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ORIGINAL ARTICLE

Effects of an intermittent exercise protocol on ankle control during a single-legged landing

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Abstract

Purpose To identify the effects of fatigue from an exercise protocol (similar to a soccer match) on ankle motion and forces during single-legged drop landing.

Methods Seventeen males aged (mean ± SD) 22.2 ± 2.0 years participated in this repeated measures study. A 90-min intermittent exercise protocol with a 15-min rest at halftime was performed. Before, at halftime and after the exercise, participants were tested via a single-legged drop landing task onto a force platform whilst wearing a three-dimensional inertial measurement system (Xsens). Ankle angles (plantarflexion/dorsiflexion and inversion/eversion) were analysed before landing and at peak ground reaction force after landing, and center of pressure was analysed at peak ground reaction force.

Results No significant differences were found for the outcomes between pre-, halftime and post-exercise ($p > 0.05$).

Conclusions Findings suggest that exercises simulating a soccer match (regarding exertion) do not necessarily lead to significant changes in ankle motion or forces around the ankle.

Keywords Biomechanics · Kinetics · Kinematics · Team sports

Abbreviations

GRF	Ground reaction force
CAIT	Cumberland ankle instability tool
SD	Standard deviation
ESSA	Exercise and sports science Australia
HR	Heart rate
RPE	Rating of perceived exertion
CoP	Center of pressure
CMJ	Counter movement jumps

Introduction

The ankle is highly susceptible to injuries in soccer, with 21% of all injuries being to the ankle joint [1]. Ankle injuries (most commonly sprains) can limit players' physical performance and may have on-going effects after the injury [2], thus prevention of ankle injuries is important in soccer.

Ankle sprains typically occur when the ankle is inverted during plantarflexion [2] and most are reported at the end of each half of a match [3]. This could be due to the increased levels of physical fatigue players experience towards the end of each half of the match [4]. Fatigue seems to reduce passing and shooting abilities [5] of athletes in soccer, and also sprinting performance during soccer matches [6]. Likewise, when muscles are fatigued, a reduced control of the ankle joint is expected [7]. These could be observed as changes in ankle joint angle, torque, power, or ground reaction force (GRF) during dynamic movements such as landing from a jump [8–10]. Furthermore, single-legged landing can impose large loads to the ankle joint [11] leading to loss in balance [9, 12] and injuries [13].

A number of studies showed that when fatigued, ankle dorsiflexion is reduced at landing [14] and at maximum knee flexion after landing [8, 10]. Fatigue also leads to a decrease in GRF after landing [10, 15]. However, these protocols are laboratory based and not specific to the movements performed in a team sport scenario, such as soccer. Therefore, the level of fatigue induced in real world activity may differ from that seen in many previous studies [9]. A better approach could be to replicate the physiological and

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movement demands of team sports using sports specific tasks for the duration of match-play [16, 17]. The intermittent exercise protocol used in the current study has been previously developed and validated by Kingsley et al. [17], and it was shown to replicate the effects of phosphatidylserine on oxidative stress seen in soccer players; the protocol has also been successfully used in other previous studies [16, 18].

Therefore, the aim of the current study was to identify the effects of an intermittent exercise protocol (time and physical exertion replication) on ankle joint motion and external forces during a single-legged drop landing test.

Methods

Study design

This repeated measure study included three time points of data collection, that is, before (pre), during half time (mid), and after (post) an exercise protocol simulating a soccer match. Soccer match comprises of two 45 min playing halves and a 15 min rest interval in between.

Participants

We recruited 17 male recreational athletes for this study (mean ± SD; age 22.2 ± 2.0 years, height 181.0 ± 7.0 cm, weight 79.8 ± 10.0 kg, body mass index 24.5 ± 3.3 kg/m^2). Participants were considered recreational athletes if they were engaged in a team sport (e.g. Australian football, soccer, etc.) and in regular activity (training and/or competition matches) once or twice a week during their respective sporting season. This study was approved by the La Trobe University, institutional ethics review committee in the spirit of the Helsinki Declaration (approval number: HEC16-126 on 10/01/2017) and informed consent was obtained from all participants prior to data collection. Participants were included if they had no physical constrains for exercise as identified via an exercise ESSA, Australia pre-screening tool questionnaire [19]. Participants were excluded if they had previous ankle sprains or any persisting ankle instabilities (identified with the Cumberland Ankle Instability Tool—CAIT score above 25) [20]. They were also excluded if they had pain, injury or had surgery on their lower limb(s) in the previous six months. Furthermore, they were excluded if they were unable to reach a minimum of level 7 in the multistage fitness test.

