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MANUSCRIPT TITLE: Biomechanical and physiological response to a contemporary soccer match-play simulation.

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LABORATORY: Edge Hill University (Exercise Physiology Laboratory)

AUTHORS: Richard Page, Kelly Marrin PhD, Chris Brogden, Matt Greig PhD

DEPARTMENT AND INSTITUTION: Department of Sport & Physical Activity, Edge Hill University, St. Helens Road, Ormskirk, Lancashire, L39 4QP, United Kingdom

CORRESPONDING AUTHOR:

Dr Matt Greig

Address as above

Tel: (+44) 01695 584848

Fax: (+44) 01695 584812

E-mail: matt.greig@edgehill.ac.uk

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ABSTRACT

The intermittent activity profile of soccer match-play increases the complexity of the physical demands. Laboratory models of soccer match-play have value in controlled intervention studies, developed around manipulations of the activity profile to elicit a desired physiological or biomechanical response. Contemporary notational analyses suggest a profile comprising clusters of repeat sprint efforts, with implications for both biomechanical and physiological load. Eighteen male soccer players completed a 90min treadmill protocol based on clusters of repeat sprint efforts. Each 15min bout of exercise was quantified for uni-axial (medial-lateral [PL_{ML}], anterior-posterior [PL_{AP}] and vertical [PL_{V}]) and tri-axial PlayerLoad^{TM} (PL_{Total}). The relative contributions of the uni-axial PlayerLoad^{TM} vectors ($PL_{ML\%,}$ $PL_{AP\%,}$ and $PL_{V\%}$) were also examined. In addition to rating of perceived exertion, the physiological response comprised heart rate, blood lactate concentration, and both peak and average oxygen consumption. Tri-axial PlayerLoad^{TM} increased ($p = 0.02$) with exercise duration (T_{0-15}= 206.26 ± 14.37 a.u; T_{45-60} = 214.51 ± 14.97 a.u) and remained elevated throughout the 2nd half. This fatigue effect was evident in both the PL_{ML} and PL_{AP} movement planes. The mean relative contributions of $PL_{V\%}$:$PL_{AP\%}$:$PL_{ML\%}$ were consistent at ~ 48:28:23. The physiological response was comparable with match-play, and a similar magnitude of increase at ~5% was observed in physiological parameters. Changes in PlayerLoad^{TM} might reflect a change in movement quality with fatigue, with implications for both performance and injury risk, reflecting observations of match-play. The high frequency of speed change elicits a 23% contribution from medio-lateral load, negating the criticism of treadmill protocols as 'linear'.

Key Words: soccer, physiology, biomechanics, fatigue, accelerometry, PlayerLoad

INTRODUCTION

The influence of fatigue on both performance and injury risk in soccer has been well documented, driving the development of laboratory-based models designed to replicate the physical demands of match-play (17, 32). Typically authors refer to the activity profile as validated against notational analyses of match-play. Soccer is characterised by an intermittent and irregular activity profile, increasing the complexity of both the biomechanical and physiological response. Recently, PlayerLoad^{TM} calculated from the tri-axial accelerometer function of Global Positioning System (GPS) devices has been used as a biomechanical measure of intensity in intermittent team sports (7, 11, 16). Technological advancements have enhanced the collection of data during match-play, which offers the ultimate in ecologic validity, but a lack of experimental control. Laboratory protocols offer the control required to mechanistically examine the influence of stressors relevant to the elite soccer players. Practical applications could include the investigation of fixture congestion and recovery strategies, heat stress, return-to-play assessments, and the manipulation of running velocity profiles for training purposes (overload or rehabilitation). Laboratory protocols also provide a reduced injury risk, negating the physical contact which accounts for more than 70% of all injuries (3).

Where protocols have utilised prolonged bouts of high intensity work (18, 23) to elicit a favourable physiological response, they have invalidated the biomechanical integrity of the velocity profile. However, a high frequency of speed changes to more accurately model the velocity profile has elicited a low physiological response (17). The structure of the intermittent velocity profile will inevitably affect the physical response, and the arbitrary and ad hoc distribution of speed changes used in previous studies may not reflect match-play. Contemporary notational analyses suggest that high intensity efforts in team sports typically occur in ‘clusters’ (33). By clustering the high intensity efforts incidences of instantaneous fatigue (4, 18, 23, 28) can be induced, and an elevated and valid physical response can be achieved. The aim of this study was to quantify and validate the biomechanical and physiological response to a novel soccer-specific protocol characterised by clusters of high intensity efforts. A secondary aim is to consider the previous criticism of treadmill protocols as being uni-directional, and thus not replicating the mechanical load associated with match-play (32). It was hypothesized that the clustering of high intensity activity would elicit both temporary and cumulative physical fatigue representative of soccer match-play. It was also hypothesized that this current soccer-specific protocol would be valid representation of soccer match-play in relation to both the input (the velocity profile) and the output (the physical response).

