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Article *in* Science and Medicine in Football · March 2017

DOI: 10.1080/24733938.2017.1383623

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Science and Medicine in Football

ISSN: 2473-3938 (Print) 2473-4446 (Online) Journal homepage: http://www.tandfonline.com/loi/rsmf20

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To cite this article: Jace A. Delaney, Heidi R. Thornton, Amber E. Rowell, Ben J. Dascombe, Robert J. Aughey & Grant M. Duthie (2017): Modelling the decrement in running intensity within professional soccer players, Science and Medicine in Football, DOI: 10.1080/24733938.2017.1383623

To link to this article: http://dx.doi.org/10.1080/24733938.2017.1383623

Published online: 09 Oct 2017.

SCIENCE AND MEDICINE IN FOOTBALL, 2017
https://doi.org/10.1080/24733938.2017.1383623

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ORIGINAL INVESTIGATION

Modelling the decrement in running intensity within professional soccer players

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ABSTRACT

Knowledge of the most intense periods of competitive soccer may assist in the development of specific training methodologies. **Objectives:** To quantify the peak running intensity of professional soccer and to establish the rate of decline in this intensity as a function of time. **Methods:** Activity profiles were obtained from 24 players across 40 professional matches. Peak values were calculated for moving averages 1–10 minutes in duration for relative distance (m·min^{-1}), high-speed relative distance (HS m·min^{-1}), average acceleration/deceleration (m·s^{2}) and metabolic power (P_{met}). To quantify the decrease in running intensity for longer moving average durations, each measure was evaluated relative to the moving average duration, as a power law relationship. **Results:** Peak relative distance and P_{met} were lowest for central defenders (effect size [ES] = 0.79–1.84), whilst acceleration/deceleration intensity was highest for wide defenders (ES = 0.67–1.42). Differences in the rate of decline in running intensity between positions were considered trivial to small, indicating a similar rate of decline in running intensity across positions. **Conclusions:** Using power law, the peak running intensities of professional soccer can now be predicted as a function of time, providing coaches with a useful tool for the prescription and monitoring of specific training drills.

ARTICLE HISTORY
Accepted 30 March 2017

KEYWORDS
Global positioning systems; metabolic power; acceleration; football

Introduction

Soccer is characterised by brief bouts of high-intensity running interspersed with longer periods of low-intensity activity (Rampinini et al. 2007). Typically, a competitive match involves players covering between 10 000 and 12 000 m, depending on position (Mohr et al. 2003; Rampinini et al. 2007). There is a need for well-developed acceleration capacity (Varley and Aughey 2013), as this is vital for pivotal moments of a match such as competing for the ball with an opposition player, or creating/stopping goal scoring opportunities (Reilly et al. 2000). During professional match play, wide defenders (WD) have been shown to complete more maximal accelerations (>2.78 m·s^{-2}) compared to all other positions. Depending upon team formation, the WD position has a dual role of maintaining their defensive structure but also providing support as a wide passing option when setting up for goal scoring opportunities (Di Salvo et al. 2009), explaining the elevated acceleration response amongst this positional group. Whilst data such as these may be useful for quantifying player movement during competition, whole match values may not be sensitive enough to detect the most intense period of a match. As a result, they provide inadequate information for the prescription of training relative to the acute within-match requirements of professional soccer.

The chaotic nature of the running intensity of team sports is well-known, whereby changes in athletes' physical output throughout a match can be attributed to a multitude of factors, including fatigue (Bendiksen et al. 2012), pacing (Edwards and Noakes 2009) and match situation (Carling and Dupont 2011). The within-match fluctuations in running intensity have been assessed by separating matches into discrete blocks lasting 5–15 min in duration (Mohr et al. 2005; Bradley and Noakes 2013; Barrett et al. 2015). Running intensity declined following both the initial period of the match (Barrett et al. 2015) and immediately succeeding the most demanding block of play (Bradley and Noakes 2013). These data outline the need to prepare athletes for the most demanding periods of play, which are commonly associated with point scoring or match deciding situations (Reilly et al. 2000). However, pre-defined segments of time may not be sensitive to small fluctuations in running intensity if the variation occurs across the designated time segment (Di Salvo et al. 2009). In comparison, possession changes, goal attempts and defending against attacking plays occur randomly within a match, and therefore, a moving average method has been proposed as the appropriate method for detecting the most demanding periods of play (Delaney et al. 2015, 2016).

