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Research article

Is Plantar Loading Altered During Repeated Sprints on Artificial Turf in International Football Players?

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Abstract
We compared fatigue-induced changes in plantar loading during the repeated anaerobic sprint test over two distinct distance intervals. Twelve international male football outfield players (Qatar Football Association) completed 6 × 35-m sprints (10 s of active recovery) on artificial turf with their football boots. Insole plantar pressure distribution was continuously recorded and values (whole foot and under 9 foot zones) subsequently averaged and compared over two distinct distance intervals (0–17.5 m *vs.* 17.5–35 m). Sprint times increased ($p < 0.001$) from the first (4.87 ± 0.13 s) to the last (5.63 ± 0.31 s) repetition, independently of the distance interval. Contact area (150 ± 23 *vs.* 158 ± 19 cm^2; -5.8 ± 9.1%; $p = 0.032$), maximum force (1910 ± 559 *vs.* 2211 ± 613 N; -16.9 ± 18.2%; $p = 0.005$) and mean pressure (154 ± 41 *vs.* 172 ± 37 kPa; -13.9 ± 19.0%; $p = 0.033$) for the whole foot were lower at 0–17.5 m *vs.* 17.5–35 m, irrespectively of sprint number. There were no main effects of sprint number or any significant interactions for any plantar variables of the whole foot. The distance interval × sprint number × foot region interaction on relative loads was not significant. Neither distance interval nor fatigue modified plantar pressure distribution patterns. Fatigue led to a decrement in sprint time but no significant change in plantar pressure distribution patterns across sprint repetitions.

Key words: Repeated-sprint ability, plantar loading, pressure distribution patterns, team sports, distance interval.

Introduction

Characterisation of the location and magnitude of plantar loading parameters can help with injury prevention (Rice et al., 2016), rehabilitation (Thomson et al., 2017) and soccer footwear design (Hennig and Sterzing, 2010). In-shoe measurement of plantar loading on the actual field of play (football pitch) allows for the analysis of football-specific movements (Eils et al., 2004; Orendurff et al., 2008), different surfaces (Ford et al., 2006) and different outsole cleat configurations at the foot-shoe-surface interface (Wong et al., 2007).

Greater vertical forces, impact loading rates and peak plantar pressure are known to occur when running in football boots compared to running or training shoes (Carl et al., 2014; Smith et al., 2004). These high peak pressures are focused at the forefoot (*i.e.*, hallux, medial, central and lateral forefoot) during acceleration (Orendurff et al., 2008; 2009). Accordingly, it has been suggested that use of football footwear may augment the risk of developing certain lower limb injuries such as metatarsal stress fractures (Eils et al., 2004; lee and Chung, 2016; Oztekin et al., 2009).

While rare in elite male football, injuries to the 5th metatarsal in particular are problematic and often result in long absences from football (Ekstrand and van Dijk, 2013). Intuitively, muscle fatigue is thought to play a role in the development of metatarsal stress fractures as forefoot loading increases in runners who are in a fatigued condition (Weist et al., 2004). However, football-specific studies investigating fatigue-induced alterations in plantar foot-loading are very rare. In one previous study on elite U19 male football players a performance decrement (~3%) was not associated with any significant alterations in plantar pressure patterns during repeated 20-m sprints with 20-s of recovery (6 total) (Girard et al. 2011c). It is also reported that most of sprint mechanical variables differ between early acceleration (5–10 m) and near top speed (30–35 m) over a repeated-sprint series (12 × 40-m sprints) due to the increase in running velocity; these changes, however, were of similar magnitude with sprint repetitions (fatigue) between these 2 sprint phases (Girard et al., 2011b). To date, it is unknown how plantar loading parameters may change with longer (> 20 m) sprint efforts and less rest (< 20 s) between sprint intervals, likely eliciting greater exercise-induced metabolic disturbances (Saraslanidis et al., 2011), or indeed other fatigue inducing protocols.