Procedures

Prior to data collection, participants were asked to attend a familiarization session, in which they were introduced to all measurement tasks, the intermittent exercise protocol and performed the multistage fitness test. A minimum of 72 h recovery was enforced between familiarization and experimental testing to ensure recovery from any fatigue from the previous session (recovery period ranged between 4 and 7 days). In addition, participants were asked to avoid moderate/strenuous activity and to maintain regular dietary habits 24 h before all testing sessions. Furthermore, they were asked to wear sports sneakers during the protocol and data collection.

The multistage fitness test has been previously described by Leger and Lambert [21]. In short, participants completed shuttle runs over a distance of 20 m in time with audio bleeps and continued until the bleeps became too quick for participants to cover the 20 m distance in time. From this test, the fitness level of participants was determined.

For the experimental session, participants wore a heart rate strap (Polar A300, Australia) and to track the lower body motion, seven wireless sensors sampling at 60 Hz (MTw Awinda, Xsens, Netherlands) were placed on each limb at the top of the foot, medial aspect of the lower leg, upper leg and one sensor was placed on the sacrum, according to manufacturer guidelines. These sensors were removed after data collection at pre-exercise (before the intermittent exercise protocol) and replaced and recalibrated for the mid and post-exercise data collection. Force data were simultaneously obtained by a force plate (9286BA; version 5.3.0.7, Bioware, Kistler Instrument Corp, USA) recording at 960 Hz. Motion and force data were off-line synchronized for further analysis using a digital trigger sent by the motion tracking system to the force plate data acquisition board.

Prior to testing, participants performed a 5 min warm up that included two laps of the intermittent exercise protocol. Once warmed up, participants performed three single-legged drop landings per leg from a 20 cm box (Fig. 1) to the force platform which was 25 cm away from the box. They were asked to keep their hands on their waist, balance for 3 s on the supporting limb and jump naturally to land as close to the centre of the force plate as possible [9]. When landing, the non-supporting limb remained in the air and this position was maintained for five seconds after landing (Fig. 1b). Participants performed three trials per limb in a randomized order. The same testing procedures were repeated at mid and post-exercise.

In addition, three counter movement jumps were also performed after the single-legged drop landings. The

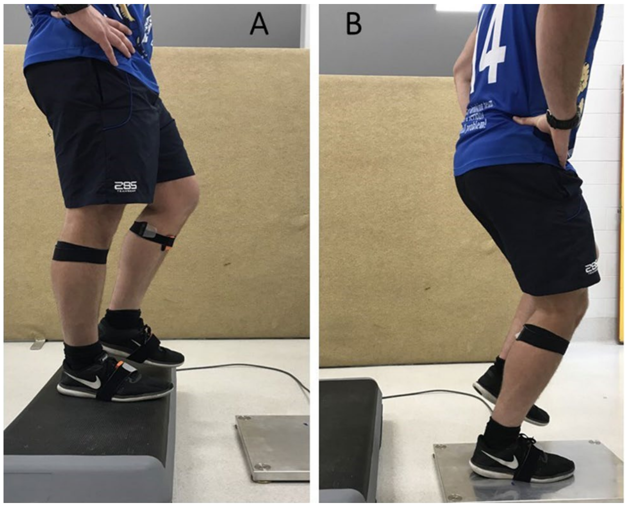


Fig. 1 Single-legged drop landing test. **a** starting position on a 20 cm box; **b** ending position on the force platform

purpose of these jumps was to assess changes in lower limb power and jump height, which is a sensitive tool to assess loss of power due to fatigue [22]. During all pre-testing trials, 1 min of recovery was given between trials.

Intermittent exercise protocol

Once participants completed all pre-exercise testing they started the exercise protocol, which replicated the movements and physiological effort from a soccer match [16, 17]. The protocol consisted of two blocks (first half and second half) of exercise lasting 45 min each, with 15 min rest given between blocks (half time). Each 45 min block consisted of 21 laps over a 20 m distance, containing specific soccer activities through the laps. Specifically, these consisted of three consecutive walks (Fig. 2: A to B, B to A and A to B), one sidewalk (Fig. 2: B to C), one sprint (Fig. 2: C to D), five forward jogs (Fig. 2, D to C), one backward jog (Fig. 2: C to D) and two strides at approximately 85% of maximal oxygen consumption (Fig. 2: D to C and C to D). Participants started the next set of laps at D and repeated the same sequence except where they first performed a sprint they now performed a zigzag run. Movement tasks were dictated by predetermined audio signals playing from a loud speaker.

