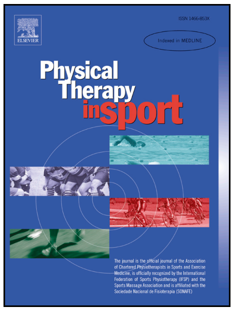

The biomechanical and physiological response to repeated soccer-specific simulations interspersed by 48 or 72 h recovery

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ABSTRACT

Purpose: To assess the residual fatigue response associated with the completion of two successive soccer-specific exercise protocols (SSEP). ***Methods:*** Twenty male soccer players were pair-matched before completing SSEPs, interspersed by either 48 or 72 h. Outcome variables were measured every 15 mins, and comprised uni-axial measures of PlayerLoad, mean (HR) and peak heart rate (HR_{peak}), blood lactate concentration, mean and peak ($\dot{V}O_{2peak}$) oxygen consumption, and rating of perceived exertion (RPE). ***Results*****:** **N**o significant (*P*>0.05) group interactions were identified for any outcome variables. Uni-axial (and total) PlayerLoad exhibited a significant (*P*<0.05) main effect for time, with the exception of the relative contribution of medial lateral PlayerLoad. Total PlayerLoad during the final 15mins (222.23 ± 15.16 a.u) was significantly higher than all other time points. All other outcome variables also exhibited a significant main effect for time, with HR, HR_{peak} and $\dot{V}O_{2peak}$ also exhibiting significantly higher values in the first trial. There was also a significant (*P*=0.003) trial*time interaction for RPE. ***Conclusions*****:** With equivalence at baseline, there was no difference in the fatigue response associated with two SSEPs interspersed by either 48 or 72 h recovery. The current study has implications for the design and micro management of training and competition schedules.

Key words: Fixture Congestion, Physiology, Biomechanics, PlayerLoad

HIGHLIGHTS

- Standardised protocols (SSEP) can be used to simulate short-term fixture congestion
- Two SSEPs were interspersed by 48 or 72 h recovery.
- A number of physiological and mechanical measures were recorded during the SSEPs
- There was no difference in the fatigue response associated with two SSEPs
- These data have implications for the design and management of activity schedules

INTRODUCTION

Fixture congestion is a contemporary concern within soccer (Carling et al., 2015) with implications for performance (Odetoyinbo, Wooster & Lane, 2007; Carling, Le Gall & Dupont, 2012; Rollo, Impellizeri, Zago & Laia, 2014) and injury risk (Dupont, Nédélec, Mccall, Mccormack, Berthoin & Wisloff 2010; Ekstrand, Hägglund & Waldén, 2011; Nédélec, Mccall, Carling, Legall, Berthoin & Dupont, 2013, Dellal, Lago-Peñas, Rey, Chamari & Orhant 2015). The most successful teams are often required to compete in the largest number of competitions (Dupont et al., 2010), with the 2015 UEFA Champions League winners playing in 60 matches across the 2014-2015 season. Due to the high frequency of matches associated with modern soccer (Krustrup, Mohr, Steensberg, Bencke, Kjaer & Bangsbo, 2006; Nédélec et al., 2013), players are often required to compete with only two to three days recovery (Rollo et al., 2014; Carling et al., 2015; Dupont et al., 2010; Dellal et al., 2015). Previous fixture congestion literature has identified no differences in physical performance when successive matches are performed with a minimum of 72 h recovery (Folgado, Duarte, Marques & Sampaio, 2015). However, periods of fixture congestion also appear to expose players to increased risk of injury when successive matches are interspersed by less than 96 h (Dupont et al., 2010; Dellal et al., 2015), thus suggesting an issue with mechanical and muscular recovery. At both elite and sub-elite levels, a minimum of 48 h is typically allowed between subsequent matches (Odetoyinbo et al., 2007).

The physical response to (Mohr et al., 2003; Krustrup et al., 2006) and the time course of recovery from a single bout of soccer-specific activity (Ispirlidis et al., 2008; Magalhäes, Rebelo, Oliveira, Silva, Marques, and Ascensão, 2010) has been well considered, but not the physical response associated with successive bouts of soccer-specific activity. The majority of literature associated with fixture congestion in soccer has typically used time motion analyses to assess the physical fatigue response (Odetoyinbo et al., 2007; Carling, Orhant & Legall, 2010; Dupont et al., 2010; Carling et al., 2013; Dellal et al., 2015; Folgado et al., 2015;). Although soccer match-play offers high ecological validity, there are restrictions on data collection Stølen, Chamari, Castagna & Wisløff, 2005; Rollo et al., 2014) and matches are susceptible to contextual factors (Rollo et al., 2014). As such, previous literature has often reported equivocal findings in relation to the impact of short-term fixture congestion on injury risk and performance. It has, therefore, recently been suggested that standardised soccer-specific exercise protocols (SSEP) could provide a unique opportunity to assess the physical mechanisms associated with repeated bouts of soccer-specific activity (Carling et al., 2015). In relation to the current study, assessment of physical mechanisms is considered in relation to both the physiological and mechanical response.