The running anaerobic sprint test or RAST is a protocol (6 × 35 m with 10-s rest) commonly used by football teams to assess repeated-sprint ability (RSA) (Zagatto et al., 2009). The RAST leads to substantial alterations in stride mechanics and leg-spring behaviour (Brocherie et al., 2015) and thereby may be an appropriate test for identifying fatigue-induced changes in plantar loading parameters. In a previous study investigating plantar pressure, however, only three steps close to top speed at the end of each of the six, 20-m sprints were analysed (Girard et al., 2011c).

Therefore, the aim of this study was to test the hypothesis that fatigue-induced changes in plantar loading parameters during the RAST differ depending on the distance interval in International male football players. Assessing pressures distribution during the most demanding periods of a game (i.e., succession of intense efforts), as

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performed indirectly here from RAST completion, have important clinical implications for protecting regions of the foot that may be susceptible to injury.

Methods

Participants

After being informed of the potential risks and benefits involved, twelve International male football outfield players (mean ± SD; age 28.3 ± 5.3 years, stature 1.78 ± 0.04 m, body weight 72.4 ± 3.1 kg) belonging to the national 'A' squad of the Qatar Football Association provided their written consent to participate in this study. All players had a minimum of 5 years of experience in the domestic 1st division league (*i.e.*, Qatar Star League), with an average participation of 10-12 h of training and competitive play per week. The experiment was approved by the hospital scientific and Ethics committee and conformed to the current Declaration of Helsinki guidelines.

Experimental set-up

After a standardized warm-up of ~20 min, the participants performed the RAST involving 6 × 35 m straight-line maximal sprints in alternating directions interspersed by 10 s of recovery (Brocherie et al., 2015). After deceleration until a cone placed at 10 m, players jogged back to the starting line and assumed a standing ready position for 2 s before the next sprint. The RAST was conducted between 5 and 7 pm on a third-generation artificial turf indoor football field (FIFA approved for international football; Classic series, 3G, Mondo, Italy), while players were wearing their preferred moulded stud football boots. High reliability ($r = 0.90$) has been reported in young basketball players (Balciunas et al., 2006) or in armed force members (intraclass correlations > 0.65) (Zagatto et al., 2009) using the RAST.

Repeated-sprint ability

Sprinting times were measured to the nearest 0.01 s using dual-beam electronic timing gates (TAC System, TT Sport, Galazzano, Republic of San Marino), which height was adjusted according to the height of the participant's hip and placed at 0, 17.5 and 35 m. Each sprint was initiated from an individually chosen standing position with their leg foot in front, 50 cm behind the first timing gate. RSA was assessed using three scores: the fastest (*i.e.*, initial in all cases) sprint time, the cumulated sprint time (*i.e.*, sum of the six sprints) and the percentage decrement score calculated as {[100 − [(fastest sprint time × 6) / (cumulated sprint times)] ×100} (Girard et al., 2011a).

Instrumentation

Insole plantar pressure distribution was recorded for each sprint using the PedarX Mobile System (Novel GmbH, Munich, Germany). Each pressure insole consists of a 2-mm-thick array of 99 capacitive pressure sensors. After calibration, the insoles were placed bilaterally between the sock and shoe with no other manufacturer's insoles or foot orthotics in place so that the Pedar-X insoles were flat (Spooner et al., 2010). No participants used orthotic supports. The data logger (weight ~400 g) for data storage was in a harness on the players' waist. Plantar pressures were sampled at 100 Hz via Bluetooth technology. Data from the left and right foot were averaged for subsequent analysis. The validity (McPoil et al., 1995) and reproducibility (Kernozek and Zimmer, 2000) of the capacitive sensors in the Pedar-X have previously been reported to be excellent. Importantly, the vertical component of force data obtained by the Pedar in-shoe system correlated well with that obtained by a Kistler force platform with the benefit of being able to capture several footfalls in one trial (Barnett et al., 2001).