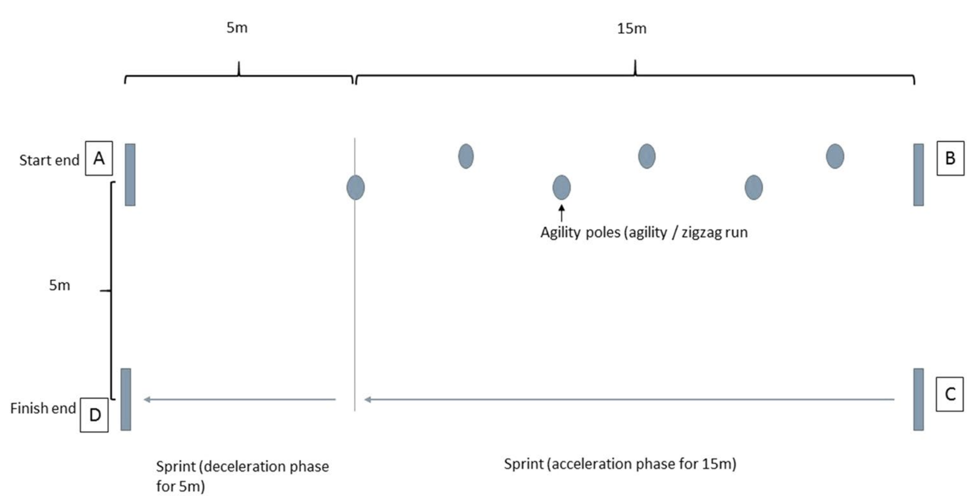
Participants were asked to complete the protocol paced by the audio signals and were frequently informed on the next activity they should complete. The audio signal was paced at the minimal performance level required for inclusion in the study. Specifically, a designated speed equivalent to level 7.1 on the multistage fitness test [21] or a maximal oxygen consumption of 36.8 mL kg^{-1} min^{-1}. Once participants completed three laps, they had a one minute of rest where heart rate (HR) and rating of perceived exertion by RPE; 20 point BORG scale [23] were recorded. To ensure completion of the protocol for the full 90 min, the intensity of the protocol was modified to each participant to ensure all participants could cope with the exertion induced by the protocol and complete both halves. All participants completed the protocol within the allocated time according to the audio signals.

Data analysis

A customized program (R2016b Matlab, MathWorks, Natick, USA) was used to time align joint angle data (computed using ZXY Euler-Cardan sequence) with peak GRF data. Force data are inherently stable and Xsens has built in filters, hence both force and position data were not filtered.

Landing was determined when vertical GRF exceeded 10 N [24] and kinematic variables from ankle position were analysed at 1 frame (16 ms) before landing, 3 frames before landing (50 ms), 5 frames before landing (83 ms) [25] and at peak vertical GRF. Outcomes from kinematics included sagittal (plantarflexion/dorsiflexion) and coronal (inversion/eversion) ankle angles and kinetics included peak GRF in the

Fig. 2 Schematic representation of the exercise protocol



vertical, mediolateral and anterior–posterior planes, as well as center of pressure (CoP) area and anterior posterior CoP displacement calculated for three seconds after landing using the ellipse method [26]. For the counter movement jumps (CMJ), vertical GRF was analyzed to determine the height of the jump using the flight time method [27]. Visual inspection of the motion tracking files was conducted to ensure that participants did not tuck during the jump, which could have affected the predicted height of the jump. A graphical representation of data analysed is presented in Fig. 3

Statistical analysis

Calculation of sample size for a repeated measures design, prior to participant recruitment, suggested that 11 participants were required for this study assuming a mean difference of 1.8° and SD of 2.5° for the measure of inversion position before landing in males (α equal to 0.05, and β equal to 0.8) [28]. The statistical software package SPSS Statistics (version 24; IBM, USA) was used for analysis. Normality was assessed for each segment of data independently. As an example, pre-landing at 50 ms for the right dominant was analysed independently from other segments. Within the ANOVA model, we used the Greenhouse–Geisser correction whenever sphericity was breached. Because only within-subjects factors were analysed, homogeneity of variance was not assessed. Data were normally distributed, therefore we used the mean of the three single-legged drop landing at each time point (pre, mid and post) for each limb, for all outcomes analyzed. Differences between dominant and non-dominant limbs were compared using a two-way (limb vs time factors) ANOVA ($\alpha > 0.05$). Repeated measures ANOVAs were performed across the three time points to compare the effects of the intermittent exercise protocol on kinematic and kinetic outcomes. Post hoc tests (Sidak) were employed whenever main effects were observed ($p < 0.05$).