Recently, in an attempt to quantify the physical demand associated with intermittent team sports, PlayerLoad^{TM} data has been calculated from tri-axial accelerometer function of Catapult (Catapult Innovations, Scoresby, Australia) GPS devices (Boyd, Ball & Aughey, 2011; Scott, Lockie, Knight, Clark & Janse De Jonge, 2013; Barron, Atkins, Edmundson & Fewtrell, 2014). The high sample rate (100 Hz) of the accelerometer in relation to the GPS (typically 5-10 Hz), and the capacity to measure movement in three planes, provides scope to further evaluate the mechanical response to exercise (Barrett, Midgley & Lovell 2014). The International Football Association Board (IFAB) has also recently approved the use of GPS technologies during competitive matches, thus allowing a method of assessing the within-match physical fatigue response. Based on previous literature (Barrett et al., 2014; Page, Marrin, Brogden & Greig 2015), PlayerLoad^{TM} appears to be sensitive enough to detect fatigue induced differences in movement efficiency during the completion of soccer-specific activity, and may therefore offer an additional and novel opportunity to detect temporary, cumulative, and residual physical fatigue during periods of short-term fixture congestion.

Given the potentially detrimental effects associated with periods of short-term fixture congestion, the aim of this current study was to quantify the physical fatigue response associated with two successive SSEPs interspersed by 48 h or 72 h recovery, relevant to the demands of the modern player. It was hypothesised that there would be a significant residual mechanical fatigue response when two successive SSEPs were interspersed with 48 h recovery, but not following a 72 h recovery period. It was also hypothesised that there would be no significant residual physiological fatigue response observed during a second SSEP when compared to a first SSEP completed 48 or 72 h previously.

METHOD

Participants

Twenty male semi-professional soccer players volunteered to complete this study during the English competitive soccer season. The physical and anthropometrical characteristics of the participants are shown in table 1. The inclusion criteria specified that players demonstrated the capacity to complete a 30 min familiarisation sessions specific to the SSEP, were outfield players, and were injury free for a minimum of 6 months prior to testing. Additional to weekly matches, the participants were also required to have completed typical training volumes equating to > 4 $h \cdot wk^{-1}$ during the preceding soccer season. All participants were paid semi-professional soccer players competing in the fifth tier of English football.

Prior to the start of each experimental trial, participants were required to undergo a comprehensive health screening procedure to further assess the participant’s eligibility and also highlight potential risks. The comprehensive health screening procedure was completed by the lead researcher and comprised a health, physical activity, and pre-exercise control questionnaire. Both heart rate and blood pressure were also measured (Omron, Mx3 plus, Netherlands), values of > 90 $b \cdot min^{-1}$ and > 140 mmHg / 90 mmHg respectively were contraindications to exercise. Participants were informed of the risks and procedures involved in testing and were required to provide written informed consent prior to the commencement of the study. The experimental protocol was previously approved by the local university ethics committee and conformed to the Declaration of Helsinki. All equipment was risk assessed and calibrated in accordance to the manufacturers guidelines prior to testing commencing.

Experimental Design

A between-subjects matched-pairs design was utilised, with participants being matched for: age, playing position, height, mass, and the physical response to a 30 minute familiarisation trial. Independent T-tests were conducted for all measures reported in table 1, with no significant differences being observed between the two groups (*P* values ranged between 0.24 to 0.94). Thereafter, one participant from each pair was randomly assigned to the 48 h recovery group (*N* = 10) and one to the 72 h recovery group (*N* = 10).

Table 1. The physical and anthropometrical characteristics of the two groups (48 h and 72 h), and the physical response to a 30 minute familiarisation trial.

	Groups	
	48hr (*N* = 10)	72hr (*N* = 10)
Age (years)	22.10 ± 2.69	21.60 ± 2.12
Height (cm)	176.63 ± 5.80	179.82 ± 6.17
Mass (kg)	74.47 ± 5.68	77.44 ± 8.21
Average HR (beats·min^{-1})	146 ± 14	142 ± 11
Peak HR (beats·min^{-1})	162 ± 13	157 ± 12
Average Vo$_2$ (ml·kg^{-1}·min^{-1})	33.71 ± 2.11	32.71 ± 2.65
Peak Vo$_2$ (ml·kg^{-1}·min^{-1})	45.92 ± 3.53	45.79 ± 4.40
Bla (mmol·L^{-1})	2.2 ± 0.7	2.2 ± 1.0
PlayerLoad^{TM} (a.u)	209.13 ± 10.59	205.58 ± 12.88
RPE (a.u)	10 ± 1	11 ± 2

