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Original research

The influence of soccer-specific fatigue on functional stability

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Abstract

Objective: To quantify the influence of soccer-specific fatigue on functional stability.
Participants and design: Ten male semi-professional soccer players completed a 90 min treadmill protocol replicating the activity profile of match-play with a passive 15 min half-time interval.
Main outcome measures: At 15 min intervals players completed a 30 s single-legged balance task on an unstable platform. Balance performance was quantified as a stability index and the mean deflection of the platform.
Results: There was no significant ($P>0.05$) main effect for exercise duration in the stability index, suggesting that balance performance was maintained throughout the simulated match. However, the mean deflection of the platform was significantly ($P<0.05$) shifted toward anterior displacement during the last 15 min of each half.
Conclusion: A change in balance strategy was evident during the latter stages of match-play, which may increase injury risk. It is recommended that soccer players perform proprioception training in the rested and exercised state to further develop neuromuscular control.

Keywords: Soccer; Stability; Fatigue; Injury

1. Introduction

Epidemiological research into soccer injuries has consistently reported joint sprains to be a primary injury type, with approximately 20% of all injuries attributed to joint sprains (Hagglund, Walden, & Ekstrand, 2004; Hawkins, Hulse, Wilkinson, Hodson, & Gibson, 2001). The knee and ankle joints accounted for 34% of all injuries in the Football Association audit, with the most common type being a joint sprain injury. Hawkins et al. (2001) reported significantly more injuries to the dominant leg, which has previously been attributed to greater exposure to forced inversion and eversion in jumping and kicking activities (Ekstrand & Gillquist, 1982). Woods, Hawkins, Hulse, and Hodson (2003) suggested that the high incidence of joint sprains might also be attributed to the specific running requirements in soccer. The activity profile of soccer match-play is multi-directional and irregular in both intensity and duration.

In addition to highlighting the primary injury types and sites, epidemiological research has also examined the time pattern of injury incidence during soccer match-play. Woods et al. (2003) reported that 48% of ankle sprain injuries were sustained in the last third of each half during matches. Aetiological risk factors associated with joint sprain injury incidence and severity (Barrack, Skinner, & Buckley, 1989) include impaired proprioceptive capacity (Renstrom & Kannus, 2000) and postural stability (Murphy, Connolly, & Beynnon, 2003). Rozzi, Yuktanandana, Pincivero, and Lephart (2000) suggested that in the fatigued state the joint may fail to produce the appropriate muscular responses which have a protective function in maintaining joint stability.

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The influence of fatigue on neuromuscular control and coordinated movement has previously been applied to balancing tasks, which require appropriate postural control such that the adaptive control system responds adequately to demands raised by the task and the environment. Riemann and Lephart (2002) stated that this complex process comprises both static (ligaments, articular surfaces) and dynamic (neuromuscular system) components. Adlerton, Moritz, and Moe-Nilssen (2003) speculated that muscular fatigue might induce a change in balance strategy that was specific to the locality of fatigue. Such compensatory strategies might increase the risk of injury to both muscular and ligamentous structures, particularly in more dynamic movements.

The aim of the present study was to examine the influence of soccer-specific intermittent activity on single-legged balance performance, and thereby to infer the effect on functional joint stability and therefore potential injury implications. The balance task was performed on a wobble-board apparatus considered appropriate to the requirements of soccer and forming part of many intervention and pre-habilitation programmes. The unstable system reacts to the movement of the player such that stress is placed simultaneously on both plantar-dorsi flexion and inversion–eversion. This multi-directional mechanical demand replicates the mechanism of ankle sprain injury evident in soccer.

2. Method

Ten male semi-professional players (age 24.7 ± 4.4 yr, body mass 77.1 ± 6.3 kg, VO_{2max} 63.0 ± 4.8 ml kg min^{-1} determined by breath-by-breath analysis of a laboratory-based graded treadmill protocol to volitional failure) participated in this study. Participants were tested between 15:00 and 17:00 h or between 18:00 and 20:00 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-h 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. Thereafter the players consumed no fluid so as to control for the possible influence of hydration status on performance.