Results

Participants achieved a mean score (SD) of 10.6 (1.8) on the multistage fitness test. Their HR, RPE and jump height are shown in Table 1. HR increased from 76 bpm (15) to 164 bpm (18) at mid and 166 bpm (18) post-exercise. RPE score increased from 6.3 (1.0) at pre to 15.0 (2.0) at mid and 15.4 (3.0) at post-exercise. Both HR and RPE were significantly increased at mid and post-exercise compared to pre-exercise ($p < 0.01$). Jump height changed from 30.5 cm (5.5) at pre to 29.9 cm (5.3) at mid to 29.8 cm (5.8) post-exercise. There were no differences in jump height at any time point ($p > 0.05$; Table 1).

When comparing results between dominant and non-dominant limbs, there were no differences for any of the outcomes analyzed, therefore, data are presented for the dominant limb only. No significant differences were found at any time point before landing and at peak GRF for ankle joint angles (p ranging from 0.30 to 0.90; Table 2; Fig. 4). For pre-exercise, plantarflexion/dorsiflexion varied from 3.9° (10.2) plantarflexion (16 ms before landing) to 7.5° (11.6) dorsiflexion (50 ms before landing); inversion/eversion varied from 2.2° (8.9) eversion (50 ms before landing) to 4.9° (5.9) inversion (16 ms before landing). For mid exercise, plantarflexion/dorsiflexion varied from 4.5° (10.6) plantarflexion (16 ms before landing) to 9.9° (7.3) dorsiflexion (50 ms before landing); inversion/eversion varied from 0.1° (7.7) eversion (50 ms before landing) to 4.1° (6.2) inversion (16 ms before landing). For post-exercise, plantarflexion/dorsiflexion varied from 3.3° (9.9) plantarflexion (16 ms before landing) to 9.6° (5.5) dorsiflexion (50 ms before landing); inversion/eversion varied from 5.3° (7.0) eversion (83 ms before landing) to 3.4° (8.7) inversion (16 ms before landing). At peak GRF, participants landed with 0.3° (9.1) of plantarflexion and increased to 0.6° (8.1) at mid and 2° (6) post-exercise. At the same point, they landed with an ankle inversion of 2.6° (5.3) pre-exercise and 0.9° (5.8) post-exercise (Table 2; Fig. 4).

No significant differences were found at peak GRF for measured GRF and CoP (p ranging from 0.21 to 0.78; Table 3; Fig. 5). vGRF changed from mean (SD); 3.3 (0.58) xBW to 3.37 (0.48) xBW post-exercise and CoP area changed from 0.01 (0.01)cm^2 before exercise to 0.07 (0.25) cm^2 at mid exercise to 0.01 (0.01)cm^2 post-exercise.

Discussion

Results shown by the current study did not support our hypothesis as ankle angles, GRF and CoP did not change throughout the intermittent exercise protocol, however, some of the results raise some discussion on possible increased range of motion after the exercise protocol. Our study showed that there were no significant changes in ankle angles (plantarflexion/dorsiflexion or inversion/eversion) pre-landing or at peak GRF (Tables 2, 3). No previous work has evaluated the effects of team sports performance on ankle angles immediately prior to initial contact of the foot. This point provides important information in regards to how the foot is prepared prior to landing. Results measured at the peak GRF are in line with Schmitz et al. [9], who investigated biomechanical changes of the lower limbs after a 90 min intermittent exercise protocol. They measured biomechanical variables from initial contact to maximum knee flexion and reported that their exercise protocol did not change the ankle angles or forces. In contrast, other studies which had different fatigue protocols, and were not similar to a soccer match, reported significant main effect from fatigue