Participants were required to attend the laboratory on three occasions to complete a familiarisation trial followed by two experimental trials. A minimum of 96 h interspersed the familiarisation trial and the start of the first experimental trial. Thereafter, the participants then completed the second experimental trial following their prescribed recovery duration (48 h or 72 h). The familiarisation trial comprised 2 x 15 min bouts of the SSEP. The experimental trials consisted of the completion of two identical treadmill based SSEP (Page et al., 2015). The SSEP was utilised to ensure mechanistic rigour by standardising both the locomotion and speed profile performed by the participants. By ensuring each bout of activity was standardised between trials, any observed differences in the dependant variables were attributable to the different recovery durations (48 h vs. 72 h) and not due to differences in speed profiles performed across the two trials. It was identified that although free-running SSEPs may offer increased ecological validity when compared to treadmill-based protocols, free-running SSEPs do not typically standardise the running speeds performed by the participants and, consequently, this makes it more difficult to mechanistically interpret the differences in the physical fatigue response. The SSEP was based on notational analysis of match-play incorporating six locomotion categories (Mohr et al., 2003). The protocol was developed to replicate the clustering of high intensity efforts interspersed with low intensity activity as observed during match-play (Spencer, Lawrence, Rechichi, Bishop, Dawson & Goodman, 2004). Figure 1 provides a schematic representation of the velocity profile associated with a 15 min bout, and this exercise bout was repeated 6 times across each 90 min test, with a 15 min passive rest period interspersing the 3rd and 4th bouts to simulate half-time (HT). Due to the restraints of the treadmill, backwards running was integrated with low intensity running at a velocity of 11.6 $km \cdot h^{-1}$, and the maximal sprints were assigned a velocity of 25 $km \cdot h^{-1}$. Furthermore, the maximum treadmill acceleration (and deceleration) of 1.39 $m \cdot s^{-2}$ was applied to each change in velocity. The SSEP's were also conducted with varying levels of gradient to help account for the lack of air resistance associated with laboratory testing (Jones & Doust, 1996). The velocity profile results in a total distance covered of 12.16 km, which is towards the upper end of the average total distance covered in a competitive adult match (Stølen et al., 2005).

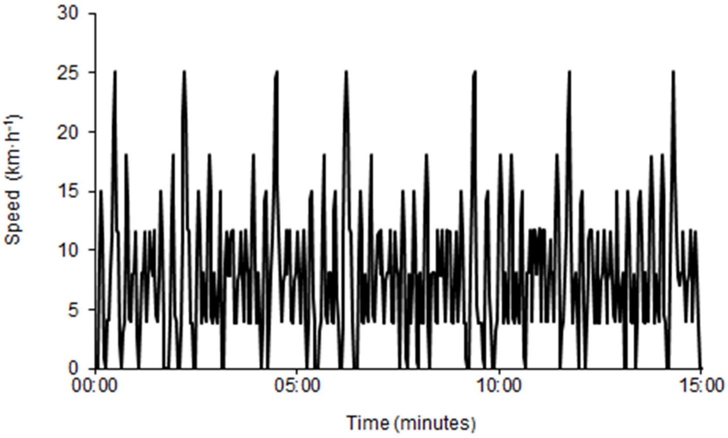

Figure 1. Schematic representation of a 15 min bout of the SSEP

In an attempt to control for circadian variation, all experimental trials were completed in accordance with the participants regular training times (Rae, Stephenson & Roden 2015). All trials were conducted in an ambient controlled environmental chamber with temperature and humidity maintained at 21 ± 0.5 °C and 35 ± 1.5 % respectively. For all studies, participants were required to consume a minimum of 500 ml of water 2 h prior to testing, refrain from consuming caffeine 24 h prior to all experimental trials, and attend the laboratory on each occasion in a 3hr post-absorptive state following a 48 h period of abstinence from vigorous exercise, the use of recovery strategies, and alcohol. Participants were also asked to wear similar apparel and the same running shoes for each trial.

Experimental procedures

Prior to each experimental trial, a portable refractometer (Osmocheck, Vitech Scientific, West Sussex, UK) was used to ensure participants were euhydrated (urine osmolality of

<700 mOsm/kgH_2O). During the completion of the SSEP, participants were required to wear a face mask associated with a portable metabolic analyser. Participants were therefore only able to consume water pre-trial, during the HT period, and post-trial. No alternative drinks or foods were allowed to be consumed during any of the experimental trials. During the experimental trials, only one male researcher and the participant were present. Previous research has identified that performance, perceptions of effort, and physiological response may be influenced by both the gender (Winchester et al., 2012) and the number (Rhea, Landers, Alvar & Arent, 2003) of observers. Prior to each trial, participants were also required to complete a standardised treadmill based intermittent warm-up followed by a period of self-directed stretching. The warm-up consisted of the completion of prolonged ad hoc distributions of different locomotion categories and, was designed to replicate the intensities, durations, and distributions of speed changes associated with a pre-match warm up routine (Greig, McNaughton & Lovell 2006).