In an attempt to quantify the peak running intensities of competition, a moving average technique has been applied to a number of locomotor measures, across a range of team sports (Furlan et al. 2015; Delaney et al. 2016). A substantial decline in running intensity has been observed in rugby league players as the duration of moving average increased from 1 to 10 min

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(Delaney et al. 2016). This decline in the peak running intensity as duration increased provides preliminary quantification of the rate of decline in activity in high-level team sport athletes. Further to this, the interaction between running time and distance has been assessed amongst individual sports, where it was proposed that an apparently non-linear relationship can be accurately evaluated using log or power analyses (Katz and Katz 1999). Whilst team sports represent an environment where external factors may have a greater influence on the running requirements of the activity such as strength of the opposition and match location (Kempton and Coutts 2015; Paul et al. 2015), it may be that a power law relationship still exists between running intensity and duration. Therefore, mathematical modelling of the relationship between peak running intensity achieved and the moving average duration may reveal novel information regarding both the peak running capacity athletes during competition (i.e., the greatest running intensity an athlete might reach within a match) and the rate of decline in intensity as a function of time. Such data may assist coaches in predicting the required running intensity of specific training drills relative to peak match activity profiles, or detecting deficiencies within individuals. Therefore, this study aimed to: (1) quantify the peak running intensities generated by professional soccer players during competition, and (2) establish the rate at which this peak running intensity declines as a function of time.

Methods

An observational design was used to evaluate the rate of decline in running intensity as the moving average duration increased, amongst professional soccer players. Data were collected from 24 elite-level players (age; 24.4 ± 5.4 yr, height; 1.79 ± 0.06 m, body mass; 75.2 ± 5.8 kg) playing for the same team in the Australian A-League competition. Players were assessed during 40 games, with a total of 434 individual match observations (18 ± 10 matches per player, range 1–34), that were representative of the entire playing cohort. Match files were classified according to position, as central midfield (CM; *n* = 49), central defender (CD; *n* = 78), striker (STR; *n* = 33), wide defender (WD; *n* = 83), wide midfield (WM; *n* = 103) and winger (WNG; *n* = 88). The team in question typically utilised a 4–3–3 formation (2 CD and 2 WD; 1 CM and 2 WM; 1 STR and 2 WNG). Informed consent and institutional ethics approval was attained prior to the commencement of the study (HREC no: H-2013–0283).

Activity profile

During matches, players' movements were recorded with a portable GPS unit (10 Hz; CatapultSports™ OptimEye S5, Melbourne, Australia; Firmware 7.22), placed between the shoulder blades in a custom-made vest worn underneath their playing jersey. Upon completion of each match, data were downloaded using the same version of the appropriate proprietary software (CatapultSports™ Openfield software; version 1.11.1), where a raw speed ($m{\cdot}s^{-1}$) trace for the entire match (inclusive of stoppage time) was exported and further analysed using customised software (R, v R-3.1.3.), which removed data points where speed exceeded 10 $m{\cdot}s^{-1}$ or acceleration/deceleration exceeded 6 $m{\cdot}s^{-2}$ (Weston et al. 2015). These instances were replaced with zero values, and given the nature of the peak intensity analysis utilised in the present study (details below), this was deemed to have little effect on the values observed for each match file. The number of available satellites and horizontal dilution of precision during the testing period were 10.6 ± 1.7 and 0.86 ± 0.28, respectively.

Four measures of running intensity were chosen, based on current trends in player monitoring within high-level soccer, which were identified as total distance, high-speed distance (>5.5 $m{\cdot}s^{-1}$), acceleration variables and metabolic power (Akenhead and Nassis 2016). Specifically, relative distance ($m{\cdot}min^{-1}$) was calculated as total distance covered per unit of time, along with relative distance covered above a predefined high-speed threshold (>5.5 $m{\cdot}s^{-1}$; HS $m{\cdot}min^{-1}$) (Akenhead and Nassis 2016). Further to this, the change-of-direction requirement of the activity was assessed using a novel average acceleration/deceleration (AveAcc; $m{\cdot}s^{-2}$), which has recently been proposed (Delaney et al. 2016). This technique involved taking the absolute value of all acceleration/deceleration data, and averaging over the duration of the defined period. Whilst it is acknowledged that the amalgamation of both acceleration and deceleration data into one measure may mask the mechanism behind the load (i.e., energetically demanding acceleration efforts vs. eccentrically damaging decelerations (Osgnach et al. 2010; Young et al. 2012), this metric was considered indicative of the combined acceleration and deceleration intensity of the activity. Metabolic power (P_{met}) was calculated using methods detailed previously (Osgnach et al. 2010; di Prampero et al. 2015), as a representation of the combined external demands of the activity, inclusive of both acceleration and deceleration, and speed-based movements. A moving average technique was then applied to each of the output variables, using 10 different durations (i.e., 1–10 min), and the peak value achieved throughout each match for each variable was recorded.