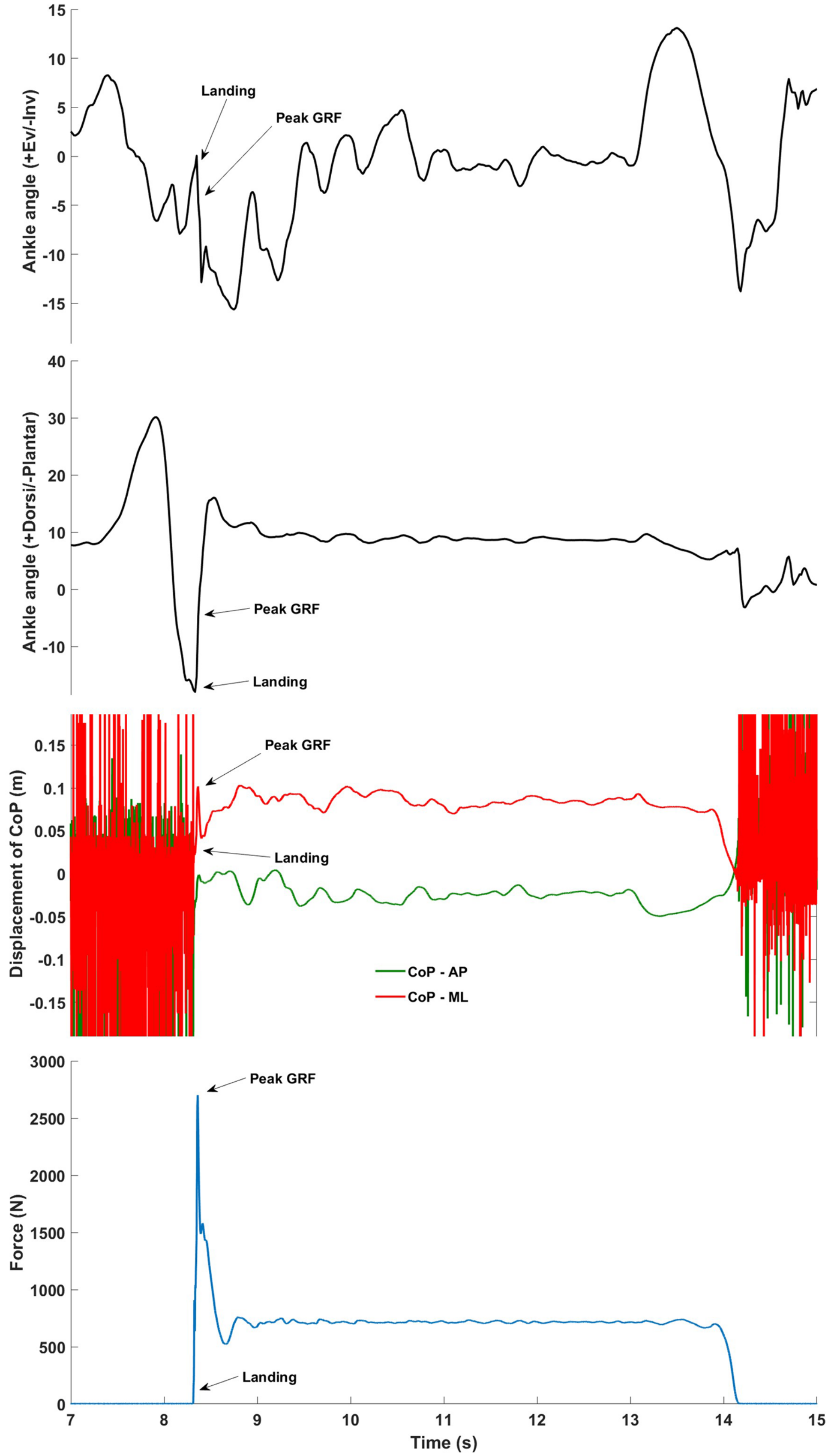


Fig. 3 Graphical representation for each outcome analyzed. Figure also shows time of peak ground reaction force (GRF) and time of landing. From bottom to top figures are GRF (Newtons), centre of pressure (CoP) displacement (m) in anterior/posterior direction (AP) and mediolateral direction (ML), ankle eversion/inversion (degrees), ankle dorsiflexion/plantarflexion

Table 1 Exercise intensity data pre, mid and post in soccer exercise protocol

	Pre mean (SD)	Mid mean (SD)	Post mean (SD)[a]
HR	76 (15)	164 (18)	166 (18)
RPE	6.3 (1.0)	15.0 (2.0)	15.4 (3.0)
CMJ height (cm)	30.5 (5.5)	29.9 (5.3)	29.8 (5.8)

HR heart rate, *RPE* rate of perceived exertion, *CMJ* counter movement jump

[a]Note one participant did not complete the second half ($n = 16$). No significant difference observed between pre, mid and post ($p < 0.05$)

for the dorsiflexion at landing [29]. They assessed landing biomechanics and designed a protocol that fatigued the knee muscles with step-ups and continued until their participants could no longer perform 80% of their maximum hop distance. Therefore, these combined results suggest that team sports performance, as performed in the studies mentioned, does not seem to fatigue the ankle enough to influence kinematics and kinetics during landing.

In our study, GRF did not show any significant change before and after the intermittent exercise protocol (Tables 2, 3). Two previous studies analysed GRF after fatigue in single-legged drop landing [15, 24]. While one study showed increased GRF from 0.3 to 0.5 xBW after fatigue [24], the study by Madigan et al. [15] reported decreased GRF after fatigue (from 3.6 to 3.2 xBW). However, both these studies used shorter and more intense protocols compared to a 90 min intermittent exercise protocol used in the current study. Brazen et al.[24] explained that after fatigue the ability of muscles to absorb forces reduces and leads to increased forces at landing. Whereas, Madigan et al. [15] suggested that landing strategy changes in an attempt to minimize impact forces at landing after fatigue. Furthermore, these studies analysed GRF from initial contact to maximum knee flexion after landing, whereas in the current study, GRF was analysed at the maximum acceleration point after landing (i.e. peak GRF). Therefore, the type of protocol employed seemed to play a key role in how participants fatigued.