METHODS

Experimental Approach to the Problem

This current study consisted of a single trial design to determine the validity of a contemporary soccer-specific protocol. The dependant variables were chosen to quantify and validate the physical response to the protocol by utilising contemporary measurements which are regularly used within an applied setting. The use of a standardised protocol increases the mechanistic rigour by not allowing the participants to vary their running speeds. Similarly, any observed changes in the physical response, are attributable to fatigue induced changes. The use of GPS based tri-axial accelerometry also offers a novel method of assessing the mechanical demand of treadmill running whilst also, allowing comparisons to soccer match-play.

Subjects

Eighteen male semi-professional soccer players (mean ± SD: age 22.5 ± 3.5 yrs, height 177.4 ± 6.8 cm, body mass 76.5 ± 6.8 kg), volunteered to complete this study within a month, after the end of the competitive soccer season. Additional to weekly matches, the participants completed a minimum of two training session per week during the preceding soccer season. All participants were paid semi-professional soccer players competing in the 5th tier of English football. Inclusion criteria specified that players reported as being injury free for a minimum of 6 months prior to testing, were outfield players, and demonstrated the capacity to complete the 30 minute familiarisation sessions specific to the test protocol.

Prior to the start of the experimental trial, participants were required to undergo a comprehensive health screening procedure to ensure they were injury free, not taking any medication, were all non-smokers and were able to participate in exercise. Both resting heart rate (HR) and blood pressure were measured (Omron, Mx3 plus, Netherlands), values of >90bpm and >140/90mmHg respectively were contraindications to exercise. The study was approved by the University Research Ethics Committee and conformed to the declaration of Helsinki. Written informed consent was obtained for all participants prior to the commencement of data collection.

Procedures

Participants attended the laboratory on three occasions to complete two familiarisation trial followed by an experimental trial. A minimum of 72hrs recovery interspersed each of the trials. Participants attended the laboratory in a 3hr post-absorptive state following a 48hr period of abstinence from vigorous exercise and alcohol. Participants were also asked to refrain from consuming caffeine 24hrs prior to all experimental trials, consume 500ml of water 2hrs prior to testing, and attend the testing session euhydrated (urine osmolality of <700mOsm./kgH_2O). Urine osmolality was assessed using a portable refractometry device (Osmocheck, Vitech Scientific, West Sussex, UK) prior to the completion of the experimental trial. All trials were conducted in an ambient controlled environment with temperature and humidity maintained at 21 ± 0.5 °C and 35 ± 1.5 % respectively. To account for the effects of circadian variation (21) all trials were completed between 17:00-20:00hrs. The soccer-specific protocol was programmed into a motorised treadmill (H/P/Cosmos Pulsar 4.0, H/P/Comsos Sports and Medical GmbH, Germany), upon which participants completed a standardised intermittent warm-up followed by a period of self-directed stretching. The warm-up consisted 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.

The soccer specific protocol

The exercise protocol consisted of 6 x 15min bouts of intermittent activity, with a 15min passive recovery between the 3rd and 4th bouts to represent half-time. The activity profile was based on notational analysis of match-play with backward running integrated with low intensity running at a velocity of 11.6 km·h^{-1} , and the sprint assigned a velocity of 25 km·h^{-1} (23). The 90min notational data was divided to provide a 15min bout, from which the exercise protocol was designed. The maximum treadmill acceleration (and deceleration) of 1.39 m·s^{-2} was applied to each change in velocity, with the duration of speed change factored into the duration of the subsequent activity. The structure of the 15 minute activity period was developed to replicate the clustering of high intensity efforts interspersed with low intensity bouts as observed in match-play (33). Figure 1 provides a schematic representation of the activity profile, conducted with varying levels of gradient to account for the lack of air resistance associated with laboratory testing (19). The ordering of the discrete bouts as presented in Figure 1, along with the velocity, duration, gradient and acceleration settings enables replication of the protocol (dependent on the acceleration capacity of the treadmill).