Global positioning system based (MinimaxX, S4, Catapult Innovations, Scoresby, Australia) accelerometry (Kionix KX94, Kionix, Ithaca, New York, USA) was recorded at 100 Hz to quantify tri-axial PlayerLoad^{TM} (PL_{total}). Tri-axial PlayerLoad^{TM} is expressed as the square root of the sum of the squared instantaneous rate of change in acceleration in each of the three movement planes (Boyd et al., 2011). To reduce movement artefact the GPS device was housed in a standardised neoprene vest (Catapult Innovations, Scoresby, Australia) at the cervical region of the spine. Accelerometry data was recorded for the duration of each experimental trial, and was retrieved post-testing using the Catapult Sprint software (Version 5.0.9.2; Firmware 6.75). Uni-axial PlayerLoad^{TM} was also quantified in the medial-lateral (PL_{ML}), anterior-posterior (PL_{AP}) and vertical (PL_V) movement planes for each 15 min bout of the SSEP's. The relative contributions of each uni-axial PlayerLoad^{TM} vector to PL_{total} ($PL_{ML\%}$, $PL_{AP\%}$, and $PL_{V\%}$) were also quantified. Total PlayerLoad^{TM} has been shown to possess good test-retest (Barrett et al., 2014), and both between and within-device reliability (Boyd et al., 2011). Moreover, PL_{Total} has also been shown to possess good convergent validity with measures of exercise intensity (Barrett et al., 2014).

During the completion of the SSEP, the participants were continuously fitted with a a breath by breath portable metabolic analyser (Cosmed K4, Rome, Italy) and a heart rate monitor (Polar, Team system, Finland) to quantify values for mean ($\dot{V}O_{2mean}$) and peak oxygen consumption ($\dot{V}O_{2peak}$), and both mean (HR_{mean}) and peak (HR_{peak}) heart rate respectively. Finger-tip capillary blood lactate concentrations (BLa; Lactate Pro, LT-1710, Arkray, Kyoto, Japan) and ratings of perceived exertion ([RPE] Borg, 1970) were also measured during each experimental trial. In addition to RPE, all physiological variables were recorded at rest following a 15 min period of supine rest and following the completion of each 15 min bout of SSEP. Blood lactate concentrations were also measured following the 15 min HT period. The physical measurements were chosen to replicate those commonly used to monitor fatigue and training load within an applied sport setting (Halson, 2014).

Statistical analyses

Statistical analyses and the variables that were to be included were decided *a priori*. The assumptions associated with a repeated measures general linear model (GLM) were assessed to ensure model adequacy. To assess residual normality for each dependant variable, q-q plots were generated using stacked standardised residuals. Scatterplots of the stacked unstandardised and standardised residuals were also utilised to assess the error of variance associated with the residuals. Mauchly's test of sphericity was also completed for all dependent variables, with a Greenhouse Geisser correction applied if the test was significant. The aforementioned physical measures did not violate any of the assumptions, and therefore inferential analyses were performed. Inferential analyses were performed using a mixed method three-way (group*trial*time) repeated measure general linear model (GLM) to examine differences in the physical response between the two groups (48 h vs. 72 h of recovery), the two trials, and over time. Where significant main effects or interactions were observed, post hoc pairwise comparisons with a Bonferonni correction factor were applied. Where appropriate, 95% CI for difference were also presented. To help enable the reader to identify substantive significance associated with significant main effects and interactions, partial eta squared (η^2) values were calculated to estimate effect sizes for all significant main effects and interactions. Partial eta squared is classified as small (0.01 to 0.059), moderate (0.06 to 0.137), and large ($\geq$0.138) (Richardson, 2011). All statistical analysis was completed using PASW Statistics Editor 22.0 for windows (SPSS Inc, Chicago, USA). Statistical significance was set at $P \leq 0.05$. All data is reported as mean ± SD unless otherwise stated.

RESULTS

Mechanical responses

In relation to the mechanical fatigue response associated with the two groups, the GLM identified that there were no significant group*trial*time ($P > 0.05$), group*time ($P > 0.05$), nor group*trial ($P > 0.05$) interactions for any of the PlayerLoad^{TM} measures.

There was also no significant trial*time ($P > 0.05$) interactions for any of the mechanical measures.

As illustrated in figures 2 and 3, the GLM identified a significant main effect for time for the PL_{total} data ($P < 0.001$, $\eta^2 = 0.58$), PL_{AP} ($P < 0.001$, $\eta^2 = 0.19$), PL_{ML} ($P < 0.001$, $\eta^2 = 0.37$), PL_V ($P = 0.002$, $\eta^2 = 0.19$), $PL_{V\%}$ ($P < 0.001$, $\eta^2 = 0.59$) and $PL_{AP\%}$ ($P < 0.001$, $\eta^2 = 0.64$). There was however no significant ($P = 0.76$) main effect for time for the $PL_{ML\%}$ data, with average values consistent at 22.87 ± 1.56 %. Post hoc pairwise comparisons associated with the main effects for time are illustrated in table 2. The GLM also did not identify any significant ($P > 0.05$) main effects for trial for any of the PlayerLoad^{TM} measures.