Our study found no differences in balance (CoP area and displacement) after 90 min of a intermittent exercise protocol. This finding is in agreement with the study by Greig et al. [30] that analysed balance after a 90-min intermittent exercise protocol, which showed balance did not change. They investigated changes in CoP throughout the protocol and observed that when participants were tired they tended to deviate more towards anterior posterior or mediolateral directions. However, the overall displacement of CoP after 90 min did not change [30]. Therefore, it seems that the central nervous system is capable of controlling balance after 90 min performance of intermittent exercise and it was similar to the findings of the current study.

Vertical jump height did not change after the intermittent exercise protocol, suggesting that at the end of a 90-min intermittent exercise protocol, muscle power was not largely affected by this type of exercise. Our modified protocol aimed to induce both cardiovascular and muscular fatigue through a 90-min soccer match [17] and included running, walking, changing directions and sprinting. However, studies investigating the effect of fatigue on jump performance used different fatiguing protocols to induce fatigue. Some studies used activities to induce local fatigue such as repeated squatting or flexion/ extension of the knee [8, 11, 31], whereas

Table 2 Dominant ankle kinematic data pre-, mid- and post-soccer exercise protocol at 83 (5 frames), 50 (3 frames) and 16 (1 frame) ms before landing, as well as at peak Ground Reaction Force (GRF)

	Mean (SD)			Mean difference (95% confidence interval)		
	Pre	Mid	Post	Pre–mid	Pre–post	Mid–post
Angle 83 ms before landing (°)						
Plantarflexion/dorsiflexion	6.3 (10.5)	8.8 (7.1)	8.3 (6.0)	− 2.5 (− 6.8 to 1.8)	− 1.9 (− 5.9 to 2.1)	0.5 (− 2.6 to 3.7)
Eversion/inversion	1.98 (8.8)	− 0.1 (7.6)	5.3 (7.0)	2.1 (− 1.9 to 6.1)	− 3.4 (− 7.3 to 0.5)	− 5.5 (− 9.1 to − 1.9)
Angle 50 ms before landing (°)						
Plantarflexion/dorsiflexion	7.5 (11.6)	9.9 (7.3)	9.6 (5.5)	− 2.4 (− 7.0 to 2.2)	− 2.1 (− 6.3 to 2.1)	0.3 (− 2.8 to 3.4)
Eversion/inversion	2.2 (8.9)	0.1 (7.7)	4.5 (7.5)	2.7 (− 2.0 to 6.1)	− 2.3 (− 6.3 to 1.7)	− 4.3 (− 0.6 to − 8.1)
Angle 16 ms before landing (°)						
Plantarflexion/dorsiflexion	− 3.9 (10.2)	− 4.5 (10.6)	− 3.3 (9.9)	0.6 (− 5.6 to 7.8)	− 0.6 (− 6 to 6.4)	− 1.2 (− 7.6 to 5.8)
Eversion/inversion	− 4.9 (5.9)	− 4.1 (6.2)	− 3.4 (8.7)	− 0.8 (− 3.8 to 1)	− 1.5 (− 3.4 to 1.4)	− 0.7 (− 2.3 to 3.1)
Angle at peak GRF (°)						
Plantarflexion/dorsiflexion	− 0.3 (9.1)	− 0.6 (8.1)	2.0 (6)	0.3 (− 4.2 to 6.2)	− 1.7 (− 6.1 to 2.9)	− 2.6 (− 7.1 to 1.9)
Eversion/inversion	− 2.6 (5.3)	− 2.6 (5.3)	− 0.9 (5.8)	0.0 (− 3.3 to 2.1)	1.5 (− 4.3 to 1.3)	− 1.5 (− 3.5 to 1.7)

Dorsiflexion and eversion considered a positive angle. No significant difference between pre, mid and post ($p < 0.05$)