Unfortunately, due to the recent release of the model of GPS unit used in the present investigation, validity and reliability data are limited to one study, where it was reported that maximal speed during straight-line sprinting trials was comparable with the criterion radar gun (*r* = 0.95, 90% confidence interval [90% CI] 0.93–0.97; standard error of the estimate [SEE] = 1.87, 1.65–2.18 $m{\cdot}s^{-1}$) (Roe et al. 2016). In addition, pilot data from our laboratory have revealed that compared to previously validated 5 Hz devices (Scott et al. 2016), these 10 Hz units possessed stronger inter-unit reliability for all measures used within this study (CV = 0.9–1.0% vs. 0.5–5.7%). Though this does not confirm the validity of these units, these units were deemed acceptable for discriminating positional demands during competition.

Running intensity modelling

To quantify the decrease in running intensity for longer moving average durations, each of the four peak output measures were evaluated relative to the moving average duration, as a power law relationship (Katz and Katz 1994, 1999). A power law curve describes non-linear but clearly dependent relationships between two variables (*x* and *y*) can be given by the equation:

$$y = cx^n \quad (1)$$

where n and c are constants. A plot of log (x) against log (y) results in a straight line with slope n and intercept of c^e (Katz and Katz 1994). Linear regression revealed the values for n and c for each variable within each match file. The exponential of c was calculated, and therefore, a predictive equation of running intensity (i) as a function of time (t) was achieved, using the formula:

$$i = ct^n \quad (2)$$

As such, running intensity was deemed to be proportionately related to the duration of the moving average window (i.e., time). An example of this method can be found in Figure 1, where the raw relative distance achieved is plotted as a function of time (symbols), and the predicted values from the log transformed data are represented by the curve. The close relationship between the predicted and actual data demonstrates the "fit" of the model and provides support for the use of this method. Data were then collated by playing position and averaged, to provide a position-specific framework of the decline in running intensity as the moving average increased.

Statistical analysis

Goodness of fit for the log-transformed data was assessed using Pearson's correlation coefficient (r) and was rated as: <0.1 trivial, <0.3 small, <0.5 moderate, <0.7 large <0.9 very large and >0.9 almost perfect (Hopkins et al. 2009). Pairwise comparisons between positional groups were investigated using linear mixed models, as these models appropriately handle repeated-measures data. Random effects (individual athletes) were specified to allow for different within-subject standard deviations by the use of random intercepts, and fixed effects (positional groups) were included to describe the relationship with the dependent variables. The least squares mean test provided positional comparisons from the final models, that were further assessed using a magnitude-based inference network (Hopkins 2007). Standardised differences between positional groups were assessed using effect sizes (ES), classified according to Hopkins et al. (2009) as: <0.20 trivial, 0.21–0.60 small, 0.61–1.20 moderate, 1.21–2.0 large and >2.01 very large. Differences were considered real if they were at least *likely* (i.e., >75% chance) of being greater than the smallest worthwhile difference (SWD), calculated as 0.2 × the between-subject standard deviation (SD). Descriptive statistics are reported as mean ± SD, and whilst all other data are reported as mean ± 90% CI, unless otherwise stated. Statistical analyses were performed in a customised spreadsheet (Microsoft Excel, Redmond, USA) (Hopkins 2007) and R Studio Statistical software (V 0.99.446).

Results

All log-transformed output variables exhibited almost perfect relationships with log-transformed moving average duration (r = 0.97 ± 0.00 to 0.98 ± 0.00). Figure 2 illustrates the raw peak running intensities achieved by professional soccer players during competition by position, as a function of moving average duration. Results of the running intensity modelling analysis can be found in Table 1. The relative distance and P_{met} intercepts were at least *likely* lower for the CD group compared to all other positions (ES = 0.79–1.84). AveAcc intercept was highest for the WD group, compared to all other positions (ES = 0.67–1.42). There was a *likely* small increase in the HS relative distance intercept for the STR and WD positions when compared to the WNG group (ES = 0.35–0.43), and *very likely* moderate increases compared to all other positions (ES = 0.63–1.10). Substantial differences between positions for the slope of each calculated variable were considered small (ES = 0.32–0.55).