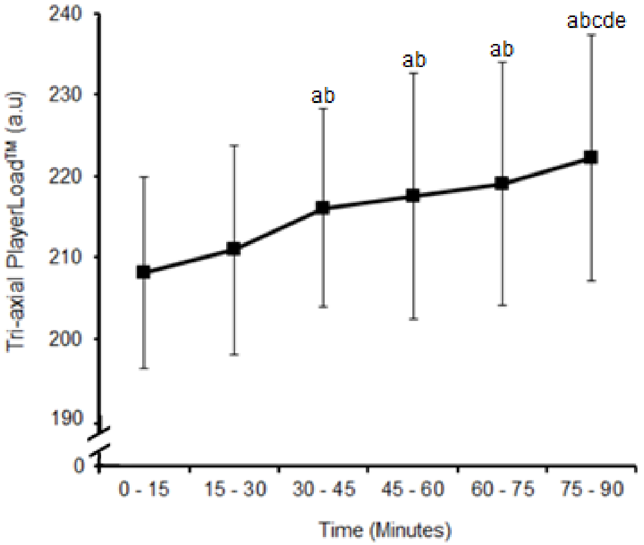

Figure 2 Time history of changes (irrespective of group or trial) in the PL_{total} data. $^{a, b, c, d, \text{ and } e,}$ denote significant differences from 0-15 mins, 15-30 mins, 30-45 mins 45-60 mins, 60-75 mins and 75-90 mins, respectively.

Table 2 Temporal fatigue response (irrespective of trial and group) associated with the tri-axial accelerometry data

Time (mins)	PL_{Total} (a.u)	PL_{V} (a.u)	PL_{ML} (a.u)	PL_{AP} (a.u)	$PL_{AP\%}$ (%)	$PL_{V\%}$ (%)
0-15	208.08 ± 11.77	107.41 ± 9.62	47.28 ± 5.36	54.12 ± 7.01	26.07 ± 3.35	51.34 ± 3.34
15-30	210.91 ± 12.89	106.74 ± 9.61	48.17 ± 6.04	56.60 ± 7.33 ^{a}	26.84 ± 3.30 ^{a}	50.36 ± 3.26 ^{a}
30-45	216 .03 ± 12.20 ^{ab}	108.81 ± 9.12 ^{b}	49.04 ± 6.10 ^{ab}	58.73 ± 7.78 ^{ab}	27.22 ± 3.42 ^{ab}	50.16 ± 3.40 ^{a}
45-60	217.56 ± 15.14 ^{ab}	109.81 ± 9.95 ^{b}	49.26 ± 5.85 ^{a}	58.84 ± 9.08 ^{a}	27.07 ± 3.53 ^{a}	50.47 ± 3.56 ^{a}
60-75	218.62 ± 15.63 ^{ab}	108.54 ± 9.71	49.65 ± 5.85 ^{a}	60.80 ± 9.18 ^{abc}	27.79 ± 3.45 ^{abd}	49.56 ± 3.45 ^{abd}
75-90	222.23 ± 15.16 ^{abcde}	109.47 ± 10.51	50.06 ± 6.51 ^{a}	62.03 ± 9.18 ^{abcde}	28.06 ± 3.35 ^{abcd}	49.37 ± 3.49 ^{abcd}

abcde denote significant differences with 0-15, 15-30, 30-45, 45-60, and 60-75 respectively.