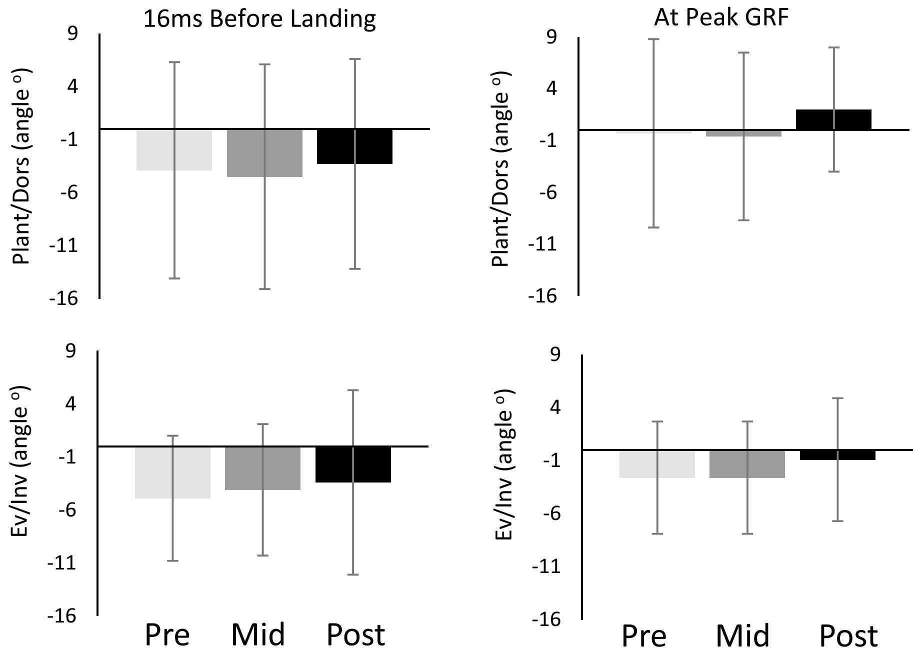


Fig. 4 Ankle position immediately before landing and at Peak ground reaction force (GRF) for the single-legged drop landing test performed pre-, mid- and post-soccer exercise protocol. Ev-eversion; Inv-inversion; Plant-plantarflexion; Dors-dorsiflexion

Table 3 Kinetic data at peak ground reaction force pre-, mid- and post-soccer exercise protocol

	Mean (SD)			Mean difference (95% confidence interval)		
	Pre	Mid	Post	Pre–mid	Pre–post	Mid–post
GRF (xBW) vGRF						
M–L	3.3 (0.58)	3.38 (0.45)	3.37 (0.48)	– 0.08 (– 0.44 to 0.28)	– 0.07 (– 0.44 to 0.3)	0.01 (– 0.32 to 0.34)
	0.17 (0.07)	0.19 (0.08)	0.17 (0.08)	– 0.02 (– 0.07 to 0.03)	0.00 (– 0.05 to 0.05)	0.02 (– 0.06 to 0.06)
A–P	– 0.21 (0.08)	– 0.18 (0.09)	– 0.20 (0.14)	– 0.03 (– 0.45 to – 0.33)	– 0.01 (– 0.49 to – 0.33)	0.02 (– 0.46 to – 0.3)
CoP area (cm^2)	7618.2 (9580.6)	5783.0 (3028.6)	5044.6 (3566.4)	1835.2 (– 3128.8 to 6799.1)	2573.6 (– 2476.8 to 7624.0)	738.4 (– 1573.1 to 3049.9)
CoP displacement (cm) A–P	1.11 (2.3)	– 0.45 (1.74)	– 0.26 (1.76)	0.66 (0.14 to 2.98)	0.85 (– 0.49 to 3.23)	– 0.19 (– 1.89 to 1.51)

No significant difference between pre, mid and post ($p < 0.05$)

vGRF vertical ground reaction force, *M–L* mediolateral direction, *A–P* anteroposterior direction, *CoP* centre of pressure, *CoM* centre of mass

others used the beep test [32]. The use of a intermittent exercise protocol may be a better and more generalizable approach when the intention of the study is to induce physical exertion similar to a real life match. Furthermore, this is more likely to help in understanding the changes that occur as a result of match performance.

For the single-legged drop landing task, some of the findings related to inversion/eversion position prior to landing raised some thoughts for further investigation. While there were no significant differences in inversion/eversion position after correcting for multiple pairwise comparison (Holm's method), the mean difference and 95%CI between mid and post-exercise for 83 ms and 50 ms prior to landing (Table 2) do not cross-zero, which could be an indication of important differences in ankle position after the exercise. At mid exercise, it seems that the ankle had a more close to neutral inversion/eversion position and moved to inversion as landing was approaching (– 0.1°; 0.1°; – 4.1°, respectively). At post-exercise, it seems that ankle position during flight time started from a more everted position and moved through a larger range of motion towards inversion prior to landing (5.3°, 4.5°, – 3.4°, respectively; Table 2). The apparent larger range of motion during flight time post-exercise (from eversion to inversion) could indicate some change in motor control leading to an increased risk of injury. However these same differences were not observed when comparing Pre