Players completed the intermittent treadmill protocol described previously by Greig, McNaughton, and Lovell (2006), replicating the activity profile of soccer match-play as described by Bangsbo (1994). In order to investigate the influence of fatigue on the mechanisms of soccer injuries, the exercise model used to elicit fatigue must be a valid representation of the activity profile of soccer match-play. It is acknowledged that the

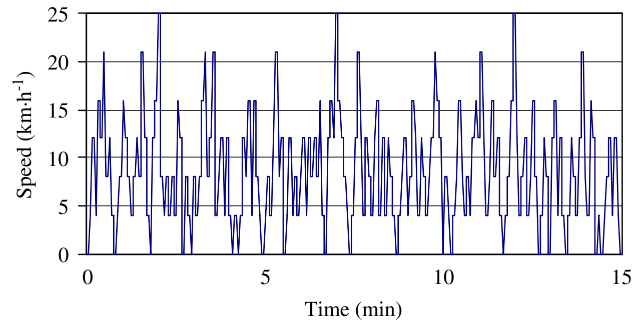

Fig. 1. The intermittent soccer-specific treadmill protocol (Greig et al., 2006).

treadmill-based running protocol is limited in replicating the multi-directional nature of soccer match-play. However, this motorised treadmill protocol does allow for a standardised activity profile not afforded by free-running or non-motorised treadmill protocols. Furthermore, the highly intermittent nature of the protocol does place a great emphasis on acceleration and deceleration. The stride pattern is therefore regularly interrupted with lateral corrections made to facilitate the change in speed, such that the running is arguably not purely linear. The 15 min activity profile (Fig. 1) was completed six times in total, with a passive 15 min half-time interval.

Pre-exercise, and at 15 min intervals throughout the exercise protocol, each player completed the balance task to assess dynamic balance. The balance task was administered using the Biodex stabilometer (Biodex Medical Systems, New York, USA). All subjects completed familiarisation trials of the balance task in the rested state on a minimum of three previous laboratory visits. The stabilometer trial comprised a 30 s single-legged balance task where the subject was instructed to keep the dynamic and unstable platform level to the best of their ability. Subjects balanced on their dominant leg, defined as the preferred kicking leg. Whilst it is the non-dominant limb that provides the balance required in kicking activities, the emphasis of this study was not on kicking technique, and the dominant limb has been identified as having a greater incidence of sprain injury incidence (e.g. Hawkins et al., 2001; Woods et al., 2003). During the balance task each player was instructed to look directly ahead, with slight flexion at the knee, equivalent to the stork stance. A difficulty level of 4 was applied to all tests (level 1 being least stable, level 8 being most stable). No visual feedback was provided to the subject with regard to performance.

2.1. Data analysis

The Biodex stabilometer is a dynamic tilting platform which pivots about a central axis, such that it is free to move simultaneously in the anterio-posterior and medio-lateral plane. Task performance was quantified according to the deviation of the balance platform over the 30 s task. The stability index is quantified as a function of the variance of platform displacement from level. Indices of stability were quantified as an overall measure, and also in both the anterior–posterior and medio-lateral planes. The same directional indices were quantified for the mean deflection over the duration of the balance task.

Task performance was quantified at 15 min intervals throughout the exercise protocol, including at the start and end of the passive half-time interval. A 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 $\pm$ standard deviation, with significance accepted at $P \leqslant 0.05$.

3. Results

In the following section it should be noted that a lower stability index is indicative of less movement during the task, and better performance. Results are summarised in Table 1, and shown subsequently in graphical format to best illustrate the temporal variation during the simulated match.

Fig. 2 shows the mean overall stability index throughout the intermittent protocol. The ANOVA revealed no significant main effect for time, such that single legged balance performance was maintained throughout the trial.