*** Insert Figure 1 about here***

Physical measurements

Tri-axial accelerometer (Kionix: KX94) data was sampled at 100 Hz, and housed within a GPS unit (MinimaxX, S4, Catapult Innovations, Scoresby, Australia). To remove movement artefact the GPS device was held in position at the cervical region of the spine and was contained within a neoprene vest. PlayerLoad^{TM} was calculated as the square root of the squared instantaneous rate of change in acceleration in each of the three movement planes (9). PlayerLoad^{TM} over each 15min bout of exercise was quantified in the medial-lateral (PL_{ML}), anterior-posterior (PL_{AP}) and vertical (PL_V) movement planes. The summation of the uni-axial PlayerLoad^{TM} values recorded in each of the movement planes was used to provide a value for tri-axial PlayerLoad^{TM} (PL_{Total}). The relative contributions of each uni-axial PlayerLoad^{TM} vector ($PL_{ML\%}$, $PL_{AP\%}$ and $PL_{V\%}$) were also quantified.

The physiological response comprised a number of parameters. Heart rate (HR) was recorded (Polar, Team system, Finland) and a finger-tip capillary blood sample analysed (Lactate Pro, LT-1710, Arkray KDK, Japan) for blood lactate concentration (BLa) at rest, immediately following each 15 minute bout as a point reading, and following the passive half-time period. Expired air was analysed using a breath by breath portable metabolic analyser (Cosmed K4 b^2, Rome, Italy) at rest and during the completion of the experimental trial. Values for average oxygen consumption ($\dot{V}O_2$) and peak oxygen consumption ($\dot{V}O_{2peak}$) were calculated for each 15 minute bout. Borg's 6-20 point scale (5) was used to record the participant's subjective rating of perceived exertion at the end of each 15 minute bout.

Statistical Analyses

All data is reported as mean ± SD unless otherwise stated. Prior to parametric analysis, the assumptions of normality were verified using the Shapiro-Wilk test. Differences between the physical responses recorded between times points (Baseline, after each 15 minute bout of activity, and at the end of the passive half time period) were analysed using a repeated measures general linear model (GLM). Where appropriate, post hoc analyses with a *Bonferonni* correction factor was applied. 95% Confidence Intervals for difference are also presented. All statistical analysis was completed using PASW Statistics Editor 20.0 for windows (SPSS Inc, Chicago, USA) with a significance level set at $p \leq 0.05$.

RESULTS

Mechanical response

Figure 2 illustrates the time history of changes in PL_{Total} across the 90min protocol, with the repeated measures GLM identifying a significant main effect for exercise duration ($p = 0.02$). Tri-axial PlayerLoad^{TM} tended to increase throughout the protocol, with significantly higher values recorded at 45-60 minutes ($T_{45-60} = 214.51 \pm 14.97$ a.u) when compared to 0-15 ($T_{0-15} = 206.26 \pm 14.37$ a.u) and 15-30 minutes ($T_{15-30} = 206.57 \pm 13.68$ a.u). The 95 % CI for these differences was 0.18 to 16.49 a.u and 0.072 to 15.81 a.u respectively. Tri-axial PlayerLoad^{TM} remained elevated throughout the second half.

*** Insert Figure 2 about here ***

The same pattern was evident for both the PL_{AP} and PL_{ML}. Uni-axial anterior-posterior PlayerLoad^{TM} was significantly lower ($p <0.001$) in the first 30 minutes (T_{0-15} = 54.74 ± 7.66 a.u; T_{15-30} = 56.58 ± 8.28 a.u) when compared to the final 30 minutes (T_{60-75} = 61.33 ± 9.48 a.u and T_{75-90} = 62.02 ± 10.48 a.u). Uni-axial medial-lateral PlayerLoad^{TM} was also significantly lower ($p = 0.03$) in the first 30 minutes (T_{0-15} = 47.14 ± 5.48 a.u and T_{15-30} = 47.14 ± 5.48 a.u) when compared to the first 15 minute bout in the second half (T_{45-60} = 49.31 ± 6.12 a.u). The 95 % CI for these differences was 0.59 to 3.75 a.u and 0.16 to 3.82 a.u respectively. There was no main effect for time associated with changes in PL_V, with values remaining consistent at ~104 a.u.