Plantar pressure data

A regional analysis of each foot was performed utilizing nine separated "masks" or areas of the foot; *i.e.*, medial and lateral heel, medial and lateral mid-foot, medial, central and lateral forefoot, hallux and lesser toes (Groupmask Evaluation, Novel GmbH, Munich, Germany) (Girard et al., 2007; 2011c). The following parameters were determined for the whole foot and the nine selected regions: maximum and mean force, peak and mean pressure, contact and mean area. Peak force and peak pressure were respectively the maximum force and pressure that occurred in one single sensor during the whole stance phase. The mean force and mean pressure were calculated by summing the forces and pressures in all sensors respectively and dividing by the number of sensors (99). Contact area and mean area were respectively the maximum and average contact area of active sensors during the whole stance phase. In addition, the relative load in each foot region was calculated as the force time integral (area under the force curve) in each individual region divided by the force time integral for the total plantar foot surface (Girard et al., 2007; 2011c). For final analysis, two distinct sprint sections corresponding to the average of all steps within 0–17.5 (acceleration phase; number of steps: 11.5 ± 0.5) and 17.5–35 m (terminal phase; number of steps: 8.8 ± 0.4) distance intervals have been compared.

Statistical analysis

Data are presented as mean ± SD. Two-way repeated-measures ANOVA [(sprint number (trial 1 to 6) × distance interval (0–17.5 m or acceleration phase and 17.5–35 m or terminal phase)] was used to compare plantar loading variables for the whole foot. A three-way repeated-measures ANOVA was performed with sprint number (trial 1 to 6), distance interval (acceleration and terminal phases) and foot region ("mask" 1 to 9) as the repeated factors and the relative load designated as the dependent variable. To assess assumptions of variance, Mauchly's test of sphericity was performed using all ANOVA results. A Greenhouse-Geisser correction was performed to adjust the degree of freedom if an assumption was violated, while post hoc pair-wise-comparisons with Bonferroni-adjusted *P* values were performed if a significant main effect was observed. For each ANOVA, partial eta-squared (η^2) was calculated as measures of effect size. Values of 0.01, 0.06, and above 0.14 were considered as small, medium, and large, respectively. All statistical calculations were performed using the SPSS statistical software V.21.0 (IBM Corp., Armonk, NY). The significance level was set at $p < 0.05$.

Results

Sprint time over the 6 sprints significantly increased (from 4.87 ± 0.13 s for the first sprint to 5.63 ± 0.31 s for the last sprint; $p < 0.001$, $\eta^2 = 0.83$), with a percentage decrement score of 8.6 ± 2.8% (Figure 1). Faster sprint times ($p < 0.001$, $\eta^2 = 0.92$) were achieved on average during the terminal phase (2.31 ± 0.05 s) compared with the acceleration phase (2.97 ± 0.04 s). However, the magnitude of change in time from sprint one to six in the acceleration (13 ± 5%) and terminal (18 ± 6%) phases did not differ ($p = 0.244$, $\eta^2 = 0.11$).

Contact area (150 ± 23 *vs.* 158 ± 19 cm^2; -5.8 ± 9.1%), maximal force (1910 ± 559 *vs.* 2211 ± 613 N; -16.9 ± 18.2%) and mean pressure (154 ± 41 *vs.* 172 ± 37 kPa; -13.9 ± 19.0%) for the whole foot were lower in the acceleration *vs.* terminal phase ($0.005 < p < 0.033$; $0.35 < \eta^2 < 0.53$; Figure 2), irrespectively of sprint number. There were no main effects of sprint number or any significant distance interval × sprint number interactions for any plantar variables of the whole foot (all $p > 0.092$; $0.05 < \eta^2 < 0.13$).

The three-way repeated-measures ANOVA did not reveal significant ($p = 0.779$; $\eta^2 = 0.35$) interaction on relative loads (Figure 3).

Discussion

Overall, RAST induced substantial fatigue levels in International male football players when performed with an exercise:rest ratio of 1:2. RSA protocol involving six sprint bouts but with shorter efforts (20 m) and longer recoveries (20-s) (i.e., exercise:rest ratio of 1:6) is less demanding (Girard et al., 2011c). When five 5-s treadmill sprints were repeated (25 s of rest), running velocity changes calculated from the early acceleration phase (*i.e.*, steps 2-5) were smaller in reference to the other sections analysed (*i.e.*, steps 7-10 or 12-15) (Girard et al., 2015). In the current study, a similar trend, albeit not significant (large effect sizes), in sprint time increase for the acceleration (~13%) and terminal (~18%) distance interval was found with fatigue, *i.e.*, from trial 1 to 6.

