter $ΔAP$ increased such that $ΔAP_{90-105}$ were significantly impaired. In lateral rotation and medial translation $ΔAP$ was consistent during the first half

FIGURE 4 The influence of fatigue on medio-lateral response displacement ($ΔML$).

FIGURE 5 The influence of fatigue on anterior-posterior displacement ($ΔAP$).
but was observed to increase significantly after the half-time interval $\Delta AP_{60}$ and over the final 15 minutes of the trial $\Delta AP_{105}$.

**DISCUSSION**

The aim of the current study was to investigate the time-history of changes in dynamic balance as a result of soccer-specific fatigue. A fatigue affect is likely to be specific to both the exercise protocol and the balance task (Adlerton et al., 2003; Paillard, 2012), thus direct comparison with previous studies is limited. The EquiTest balance task provides a reactive functional challenge to postural control since the player must respond to perturbations in the surface surround. No ‘fails’ were observed, where the player would lose control and fall from or step off the platform.

The first measure of balance performance presented was the total displacement of the centre of gravity in response to system perturbation. A greater displacement in response is representative of decreased task performance (Szturm & Fallang, 1998). There was a significant main effect for exercise duration in all three trials, with centre of gravity displacement generally increasing throughout each half. This is indicative of impaired joint stability during the latter stages of each half, mirroring the temporal pattern of ankle sprain incidence during soccer match-play (Woods et al., 2003).

Centre of gravity displacement was further considered in the medio-lateral and anterio-posterior axes. In plantar flexion, a fatigue effect was evident in anterio-posterior displacement, increasing as a function of exercise duration in each half and with displacement greater during the second half. A similar pattern was seen in medio-lateral displacement during lateral rotation and medial translation trials. This reflects a gradual fatigue effect in the planar response to the perturbation.

There was also an increase in medio-lateral displacement to plantar flexion after the half-time interval, and an increase in anterio-posterior displacement to ankle inversion during the latter stages of each half and following the passive half-time interval. Increased deviation in the AP plane during recovery from an enforced inversion movement, or in the ML plane following enforced plantar flexion is indicative of a change from a planar response to a response involving multi-directional stabilisation.

Whilst the platform is restrained to move in only one plane, i.e. translation or rotation, the ankle joint has no such constraints and is free to perform multi-angular movement in response. As exercise continued the planar perturbation of the platform produced an increasingly multi-angular response. Verhagen and Bay (2010) indicated that the typical mechanism of ankle ligamentous sprain is a combination of inversion and plantar flexion. The increasing plantar flexion and inversion of the ankle with fatigue during this soccer-specific protocol therefore increases the risk of injury. Fong, Ha, Mok,
Chan, and Chan (2012) suggested that priority be given to reducing inversion, recommending that athletes who perform sideward cutting motions try to land with a neutral ankle orientation to prevent lateral shift of the centre of pressure, and reduce the risk of inversion sprain injury.

The observation that the initial stages of the second half were identified as having impaired balance performance has many practical implications, with a high incidence of injury observed during this period of match-play (Rahnama, Reilly, & Lees, 2002). Whilst a pre-match warm-up has become an integral part of game preparation, the findings of the current study also advocate a re-warm-up before starting the second half.

Task performance was also quantified using the time duration of response. In lateral rotation the pre-exercise response was significantly shorter than at the end of each half. In plantar flexion and medial translation the response increased gradually during the first half and remained elevated during the second half relative to pre-exercise performance. This supports observations of extended latency in firing (Nyland, Shapiro, Stine, Horn, & Ireland, 1994), electromechanical delay (Gleeson, Reilly, Mercer, Rakowski, & Rees, 1998; Zhou, McKenna, Lawson, Morrison, & Fairweather, 1996), and slower muscle reaction time after fatiguing exercise (Wojtys, Wylie, & Huston, 1996). Willems et al. (2005) highlighted slower reaction time as an intrinsic risk factor associated with increased risk of ankle inversion sprains.

Fatigue-induced reductions in joint proprioception will influence both the non-contact aetiology of joint ligamentous injury (Hewett et al., 1999), and the severity of injury (Barrack, Skinner, & Buckley, 1989). The greater mechanical demand placed on joint stability in the fatigued state has greater implications as impaired proprioception might alter the coordination of muscle activation, creating inadequate stabilisation of the joint and impaired control of joint motion. In ankle sprain aetiology, previous injury is consistently reported as a primary factor (Ekstrand et al., 2011; Malliaropoulos, Ntessalen, Papacostas, Longo, & Maffulli, 2009; Verhagen & Bay, 2010). Morrison et al. (2010) suggested that patients with chronic ankle instability demonstrated a laterally shifted centre of pressure during running. This lateral shift of the centre of pressure is a risk during lateral cutting movements, and thus the agility components inherent to soccer further increase the risk of injury. Verhagen and Bay (2010) reported that re-injury can lead to chronic pain or instability. Cloke et al. (2009), in considering elite youth soccer players, also reported the potential for permanent impairment and disability impacting on future employment. In the shorter term the training and playing time lost to injury will impact on the athletic and technical development of the young player.

A recent review of ankle sprain prevention advocated a combination of an external prophylactic measure (e.g. tape or brace) with neuromuscular training (Verhagen & Bay, 2010), given the different pathways through which each measure enhances prevention. In considering practical interventions to reduce the influence of fatigue, performing balance training in the exercised state is
advocated. Hamstring strength ‘fatigability’ was shown to improve in soccer players that performed Nordic hamstring curls post-exercise (Small, McNaughton, Greig, & Lovell, 2009). A similar approach could be taken with balance and proprioception training, implementing (p)rehabilitation exercises in the exercised state. Gioftsidou et al. (2006) postulated that the mechanisms mediating balance control may have more potential for adaptation when functionally challenged, having shown greater effectiveness of a balance programme performed after training. Paillard (2012), in reviewing the effects of general and local fatigue on postural control, called for greater awareness of the consequences of muscle fatigue on ipsi and contralateral monopedal postural control, and the potential variations in compensatory postural strategies.

The findings of the current study mirror epidemiological observations of increased injury risk with fatigue. The change in balance strategy toward increased plantar flexion and inversion is typical of the inversion ankle sprain mechanism, and in both respects the findings have clear practical implications. However, it must be acknowledged that both the exercise protocol and balance task must provide a valid representation. Whilst the balance tasks used in the current study induced combined plantar flexion and inversion, the system did not allow for a combined perturbation. The approach of Fong et al. (2012) in analysing injury incidents during match-play, is an encouraging development toward ecological validity. In considering the exercise protocol, Brito et al. (2012) observed postural stability after a competitive youth soccer match, suggesting that laboratory protocols and simulated matches cannot recreate the demands of real match play. However, it is difficult to standardise exertion and activity profiles between players during match-play, and thus different levels of fatigue are inevitable. Treadmill protocols are inherently limited by the lack of opportunity to consider the multi-directional nature of match-play, but do offer a high frequency of speed change to model the intermittent activity profile. Free running protocols might offer the best compromise between ecological validity and experimental control. There have been several recent attempts to modify the Loughborough Intermittent Shuttle Test protocol (Nicholas, Nuttall, & Williams, 2000) to include additional soccer-specific components (Ali, Gardner, Foskett, & Gant, 2011; Russell, Rees, Benton, & Kingsley, 2011; Stone & Oliver, 2011), and various contemporary free-running protocols (Bendiksen et al., 2012; Cone et al., 2012; Small, McNaughton, Greig & Lovell, 2010) which might be considered as an alternative to treadmill protocols or real match-play.

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