Figure 3 quantifies the relative contribution of each uni-axial PlayerLoad^{TM} vector. There was a significant increase in $PL_{AP\%}$ as a main effect for time ($p < 0.001$), and a compensatory decrease in the $PL_{V\%}$ ($p < 0.001$). Post hoc pairwise comparisons revealed a significantly higher $PL_{AP\%}$ values over the final 30 minutes (T_{60-75} = 28.41 ± 3.53 %; T_{75-90} = 28.62 ± 3.28 %) when compared to the first 15 minutes (T_{0-15} = 26.60 ± 3.67 %). The 95% CI for these differences were 0.21 to 3.41 % and 0.37 to 3.68 % respectively. Conversely, the values for $PL_{V\%}$ in the first 15 minutes (T_{0-15} = 49.27 ± 7.30 %) were significantly lower than the last 15 minute period (T_{75-90} = 47.30 ± 6.66 %). The 95 % CI for this difference was 0.64 to 3.29 %. The repeated measures GLM identified that there was no significant difference ($p = 0.84$) in $PL_{ML\%}$ as a main effect for time, this was consistent at ~23 %.

*** Insert Figure 3 about here ***

Physiological response

The physiological response to the exercise protocol is summarised in Table 1. The repeated measures GLM identified that there was a significant increase in HR ($p < 0.001$) and BLa ($p < 0.001$) as a main effect for time, with significantly lower values identified at rest and following the completion of the passive half time period when compared to all other time points. The highest HR and BLa values were recorded over the last 15mins. Resting values for $\dot{V}O_2$ and $\dot{V}O_{2peak}$ were significantly lower ($p < 0.001$) than all other time points.

*** Insert Table 1 about here ***

RPE was observed to increase as a main effect for time ($p < 0.001$), with significantly lower ($p < 0.01$) values recorded at Rest ($T_{Rest} = 6 \pm 0$) and during the first 30 minutes ($T_{0\text{-}15} = 10 \pm 2$; $T_{15\text{-}30} = 11 \pm 2$) when compared to the final 30 minutes ($T_{60\text{-}75} = 13 \pm 0$; $T_{75\text{-}90} = 14 \pm 2$).

DISCUSSION

The aim of the present study was to quantify and validate the physical response to a soccer-specific protocol characterised by clusters of high intensity exercise, validated against previous notational analyses (23, 33). The findings of this study identify that the soccer specific protocol provides a valid simulation of the total distance covered, the velocity profile, and the physical response associated with soccer match-play, thus supporting our hypothesis. The current protocol therefore offers an opportunity of simulating soccer match-play within a safe and controlled environment. The practical applications of a valid and standardised protocol are that, it can be utilised to assess the effectiveness of soccer-specific interventions, assess the impact of exercise stressors on performance, and can be used as a training tool or method of assessment for a players return to play capabilities.

The total distance covered of 12.2 km (10, 13, 23), and the 8:1 ratio in low intensity (<15 km·h^{-1}) to high intensity work duration are similar to observations of match play (29). The frequency, duration and speed of discrete locomotive phases was based upon match-play data (20), with the clustering of high intensity efforts designed to replicate match-play observations (22). The exercise protocol thereby provides a valid representation of the distance and velocity profile associated with match-play.

Heart rate values recorded during the protocol increased from 162 ± 14 beats·min^{-1} following the first 15 minute bout to 172 ± 15 beats·min^{-1} at the end of the final 15 minute bout. Average heart rate values of ~157-176 beats·min^{-1} have been recorded during semi-professional and elite match-play (5, 23, 24). The heart rate values identified from the current protocol are similar to (5, 14, 26) and greater than other soccer-specific protocols (1).

Mean oxygen consumption values of ~34 ml·kg·min^{-1} and peak values of ~52 ml·kg·min^{-1} were recorded during the exercise protocol, with no significant change across time. Average oxygen consumption values between 37-56 ml·kg·min^{-1} have been reported in the literature (34), these values are similar to those identified for this current study. Additional comparisons are difficult given the inherent problem of measuring $\dot{V}O_2$ during match-play, thereby limiting further evaluation.

Blood Lactate values peaked at 3.2 ± 2.1 mmol·l^{-1} at the end of the protocol. The values recorded are toward the lower end of the 2-10 mmol·l^{-1} range reported in previous match-play literature (4), and higher than attained during other treadmill protocols (17). Similar to heart rate, blood lactate concentrations recovered to near baseline levels (1.5 ± 0.6 mmol·l^{-1}) following the half time period. It has been recognised that the net clearance rate of Bla is 0.1mmol·L^{-1}·min^{-1} during the passive half-time period of a soccer match (22). The net clearance rate of 0.07mmol·L^{-1}·min^{-1} observed during the half time period of the current protocol is therefore comparable to match-play data.