Fig. 3 shows the components of the overall stability index, i.e. the directional component in the anterior–posterior and medio-lateral directions. Again ANOVA revealed no significant main effect for time in either score.

Fig. 4 shows the time history of the mean deflection during the stability task, in both the anterio-posterior and medio-lateral directions. The mean deflection is a function of the average position of the participant

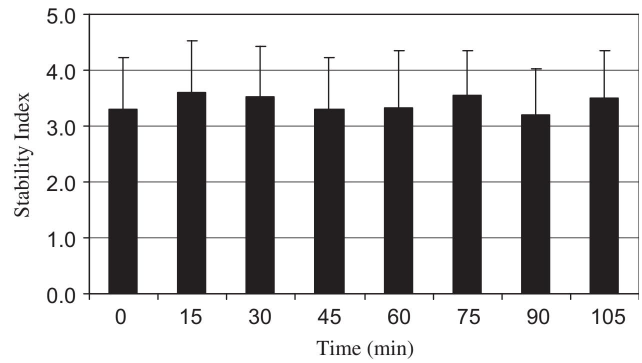

Fig. 2. Time history of overall stability index.

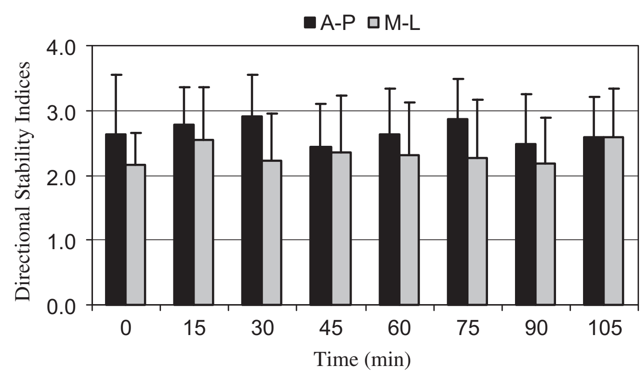

Fig. 3. Time history of anterio-posterior and medio-lateral stability indices.

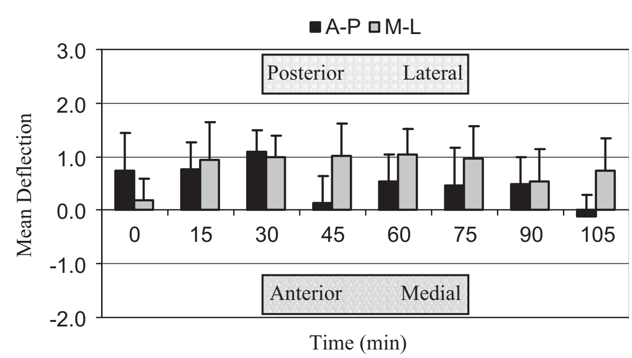

Fig. 4. Time history of mean stabilometer deflection.

Table 1
Summary of temporal changes in balance performance

Time (min)	Stability index			Platform deflection	
	Overall	Ant-Post	Med-Lat	Ant-Post	Med-Lat
0	3.29 $\pm$ 0.94	2.64 $\pm$ 0.92	2.15 $\pm$ 0.50	0.73 $\pm$ 1.41	0.19 $\pm$ 0.86*
15	3.61 $\pm$ 0.92	2.79 $\pm$ 0.57	2.54 $\pm$ 0.82	0.76 $\pm$ 1.02	0.95 $\pm$ 1.45
30	3.52 $\pm$ 0.91	2.90 $\pm$ 0.66	2.22 $\pm$ 0.74	1.08 $\pm$ 0.73	1.00 $\pm$ 0.85
45	3.30 $\pm$ 0.92	2.43 $\pm$ 0.67	2.35 $\pm$ 0.87	0.14 $\pm$ 1.06*	1.01 $\pm$ 1.16
60	3.33 $\pm$ 1.02	2.64 $\pm$ 0.70	2.30 $\pm$ 0.82	0.53 $\pm$ 1.04	1.03 $\pm$ 1.12
75	3.56 $\pm$ 0.78	2.86 $\pm$ 0.63	2.27 $\pm$ 0.89	0.47 $\pm$ 1.44	0.97 $\pm$ 1.34
90	3.20 $\pm$ 0.83	2.48 $\pm$ 0.77	2.19 $\pm$ 0.69	0.49 $\pm$ 1.08	0.54 $\pm$ 1.25
105	3.51 $\pm$ 0.84	2.58 $\pm$ 0.63	2.58 $\pm$ 0.76	−0.11 $\pm$ 0.86*	0.73 $\pm$ 1.26