Plantar loading analysis revealed significant lower contact area, maximum force and mean pressure (-5.8 ± 9.1%, -16.9 ± 18.2% and -13.9 ± 19.0%; all $P < 0.05$) values for the whole foot for acceleration (0–17.5 m) compared to terminal (17.5–35 m) phases, due to the increase in running velocity. Compared to faster velocity (17.8 ± 1.4 km/h), it has previously been reported that maximum force (-12.3%) and peak pressure (-15.1%) are lower while jogging (11.2 ± 0.9 km/h) on a treadmill at constant velocity (Fourchet et al., 2012). When twelve 40-m sprints (30 s of rest) were completed, most of the ground reaction force-related parameters increased with running velocity from 5–10 m to 30–35 m sprint sections, whereas contact time, step frequency, and vertical and leg stiffness were lower (Girard et al., 2011b). Importantly, no significant interaction was found here between sprint number and distance interval for any loading parameter. The aforementioned differences in selected plantar loading parameters beneath the foot (contact area, maximum force and mean pressure) at distinct distance intervals occurred regardless of the players' fatigue. Such apparent unchanged ability of the body to absorb loading observed across sprint repetitions extends previous observations obtained during a series of six 20-m sprints (20 s of rest) in a cohort of under-19 footballers (Girard et al., 2011c).

In the current study, in-shoe pressure insole was employed to provide more detailed information of plantar loads on the different foot regions. In line with previous observations (Girard et al., 2011c), typical plantar pressure patterns during repeated sprinting in football players indicate that the highest relative loads values are measured under the medial, lateral and central forefoot as well as the hallux and lesser toes. It is known that different surfaces

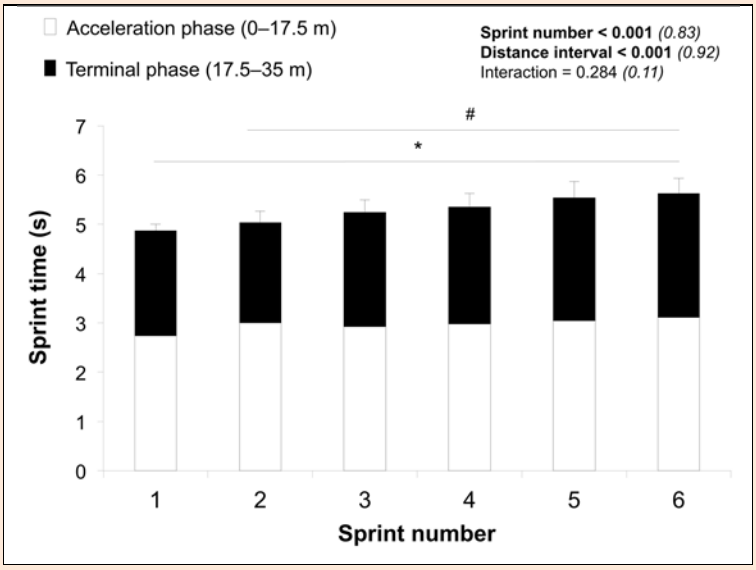

Figure 1. Changes in sprint times over the six repetitions of the repeated-sprint anaerobic sprint test. Data at the 0–17.5 m (white) and 17.5–35 m (black) distance intervals (acceleration and terminal phases, respectively) are presented. Values are mean ± SEM. * significantly ($P < 0.05$) different between the two intervals. # significantly ($P < 0.05$) different from sprint number 1.