The physiological response is thus within the range observed during match-play across a range of parameters and compares favourably with other experimental models. The prolonged periods of low intensity associated with match-play negate the accumulation of physiological stress in soccer. The use of treadmill protocols also limits the opportunity for the inclusion of utility movements and changes of direction which are likely to increase the physical demands (2, 12, 17), and laboratory-based experimental trials will inherently have a lower emotional stress than competitive match-play (35), as such, a conservative physiological response might be expected from any treadmill simulation.

Ratings of perceived exertion recorded during the protocol increased from 10 ± 2 during the first 15 minutes to 14 ± 2, equivalent to ‘Somewhat hard’, in the final 15 minutes. Values of 10-15 have been recorded during professional soccer (30). The values reported are similar to (14) and greater than (17) those reported by previous treadmill based protocols, although distances covered varies between protocols.

The physiological response elicited from the current protocol is therefore a valid representation of soccer match-play, elicited from a valid distance and velocity profile. The biomechanical validity gained in modelling a high frequency of speed change elicits a high mechanical demand upon the body. Due to the methodological issues associated with quantifying biomechanical measures during match-play, it is difficult to evaluate the biomechanical response to the protocol. GPS-mounted tri-axial accelerometry has recently become a popular method of monitoring exercise intensity in both the field and laboratory setting (5, 7, 11, 25, 30). 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. Tri-axial accelerometry provides a method of quantifying the biomechanical response to exercise, defined as PlayerLoad^{TM} (9). Tri-axial PlayerLoad^{TM} increased significantly from 206.26 ± 13.97 a.u in the first 15 minute bout to 216.04 ± 21.39 a.u in the final 15 minute bout. These values are comparable to the average tri-axial PlayerLoad^{TM} values of 213.50 a.u and 205.17 a.u identified for a 15 minute bout of match-play and free-running field test respectively (5).

Further validation of the biomechanical response to match play is limited to date, and the subsequent planar analysis represents an innovative consideration of PlayerLoad^{TM}. The increase in PL_{Total} was as a result of increases in both PL_{AP} and PL_{ML} as a function of exercise duration, with PL_{AP} and PL_{ML} peaking at 62.02 ± 10.19 a.u and 49.50 ± 6.48 a.u during the last 15 minute bout respectively.

The relative contribution of $PL_{AP\%}$ increased linearly from 26.60 ± 3.67 % during the first 15 minutes to 28.62 ± 3.37 % during the final 15 minutes. With no change in the $PL_{ML\%}$ at ~24 %, there was a compensatory decrease in $PL_{V\%}$ from 49.27 ± 7.09 % in the first 15 minute bout to 47.30 ± 6.47 % in the final 15 minute bout. In hierarchical order the mean relative contributions of $PL_{V\%}$: $PL_{AP\%}$: $PL_{ML\%}$ was ~ 48:28:23. Similar relative contributions of 44:32:24 have been identified in Australian Rules Football players in a non-fatigued, and 42:35:23 in a fatigued state (11), and the same fatigue-induced increase in $PL_{AP\%}$ and compensatory reduction in $PL_{V\%}$ (11). The percentage change at ~2 % as a result of fatigue is also similar in magnitude to the current study. Competitive youth soccer match-play (7) elicited PL_{Total} values (considering all playing positions) of 100.25 a.u/km, in comparison with the present study at 104.46 a.u/km. Further analysis of the match-play data (7) suggests uni-axial contributions of ~ 44:29:26, in comparison with 48:28:23 in the present study. The magnitude of, and uni-axial contributions to PL_{Total} from the treadmill protocol is therefore similar to soccer match-play. Greater differences between match-play and treadmill running might be expected given the constrained acceleration and deceleration speeds (± 1.39 $m \cdot s^{-2}$) of the treadmill, however, ~93% of the total distance covered during match-play occurs within ± 2 $m \cdot s^{-2}$ (7). Although the amount of distance covered at accelerations $>2 m \cdot s^{-2}$ is relatively small, the inability to achieve these speeds on the treadmill may support the slightly lower PlayerLoad^{TM} values. The lower $PL_{ML\%}$ elicited from the treadmill protocol may also be attributable to the exclusion of utility movements from the protocol; however, a recent study comparing a treadmill-based soccer-specific protocol with a free running protocol identified that the inclusion of changes of direction did not alter the mechanical response (27). Whilst direct comparisons are limited to date, both the magnitude and uni-axial distribution of PlayerLoad^{TM} suggest a valid representation of the mechanical response to match-play.