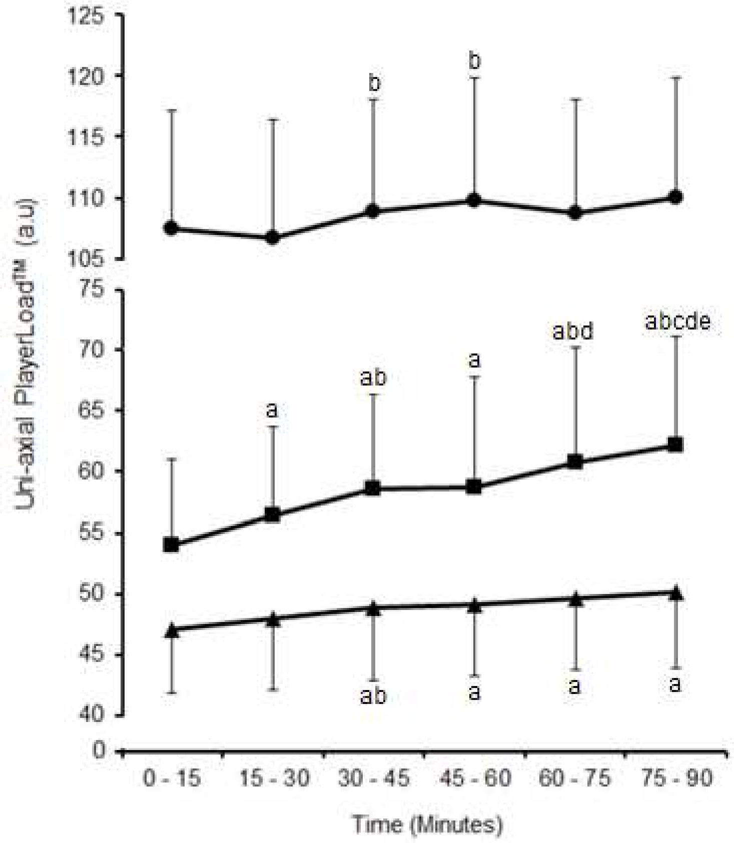

Figure 3. Time history of changes (irrespective of group or trial) in the uni-axial PlayerLoad^{TM} vectors (● = PL$_V$; ■ = PL$_{AP}$; ▲= PL$_{ML}$). $^{a,\ b,\ c,\ d,\ \text{and}\ e}$ denote significant differences from 0-15 mins, 15-30 mins, 30-45 mins 45-60 mins, and 60-75 mins, respectively.

Physiological and perceptual responses

In direct relation to the fatigue response associated with the two groups (48 vs. 72 h), the GLM did not identify any significant group*trial*time (*P* > 0.05), group*time (*P* > 0.05), nor group*trial (*P* > 0.05) interactions for any of the physiological or perceptual measures.

The GLM did not identify any significant trial*time (*P*> 0.05) interactions for any of the physiological measures, but a significant (*P*= 0.003, η^2 = 0.16) trial*time interaction was identified for RPE. Post hoc pairwise comparisons revealing significantly higher RPE values recorded at 45-60mins in the second trial (T$_{45\text{-}60}$= 12 ± 2 a.u) when compared to the first trial (T$_{45\text{-}60}$= 11 ± 2 a.u). The 95% CI for this difference was 0 to 1 a.u.

As identified in table 2, the GLM identified significant ($P < 0.001$) main effects for time for BLa ($\eta^2 = 0.34$), $\dot{V}O_{2mean}$ ($\eta^2 = 0.99$), $\dot{V}O_{2peak}$ ($\eta^2 = 0.96$), HR_{mean} ($\eta^2 = 0.97$), HR_{peak} ($\eta^2 = 0.97$), and RPE ($\eta^2 = 0.89$). The GLM did not identify a significant main effects for trial for BLa ($P = 0.76$), $\dot{V}O_{2mean}$ ($P = 0.33$), and RPE ($P = 0.14$). Post hoc pairwise comparisons identified significantly higher values in the first trial (HR_{mean} = 140 ± 13 $b \cdot min^{-1}$; HR_{peak} = 154 ± 13 $b \cdot min^{-1}$; $\dot{V}O_{2peak}$ = 40.86 ± 3.58 $ml \cdot kg^{-1} \cdot min^{-1}$) when compared to the second (HR_{mean} = 137 ± 13 $b \cdot min^{-1}$; HR_{peak} = 151 ± 13 $b \cdot min^{-1}$; $\dot{V}O_{2peak}$ = 39.28 ± 3.67 $ml \cdot kg^{-1} \cdot min^{-1}$). The 95% CI for these differences were 0 to 5 $b \cdot min^{-1}$, 0 to 6 $b \cdot min^{-1}$, and 0.04 to 3.13 $ml \cdot kg^{-1} \cdot min^{-1}$ respectively.

Table 2. Temporal fatigue response (irrespective of trial and group) associated with a number of physical measures

Time (mins)	BLa (mmol·L^{-1})	HR$_{peak}$ (b·min^{-1})	HR$_{mean}$ (b·min^{-1})	$\dot{V}O_{2peak}$ (ml·kg^{-1}·min^{-1})	$\dot{V}O_{2average}$ (ml·kg^{-1}·min^{-1})	RPE (a.u)
Rest	1.4 ± 0.4	80 ± 10	72 ± 11	9.97 ± 2.19	6.91 ± 1.85	6 ± 0
0-15	3.0 ± 2.4 ^{a}	159 ± 13 ^{a}	143 ± 12 ^{ab}	45.34 ± 4.33 ^{a}	32.74 ± 2.76 ^{a}	10 ± 2 ^{a}
15-30	2.6 ± 1.2 ^{a}	162 ± 13 ^{a}	149 ± 13 ^{ab}	45.56 ± 5.04 ^{a}	32.77 ± 3.16 ^{a}	11 ± 2 ^{ab}
30-45	3.2 ± 2.0 ^{a}	164 ± 13 ^{a}	153 ± 14 ^{abc}	46.40 ± 4.65 ^{a}	33.00 ± 3.12 ^{a}	12 ± 2 ^{ab}
HT	2.2 ± 1.3 ^{a}					
45-60	3.5 ± 2.2 ^{a}	165 ± 15 ^{a}	146 ± 13 ^{ad}	45.74 ± 4.57 ^{a}	32.62 ± 3.08 ^{a}	12 ± 2 ^{abc}
60-75	3.2 ± 1.8 ^{a}	165 ± 13 ^{ab}	151 ± 13 ^{abf}	44.88 ± 4.87 ^{ad}	32.48 ± 3.23 ^{a}	13 ± 2 ^{abcf}
75-90	3.8 ± 2.0 ^{ae}	169 ± 14 ^{abc}	156 ± 13 ^{abcfg}	46.80 ± 4.70 ^{a}	33.07 ± 3.53 ^{a}	14 ± 3 ^{abcdfg}

^{abcdefg} denote significant differences with Rest, 0-15, 15-30, 30-45, HT, 45-60, and 60-75 respectively.