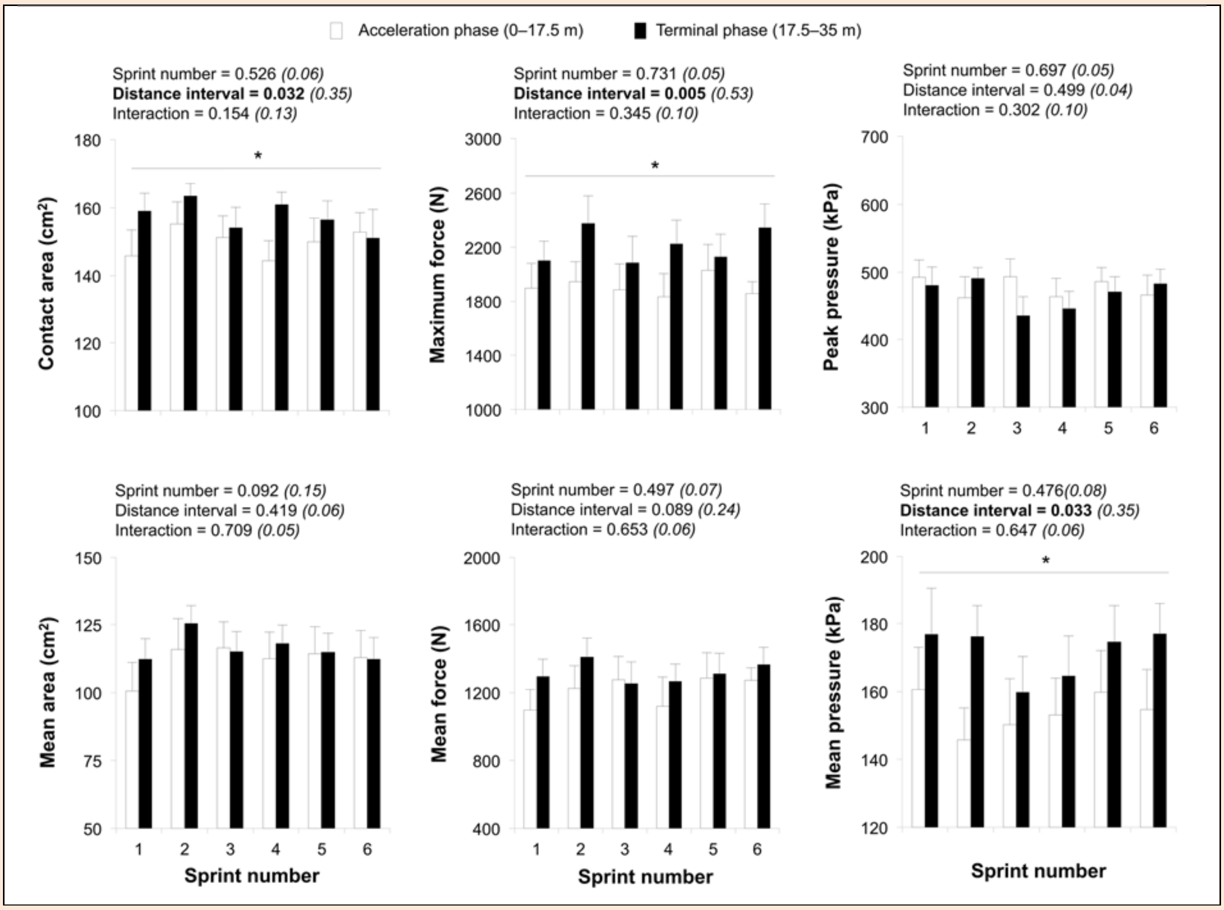

Figure 2. Plantar loading parameters for the whole foot over sprint repetitions at the 0–17.5 m (white bars) and 17.5–35 m (black bars) distance intervals (acceleration and terminal phases, respectively). Values are mean ± SEM. * significantly ($p < 0.05$) different between the two intervals.

(natural grass vs. synthetic turf) (Ford et al., 2006), cleat types and/or numbers (Wong et al., 2007), as well as variations in acceleration abilities (sprinting velocities) and foot-strike patterns between tested individuals and their anthropometric characteristics or playing background (amateur developing vs. professional adult players) (le Gall et al., 2010) could potentially modify the distribution of plantar loads. This might, in turn, explain why higher total load values under heel and midfoot areas (~35% vs. 20%) were recorded here as compared to the study by Girard et al. (2011c).