Treadmill running protocols are often criticised for being uni-directional, eliciting a linear running style and thus not replicating the movement patterns associated with match-play (32). The current protocol elicits ~23 % of all PlayerLoad^{TM} in the medial-lateral plane. The high frequency of treadmill speed change (in the anterior-posterior plane) places great demand on acceleration and deceleration mechanics. The high $PL_{ML\%}$ values suggest considerable laterality in the running technique. The activity profile provides little opportunity for constant velocity, with 231 discrete changes in speed during each 15min bout. This equates to ~15 speed changes per minute, and thus the medio-lateral displacement of the body is likely to be functional in initiating acceleration and/or deceleration. This suggests a running style more aligned to agility rather than linear speed, and might be indicative of a functional adaptation in the gait characteristics of these soccer players. The multi-directional and reactive nature of soccer, and the current training emphasis on small-sided games, is likely to induce a running gait functionally suited to agility. This observation warrants further investigation.

GPS-based tri-axial accelerometry has been used to quantify the mechanical response to incremental treadmill running (6). Further analysis of the data presented quantifies PL_{Total} at 76.94 a.u/km, which is substantially lower than the 104.46 a.u/km elicited in the present study despite the higher average velocity associated with the incremental protocol. Moreover, analysis of the uni-axial PlayerLoad^{TM} data associated with the incremental protocol identified a relative contribution of 56:23:21. In the present study $PL_{V\%}$ is reduced with a compensatory increase in $PL_{AP\%}$ and $PL_{ML\%}$ (48:28:23), reflecting the differences between incremental and intermittent running. The algorithm associated with the calculation of PlayerLoad^{TM} is based on the instantaneous rate of change in acceleration (9). The treadmill protocol used in the present study is characterised by a highly intermittent velocity profile, validated against match-play (23), and thus creates an equivalent PlayerLoad^{TM} response. In comparison, where protocols have utilised prolonged periods of activity (10), a valid PlayerLoad^{TM} would not be expected.

The increase in mechanical 'load' during the protocol mirrors observations of fatigue-induced changes in technique. Previous literature has identified a fatigue effect in agility technique (15), functional stability (16) and kicking (20). Soccer-specific activity also induces reductions in eccentric hamstring strength indicative of muscular fatigue (15, 25). During match-play, acceleration and decelerations capabilities may be compromised as a result of fatigue (1). If the hamstring muscles are required to contract eccentrically whilst in a fatigued state, then changes in running technique may occur with the high frequency of speed change. To protect the hamstring musculature from injury soccer players were observed to decrease stride length (31), which might be achieved through increased laterality in running technique. This is supported by the observed increases in both PL_{AP} and PL_{ML}. The observed reduction in PL_V is also indicative of a flatter mass centre trajectory during each stride, which could also be achieved by reducing stride length. Laterality during speed change would also increase given the treadmill inclination, the 2.5 % gradient at the highest speed elicits an 'up-hill' or 'resisted' sprint technique associated with lower stride length. Since the treadmill speed is predetermined, any decrease in stride length must be accompanied, or pre-empted, by an increase in stride frequency. If the observed changes in PlayerLoad^{TM} can be attributed to a change in movement quality then there are likely to be implications for both performance and injury risk, reflecting observations of match-play.

PRACTICAL APPLICATIONS

The treadmill protocol is based on the velocity profile of soccer match-play, and elicits a valid physiological and mechanical response. The protocol therefore provides varied opportunities for the strength and conditioning coach, primarily in representing a valid stimulus to develop match fitness without the inherent risk of injury associated with match-play. The velocity profile could be manipulated to provide an overload stimulus, for example by increasing the number of high intensity efforts within a cluster, or the number of clusters. The activity profile (and/or acceleration) could also be reduced, for applications in youth soccer for example, or in return to play management of injured players. The protocol could be repeated ad-infinitum to replicate fixture congestion, or utilised with environmental stressors, for example in relation to the Qatar World Cup. The fatigue effect associated with injury risk could also be considered, with markers of injury assessed at 15min periods (15). The protocol could also potentially be used as a screening tool, or fitness assessment in pre-season or in late stage rehabilitation. In a training context the treadmill protocol provides a pre-determined and standardised workload, in contrast to the self-paced nature of soccer match-play.