DISCUSSION

Based on recent recommendations (Carling et al., 2015), the aim of the current study was to compare the residual fatigue response associated with the completion of successive soccer simulations interspersed by either 48 or 72 h recovery. In contrast to the first hypothesis, and in support of the second hypothesis, the current data suggests that (with equivalence at baseline) there was no significant difference in the physical fatigue response elicited by the two groups. A 48h recovery period is therefore sufficient to recover the physical measures utilised in the current study. The current data supports previous fixture congestion literature that has identified no impairment of physical performance measures (Andersson, Raastad, Nilsson, Paulsen, Garthe & Kadi, 2008; Carling et al., 2012; Dupont et al., 2010; Dellal et al., 2015; Folgado et al., 2015) but contrasts other observations of reductions in some physical performance measures (Odetoyinbo et al., 2007; Carling et al., 2012; Rollo et al., 2014) during congested fixture schedules.

The lack of significant group interactions and the disparity between previous fixture congestion literature may be attributable to methodological differences, the influence of contextual factors (Rollo et al., 2014), and the large between match variability of commonly used performance parameters (Rollo et al., 2014). The current study utilised a standardised SSEP, thus preventing the players from altering the activity profile performed in the subsequent match. These data therefore begin to suggest that the reductions in performance during periods of fixture congestion may be indicative of the self-paced nature of soccer match-play, rather than a decrease in physical capacity. During actual match-play, team sport athletes may alter their activity profiles at low intensities in an attempt to preserve their HI running capacity later in the match (Smith, Mracora & Coutts, 2015). These altered pacing strategies may also be utilised during periods of short-term fixture congestion to reduce injury risk and to prolong physical performance (Folgado et al., 2015). However, the authors do acknowledge that where previous studies have identified an increased injury risk and impaired physical performance (Odetoyinbo et al., 2007; Carling et al., 2012; Rollo et al., 2014), this may be related to insufficient recovery of other mechanical measures that have not been recorded in the current study. Future research is therefore warranted to assess the residual fatigue response associated with additional physical measures during simulated periods of short term fixture congestion. The current study has assessed a number of PlayerLoad^{TM} metrics that can be used to infer aetiological markers of injury risk; however, future research may want to measure epidemiological markers such as injury incidence and severity, or look to to strengthen the association between aetiological markers and injury incidence during short-term fixture congestion.

As previously mentioned, there were no observed group interactions identified for any of the PlayerLoad^{TM} metrics, thus suggesting that there is no difference in running efficiency when two bouts of soccer-specific activity are interspersed by a minimum of 48 h. Although not directly measured, it can be inferred from these data that with no difference in the residual mechanical fatigue response, injury risk potential would not differ during these periods of simulated short-term fixture congestion. As expected, a temporal fatigue response was identified for all variables, with the exception of $PL_{ML\%}$ data. The current data therefore supports the reductions in performance (Mohr et al., 2003) and increased mechanical fatigue response observed towards the latter stages of soccer match-play (Ekstrand et al., 2011). In support of previous research, values for all accelerometry based measures were within the range observed during soccer-specific activity (Mohr et al., 2003; Stølen et al., 2005; Krustrup et al., 2006; Scott et al., 2013; Barron et al., 2014) .

The PlayerLoad^{TM} metrics have previously been shown to be sensitive enough to detect temporary and cumulative fatigue induced changes in running efficiency during the completion of soccer-specific activity (Barrett et al., 2014; Page et al., 2015); however, the sensitivity of the PlayerLoad^{TM} metrics to residual fatigue has not previously been assessed. The current data may therefore be indicative of a lack of residual mechanical fatigue during periods of short-term fixture congestion, or it may be due to the PlayerLoad^{TM} metrics not being sensitive enough to detect changes in running efficiency across successive bouts of soccer-specific activity. Based on the manufacturer's guidelines, the position sanctioned by IFAB during competitive matches, and in accordance with the majority of previous literature (Boyd et al., 2011; Scott et al., 2013; Barron et al., 2014; Page et al., 2015), the current study positioned the GPS units in a neoprene pouch between the scapulae. Recent research has critiqued the scapulae placement of the GPS unit when assessing GPS-based accelerometry because the data can be influenced by movements of the upper body irrespective of lower limb movement (Barrett et al., 2014). Future research may therefore wish to consider more functional and appropriate positions of GPS units when assessing lower limb mechanical fatigue. This in turn may also increase the sensitivity of the PlayerLoad^{TM} metrics to identify residual fatigue during periods of short term fixture congestion.