*Significant difference ($P < 0.05$).

during the task. The ANOVA revealed no significant main effect for time in the mean lateral deflection of the platform. However, there was a significant main effect ($P<0.05$) in the mean anterior–posterior deflection. The mean deflection was significantly reduced, i.e. toward the anterior direction, at the end of each half relative to all other time points.

4. Discussion

The aim of the present study was to investigate the time-history of changes in dynamic balance, considered to be indicative of functional joint stability and postural control. The effect of fatigue on balance is likely to be specific to both the exercise protocol and the balance testing protocol. In this respect comparison with previous studies is limited. The exercise protocols used in previous research have typically failed to replicate the physical demands of soccer match-play. For example, Adlerton et al. (2003) observed impaired balance after localised calf fatigue. The present study aimed to address the proposal of Lattanzio, Petrella, Sproule, and Fowler (1997) that the investigation of fatigue on proprioception be applied to the athletic setting, with assessment at intervals during the activity. It is acknowledged that the relatively small number of participants (in part due to the exclusion criteria regarding injury history) makes generalisation difficult, and consideration might be given to elite, female, and youth cohorts.

The Biodex stabilometer task provides a measure of deviation of a surface which pivots about a central axis, such that it is free to move simultaneously in the anterio-posterior and medio-lateral plane. The deviation of the platform is directly related to the stability of the player, such that greater body movement creates greater deviation in the platform and subsequently a high stability index. With no significant main effect for exercise duration it might be interpreted that the intermittent treadmill protocol had no effect on single legged balance performance.

Consideration of the directional stability indices reveals that stability was greater in the medio-lateral plane than in the anterior–posterior plane, until the post-exercise measure. This might reflect both the uni-directional mode of running imposed by the treadmill and the anatomical configuration of boney and soft tissue structures (Palastanga, Field, & Soames, 2006). Instability in the medio-lateral plane is likely to pose a greater risk for joint injury, and the finding of no fatigue effect with exercise duration suggests that joint stability was not compromised.

However, consideration of the mean deflection of the platform over the duration of the task indicates that a change of strategy might have been employed. In each trial the mean deflection was lateral to the centre of the platform, as expected. However, at the end of each half the mean deflection in the anterior-posterior direction was seen to increase in the anterior direction. This toes-down rotation of the platform is indicative of greater plantar flexion at the ankle. In a more functional setting plantar-flexion of the ankle reduces the base of support and increases the risk of ankle sprain injury due to the additional rotational and transverse movements allowed towards the more open packed position of the ankle joint (Palastanga et al., 2006).

The anterior deflection might also be achieved by increased knee or hip flexion to move the centre of mass forward. Injury risk might be increased when placing greater reliance on knee or hip strategies to maintain balance, due to changes in muscular recruitment patterns. This interpretation is supported by the observations of Adlerton et al. (2003) who reported a post-fatigue change in postural control strategy, where the habitual strategy changed from ankle to hip following localised muscle fatigue of the calf. The modifications made in the postural control pattern produce compensatory corrections around the joints to maintain functional stability. However, whilst balance performance is maintained, the fatigue-induced alterations in strategy might make the player more susceptible to injury.