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Legends to Tables & Figures

Table 1. Time history of changes in the physiological response to the soccer-specific protocol.

Figure 1. A schematic of a 15 minute section of the soccer-specific treadmill protocol.

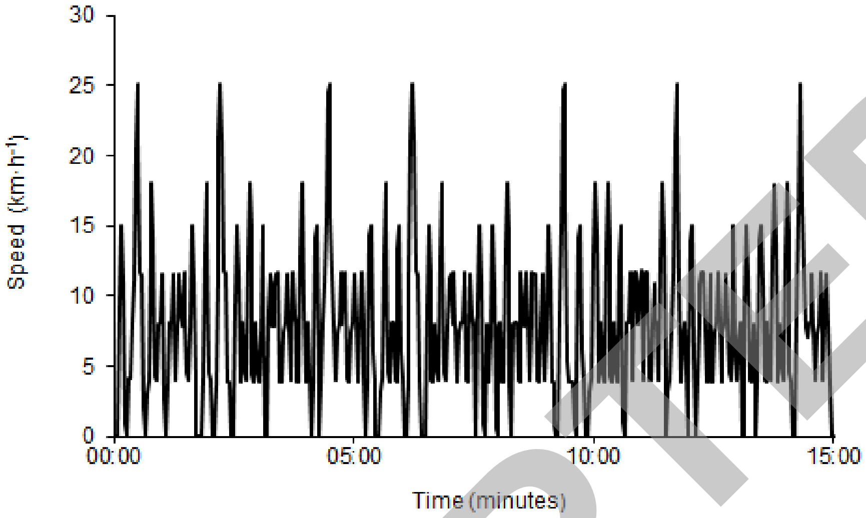
Figure 2. Time history of changes in accumulated PlayerLoad™ across the 90 minute protocol, [a] Denotes significant difference from 45-60 minutes.

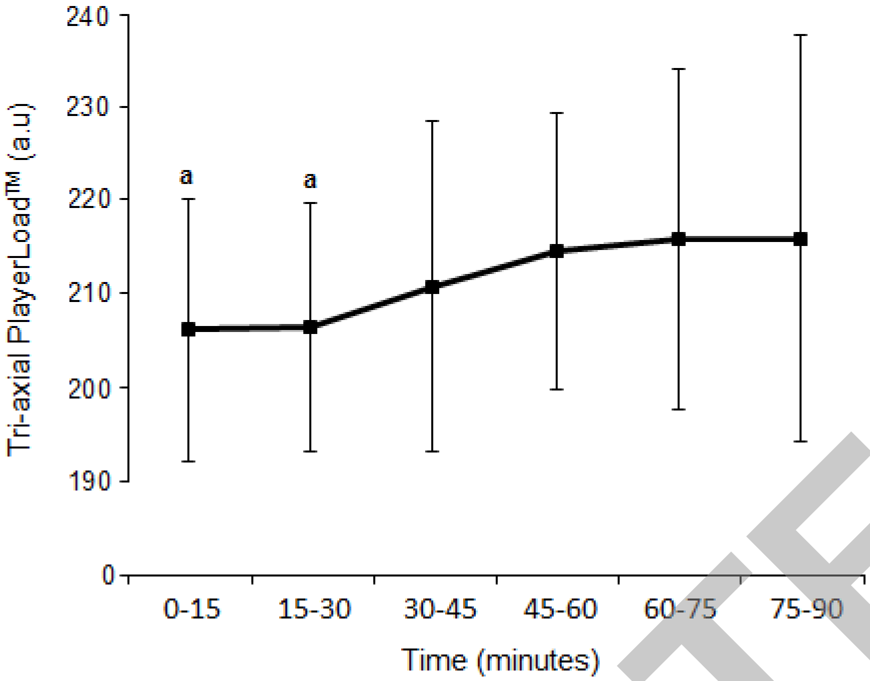
Figure 3. Time history of changes in the relative contributions of uni-axial PlayerLoad™ vectors with superimposed values.