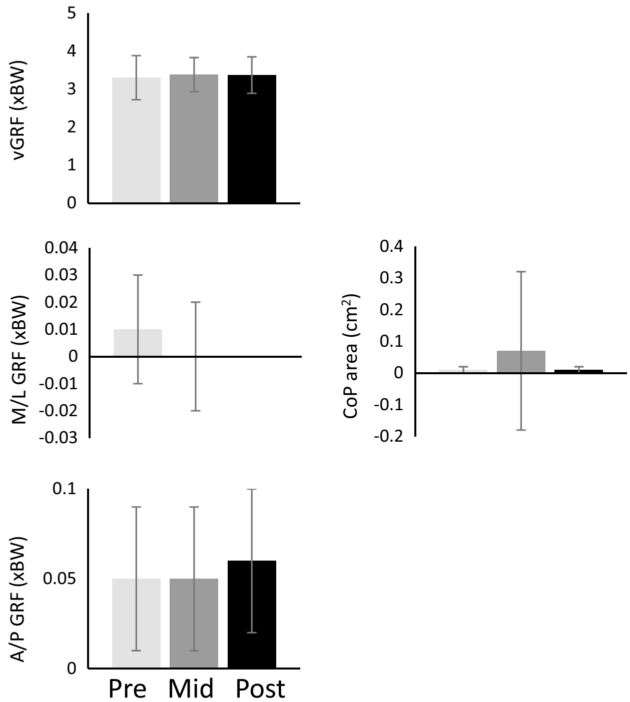


Fig. 5 Ground reaction force (GRF) and Center of pressure (CoP) at peak GRF for the single-legged drop landing test performed pre, mid and post soccer exercise protocol. *A/P* anterior/posterior; *M/L* medio/lateral; *v* vertical; *disp* displacement; *BW* body weight

and Post data, although Pre data seems to be similar to Mid exercise data (Table 2), with some visual difference to Post exercise data. Also, we would like to highlight that as we did not plan to analyse the data this way, some components for such analysis were not collected, therefore, this analysis should be considered in future studies so this possibility can be confirmed or refuted.

Future research should consider tracking the ankle joint during match-play, or simulated match-play, to improve the understanding of ankle behavior. Additionally, there is evidence to suggest that hip and knee angles change with fatigue and future work could include analyses on ankle, knee and hip joints combined, during team sports performance. Also, further understanding of how exercise exertion plays a role in soccer could be explored by analysing moments around the ankle, and perhaps even knee and hip, an analysis we were not able to perform at this stage.

Some limitations were identified in our study. Participants were prescribed a single 'base-level' of the intermittent exercise protocol with timings to ensure recreational athletes could complete the full protocol. Although all participants completed the same number of laps during the protocol, their fitness levels were different (according to the multi stage fitness test). Thus, there is a possibility that some participants would not have reached their maximum exertion levels as excepted. A second possible limitation might be that the height of the drop for the single-legged drop landing test in the present study was not optimum to identify any changes in the ankle. Another limitation is that Xsens sensors had to be removed during the exercise and re-positioned when kinematic data were collected. Ideally, sensors would have stayed on participants to ensure consistency in data collection, however, this was not practical. It is possible that the repositioning of sensors would have created some inconsistency with data collected. Furthermore, we did not collect data related to ankle mobility (ROM) prior to data collection and it is possible different mobility levels would have affected the results.

Implications for clinical practice

Our findings suggest that the soccer exercise protocol performed here for 90 min does not disturb ankle joint control during single-legged drop landing. Clinicians should not expect to easily be able to identify ankle motor control changes as fatigue, similar to a soccer match, increases troughout a match. While some changes might occur, if so, these changes are likely to be very small and unlikely to be easily detectable.

Authors' contributions LRA: conception and design, data collection, analysis and interpretation of data, writing the manuscript. RB: analysis and interpretation of data, critical revision of the manuscript, statistical expertise, supervision. DWTW: conception and design, data collection, critical revision of the manuscript, supervision. NW: conception and design, data collection, analysis and interpretation of data, critical revision of the manuscript, supervision. MN: conception and design, data collection, analysis and interpretation of data, critical revision of the manuscript, supervision.

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Availability of data and materials Unidentified data can be provided under request.

Code availability NA.

Declarations

Conflicts of interest The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

Ethics approval This study was approved by the La Trobe University, institutional ethics review committee in the spirit of the Helsinki Declaration (approval number: HEC16-126 on 10/01/2017).

Consent to participate Informed consent was obtained from all participants prior to data collection.

Consent for publication NA.

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