The alteration in balance strategy during the latter stages of each half suggests that functional joint stability is impaired during the latter stages of each half. This finding supports epidemiological observations of temporal patterns in ankle sprain incidence during soccer match-play (Woods et al., 2003). The nature of the change in balance strategy, i.e. an inverted ankle that becomes increasingly plantar-flexed during the latter stages of match-play, is also correlated to injury epidemiology. Lateral ankle sprain is a common injury, accounting for 25–50% of all injuries in sports (Balduini, Vergso, Torg, & Torg, 1987) and 17% of soccer injuries (Hawkins et al., 2001). Woods et al. (2003) reported that 77% of all ankle ligament sprain injuries were localised to the lateral complex. An inversion force applied to the foot with the ankle in plantar-flexion was described as a common mechanism of injury to the lateral ligament. This scenario is analogous to cutting manoeuvres and multi-directional jumping inherent in soccer activities.

It is not possible to conclusively state the mechanism driving the change in balance strategy during the latter stages of each half. Fatigued muscles have been shown to exhibit extended latency in firing (Nyland, Shapiro, Stine, Horn, & Ireland, 1994), electromechanical delay (Gleeson, Reilly, Mercer, Rakowski, & Ress, 1998; Zhou, McKenna, Lawson, Morrison, & Fairweather, 1996), and slower muscle reaction time (Wojtys, Wylie, & Huston, 1996). The subsequent impairment of the dynamic stabilising function of muscles is a primary factor in the non-contact aetiology of joint ligamentous injury (Hewett, Lindenfeld, Riccobene, & Noyes, 1999). Skinner, Wyatt, Hodgdon, Conard, and Barrack (1986) referred to a reduction in the ligamento-muscular protective reflex.

5. Conclusion

The temporal pattern of changes in dynamic balance performance throughout a simulated match supports epidemiological findings (e.g. Woods et al., 2003). Whilst stability was maintained, this was seemingly achieved by a change in balance strategy during the latter stages of each half. These stages of the game are therefore when the player is most susceptible to injury. This change in strategy is indicative of impaired functional joint stability, and requires a change in the muscular recruitment about those joints contributing to the balance strategy. The altered coordination of movement may further increase the injury risk.

It is suggested that players perform proprioception drills both in the rested and exercised state, for example after training. This intervention might enable the player to further develop neuromuscular control such that technique might be altered appropriately in reaction to fatigue, and hence move toward a reduction in joint sprain injury incidence.

6. Recommendations for future research

Future research should consider both kinematic and kinetic analyses of the balance task to further investigate the balance strategy used. Analysis of lower-limb joint-angle time histories and electromyographic contributions might elicit greater detail regarding co-ordination of movement and the mechanism behind the apparent change in strategy. The same experimental design could also be applied to greater variety of functional tasks, with increasing specificity toward soccer activities such as cutting and kicking.

The experimental protocol used in the present study was completed on a motorised treadmill, so as to standardise the activity profile given the focus of the study. Future research might consider the use of non-motorised treadmills, and also free-running protocols which allow greater flexibility in replicating the multi-directional demands of soccer locomotion. In addition to the exercise protocol and the functional task, consideration should also be given to the participants used. Provided there is sufficient information available to develop a specific exercise protocol, future research could consider female and youth soccer players. Sample size can be problematic in such studies, depending on the criteria for exclusion in part, but it is acknowledged that a greater subject number would enhance the application of such studies.

The exercise protocol used in the present study, and described in greater detail by Greig et al. (2006) provides a useful model for developing football science. For example, the protocol might be used to investigate the influence of hydration status on balance performance, or on the physiological and mechanical response to soccer-specific intermittent activity. The passive half-time interval might also be altered in an investigation of optimum re-warm-up strategies at half-time.

Ethical Approval

The participants used in this study did so with full and informed written consent. Specifically, both the players and coaching staff from each club were fully informed of the nature and study of the trial, and that they could withdraw from the study at any time.

Ethical approval was granted at both departmental and faculty level.

Conflict of interest statement

All authors associated with submission of this manuscript declare that there are no conflicts of interest. There are no financial or personal relationships with people or organisations which might inappropriately bias the preparation and submission of this manuscript.

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