Although there were no significant differences elicited between groups, values for HR and HR$_{peak}$ were significantly higher in the 1st trial when compared to the 2nd. The difference of 3 b·min^{-1} (~2 %) is less than the variability of 4-6.5 % identified in match-play (Halson et al., 2014). In further support of this, significantly higher $\dot{V}O_{2peak}$ values were also observed in the first trial (40.86 ± 3.58 ml·kg^{-1}·min^{-1}) when compared to the second trial (39.28 ± 3.67 ml·kg^{-1}·min^{-1}). Although not directly measured, these significant main effects for trial may be related to a lower psychological stress in the second trial, with previous literature suggesting that during exercise, sensations of effort are consciously interpreted by drawing upon mental representations and beliefs that have been constructed through similar previous occurrences (Lambert, St Clair Gibson & Noakes, 2005). The current physiological measures may not be sensitive enough to detect a residual physiological fatigue response between successive bouts of standardised soccer-specific activity, and as such, alternative measures may want to be considered when monitoring physiological fatigue during periods of short-term fixture congestion (Mohr et al., 2016).

It was also identified that RPE values were significantly higher in the first 15mins of the second half during the second trial (12 ± 2 a.u) when compared to the first (11 ± 2 a.u). There was however no significant difference in any of the other physical measures during this period, thus suggesting that the observed differences in the RPE data must be attributable to other mechanisms which were not recorded in the current study. The current RPE data supports previous observations of reduced performance (Mohr et al., 2003) and increased injury risk (Ekstrand et al., 2011) following the completion of a passive HT period. The differences in the RPE data recorded between the two trials may therefore be related to impaired mechanical function; however, this suggestion warrants further investigation.

The current observations of no difference in physical response associated with two successive bouts of soccer-specific activity interspersed by 48 or 72 h recovery cannot be generalised beyond the measures used. It has been suggested that a 48-72 h recovery period may not be sufficient to recover parameters including, but not limited to, knee range of movement (Ispirlidis et al., 2008), 20 m sprint performance (Magalhäes et al., 2010), knee flexion peak torque (Andersson et al., 2008; Magalhäes et al., 2010), creatine kinase concentrations (Andersson et al., 2008; Magalhäes et al., 2010), counter movement jump performance (Andersson et al., 2008) and muscle soreness (Andersson et al., 2008; Magalhäes et al., 2010.

These studies have assessed the time course of physical recovery following the completion of soccer-specific activity, but typically fail to consider the influence of incomplete recovery on subsequent performance. In a rare exception, insufficient physical recovery did not influence either the physiological response, or physical performance in a successive bout of match-play [31], thus supporting the current data. Future research should therefore aim to assess the recovery of additional measures during periods of short-term fixture congestion, as well as assessing the potential impact of these measures on both subsequent performance and markers of injury.

Practical applications

In support of contemporary recommendations (Carling et al., 2015), the SSEP utilised in the current study offers a unique opportunity to mechanistically assess the physical response associated with the completion of successive bouts of soccer-specific activity. The SSEP utilised in the current study could therefore also be utilised in future research to further assess the physical response associated with periods of soccer-specific fixture congestion. The current data suggests that physiological and mechanical intensity of training and or match-play would not need to be compromised when two successive bouts of soccer-specific activity are performed with a minimum of 48h recovery. Subsequently, this information enables training to be performed 48 h post match, with implications particularly in periods of fixture congestion where training load might be reduced accordingly. The current data also further supports the use of GPS-based accelerometry to monitor fatigue induced alterations in movement efficiency and/or technique during the completion of soccer-specific activity.

Conclusions

The current study has identified no difference in the physical fatigue response elicited from the completion of two successive SSEP’s interspersed with either 48 or 72 h recovery. Acknowledging the specificity of the measures recorded in the current study (Halson et al., 2014), the current data suggests that 48h recovery is sufficient to prevent any residual physical fatigue response across successive bouts of soccer-specific activity. The current study is focussed on the physical response associated with a period of short-term fixture congestion; however, future research could also utilise the current SSEP to replicate a more prolonged period of fixture congestion. Moreover, the SSEP could also be conducted with additional mechanical measures to mechanistically assess fatigue induced alterations in injury risk during periods of short-term fixture congestion (Dupont et al., 2010; Dellal et al., 2015).

Conflict of Interest

None declared

Ethical approval

We wish to confirm that this project was granted ethical approval by the Departmental Research Ethics Committee, specifically pertaining to the Dept. of Sport & Physical Activity at Edge Hill University. This process is conducted in accordance with the spirit of the Declaration of Helsinki, and requires written informed consent from all participants.

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The biomechanical and physiological response to repeated soccer-specific simulations interspersed by 48 or 72 hours recovery

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We confirm that we have provided a current, correct email address which is accessible by the Corresponding Author and which has been configured to accept email from (richard.page@edgehill.ac.uk)
Signed on behalf of all authors by:

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