It has been reported that relative load under the medial and central forefoot regions is higher while jogging *vs.* running (+6.7% and +3.7%, respectively) at steady velocities at the expense of reduced relative load under the lesser toes (-8.4%) (Fourchet et al., 2012). In the current investigation, no noticeable difference in plantar loading distribution patterns was found during accelerated runs between the two intervals of distance, while running velocity (as derived from split times) differed substantially. In reference to steady velocity running, even if it is relatively fast, completing "all-out" short sprints typical to football game (*i.e.*, straight sprinting often precedes goal situation for strikers) (Faude et al., 2012) is characterized by more forward trunk lean, forefoot predominant contact area and increased propulsive force by the lower extremities (Orendurff et al., 2008; 2009). Overall, different phases of the sprint run are likely to similarly load specific plantar regions (*i.e.*, medial, central and lateral forefoot as well as hallux and lesser toes). This occurred despite larger maximum force and mean pressure values for the whole foot associated with shorter sprint times during the terminal phase of the 35-m sprint.

We have previously argued that fatigue of a 6 × 20-m (20 s of rest) RSA protocol may have not been large enough (percentage sprint decrement score of ~3%) and therefore that tested players may have not reached a condition where meaningful plantar loading changes could be observed (Girard et al., 2011c). Despite substantial fatigue levels (percentage sprint decrement score of ~9%) experienced by our professional football players, we also fail to reveal a significant shift of plantar pressures across repetitions in this study, presumably due to the already high loads measured on the front foot surface. Whatever the exact reason, at least under the circumstances of the present study, we demonstrated that sprint repetitions had no detrimental influence on plantar loading distribution. Contrastingly, previously studies showed that increased relative loads under the medial forefoot (+7.2-9.5%), pointing a greater foot pronation, is a common fatigue occurrence associated with the completion of high-intensity runs above the anaerobic threshold for ~10-30 (Fourchet et al., 2015; Garcia-Perez et al., 2013; Weist et al., 2004). Cumulative loads experienced by long-distance