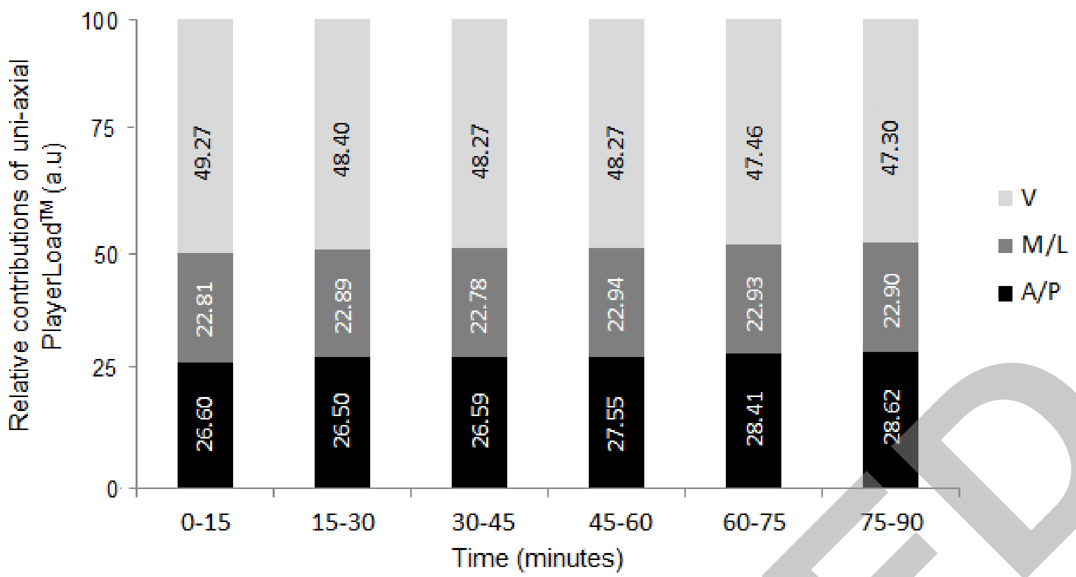
Time (mins)	Bla (mmol·l^{-1})	HR (bpm)	$\dot{V}O_2$ (ml·kg·min^{-1})	$\dot{V}O_{2Peak}$ (ml·kg·min^{-1})	RPE (a.u)
Rest	1.13 ± 0.33	63 ± 5 [c]	6.75 ± 1.47	11.57 ± 1.29	6 ± 0
0-15	2.43 ± 1.21 [ab]	162 ± 14 [abd]	33.80 ± 3.29 [a]	52.94 ± 7.34 [a]	10 ± 2 [acd]
15-30	2.28 ± 1.06 [ab]	166 ± 14 [abd]	33.39 ± 4.18 [a]	50.83 ± 8.20 [a]	11 ± 2 [acd]
30-45	2.57 ± 1.28 [ab]	165 ± 18 [ab]	33.83 ± 4.47 [a]	52.44 ± 7.19 [a]	12 ± 2 [a]
HT	1.47 ± 0.55	92 ± 16			
45-60	2.39 ± 1.45 [ab]	165 ± 15 [abd]	33.42 ± 3.99 [a]	52.22 ± 9.76 [a]	11 ± 2 [a]
60-75	2.57 ± 1.29 [ab]	168 ± 14 [abd]	33.46 ± 4.59 [a]	52.14 ± 10.91 [a]	13 ± 2 [a]
75-90	3.21 ± 2.14 [ab]	172 ± 15 [ab]	33.65 ± 4.66 [a]	52.98 ± 8.65 [a]	14 ± 3 [a]

[a] denotes a significant difference from rest; [b] denotes a significant difference from HT; [C] denotes a significant difference from 60-75mins; [d] denotes a significant difference from 75-90mins

Activity	n	Duration (s)	Gradient (%)
Standing (0km·h^{-1})	29	7.0	1.0
Walking (4km·h^{-1})	65	6.4	1.0
Jogging (8km·h^{-1})	53	3.0	1.0
Low Speed running (11.6km·h^{-1})	48	2.6	1.0
Moderate speed running (15km·h^{-1})	17	2.2	2.0
High Speed Running (18km·h^{-1})	12	2.1	2.0
Sprint (25km·h^{-1})	7	2.0	2.5




240
230
220
210
200
190
0
Tri-axial PlayerLoad™ (a.u)
a
a
0-15
15-30
30-45
45-60
60-75
75-90
Time (minutes)


Relative contributions of uni-axial PlayerLoad™ (a.u)
100
75
50
25
0
0-15
15-30
30-45
45-60
60-75
75-90
Time (minutes)
49.27
22.81
26.60
48.40
22.89
26.50
48.27
22.78
26.59
48.27
22.94
27.55
47.46
22.93
28.41
47.30
22.90
28.62
V
M/L
A/P