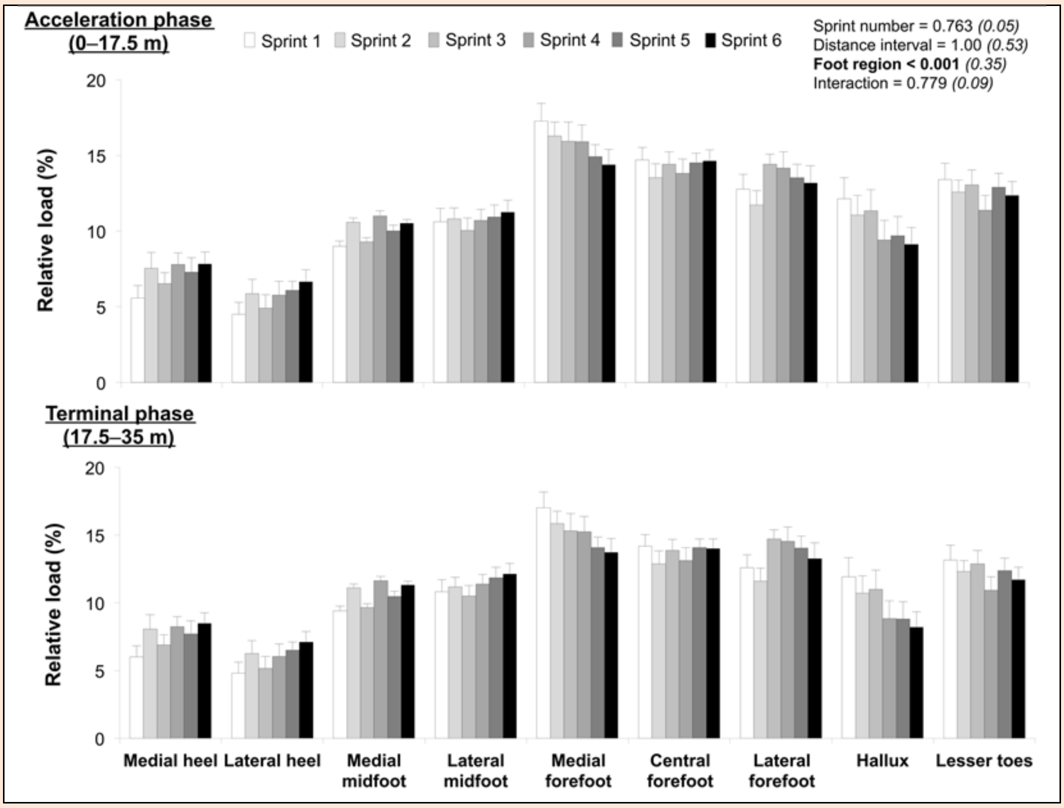

Figure 3. Relative load for each foot region over sprint repetitions at the 0–17.5 m (top panel) and 17.5–35 m (bottom panel) distance intervals (acceleration and terminal phases, respectively). Values are mean ± SEM. Note that for improved clarity post hoc results for main effect of foot region are not displayed.

runners are also known to alter plantar pressure, with reports of augmented forefoot loading at the expense of reduction in heel toes regions after 20-km (Willems et al., 2012) and marathon (Nagel et al., 2008) runs. The absence of increased loading under the forefoot areas during RAST completion (accelerated runs), including on average a total of only ~120 ground contacts, compared to the aforementioned literature including a greater number of foot impacts (> 500) yet at sub-maximal, steady-state intensity highlights the task-dependency of fatigue effects. Finally, as evidenced by the lack of a significant interaction for relative loads between sprint number, distance interval and foot region, we add the interesting observation that neither distance interval nor sprint number provoke any shift in the plantar loading distribution.

With an identical number of completed “all-out” efforts (6 sprints) for all participants in a typical heterogeneous group of team-sport athletes (*i.e.*, forwards have better RSA than defenders and midfielders) (Aziz et al., 2008), sprint times and percentage sprint decrement score values (5-15%) displayed a wide range, indicating a high inter-individual variability in RSA. Plantar loading was measured at different running velocities for each participant as reflected by large variability in plantar pressure parameters, which in turn may have reduced our ability to detect significant differences when comparing means. Individualizing the sprint dose, for instance by requiring participants to perform the number of sprints necessary to reach a target level of performance decrement, may substantially reduce inter-subject variability in performance decrement (Morin et al., 2011). Such an approach would enable a more standardized state of fatigue between individuals to successfully detect plantar pressure differences according to fatigue or sprint interval studied during RSA protocols.

Since high plantar loading has been measured during football-specific movements (*e.g.*, cuttings and jumping) (Orendurff et al., 2008), future research could investigate potential changes in plantar loading during repeated-agility protocols that are even more specific to football. While the present sample size (n=12) may appear relatively low, it must be recognized that we only recruited professional football players, all belonging to the same national team. In the future, a recruitment strategy involving multiple elite football academies would be required to significantly increase the sample (Di Mascio et al., 2015). Finally, a careful control of extrinsic factors (*i.e.*, ground, shoes) (Carl et al., 2014; Ford et al., 2006) during training involving long (> 20 m) sprints, as well as recommendations for orthotic use and foot musculature strengthening exercises (Fourchet et al., 2011) may help reduce excessive foot overload and risk of overuse injuries such as fifth metatarsal stress or acute fractures commonly reported in professional football (Orendurff et al., 2009; Oztekin et al., 2009).

Conclusion

In summary, fatigue inducing protocol completion by male International football players on artificial turf led to substantial lengthening in sprint times across repetitions. Differences in plantar loading (whole foot) occurred between the acceleration and terminal phases of each 35-m sprint, but were independent from sprint repetitions. Fatigue led to a decrement in sprint time but no significant change in plantar pressure distribution patterns across sprint repetitions.

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Key points

- Fatigue inducing protocol completion by male international football players on artificial turf led to substantial lengthening in sprint times across repetitions.
- Differences in plantar loading (whole foot) occurred between the acceleration and terminal phases of each 35-m sprint, but were independent from sprint repetitions.
- There was no significant change in plantar pressure distribution patterns across sprint repetitions.

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