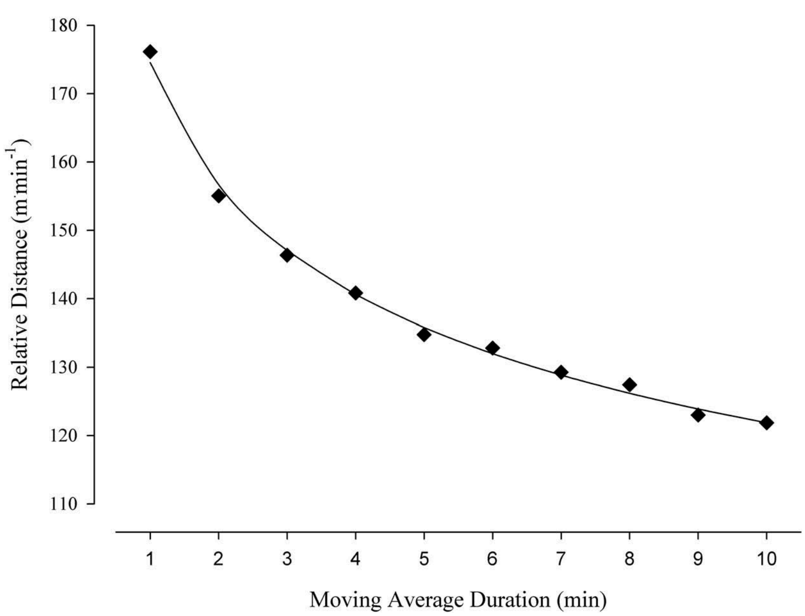

Figure 1. Example of power law analysis. Raw relative distance (y-axis; m·min^{-1}) is plotted for each moving average duration. Curve represents predicted values as a function of time (x-axis).

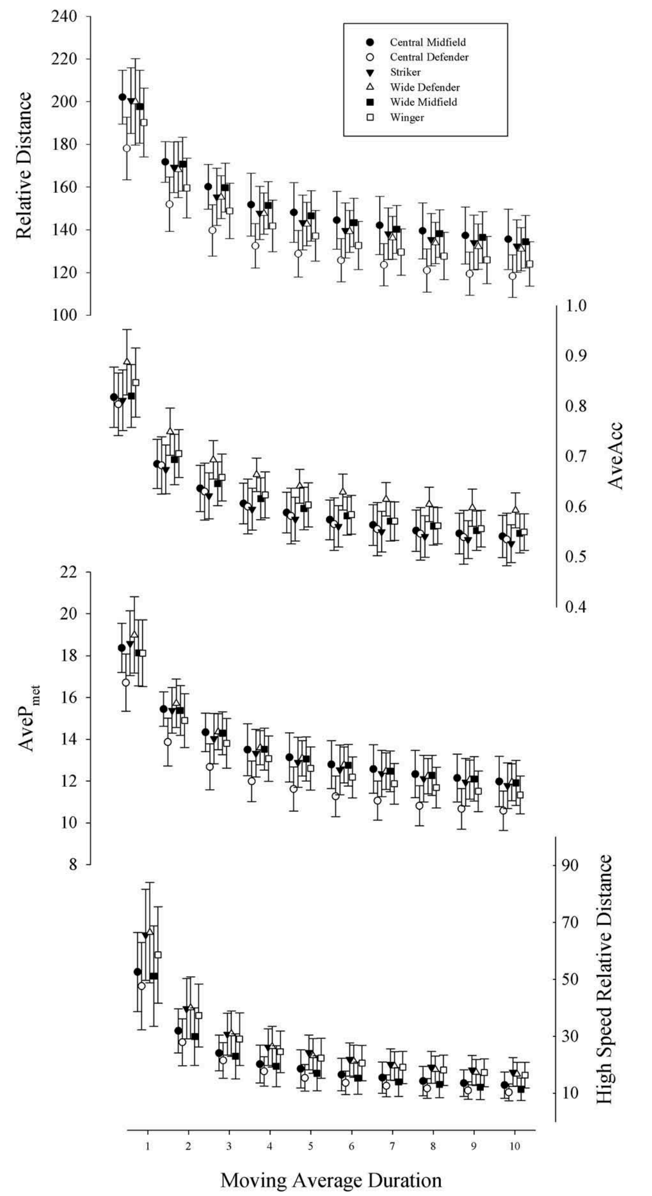

Figure 2. Peak running intensity achieved for each position, for each moving average duration. Data are mean ± SD.

Table 1. Intercept and slope values for estimating match intensity by duration for professional soccer players.

Variable		Central Midfield	Central Defender	Striker	Wide Defender	Wide Midfield	Winger	Effect Size > 0.60
Relative Distance (m·min^{-1})	Intercept	196 ± 12^{bf}	173 ± 14	193 ± 13^{bf}	194 ± 17^{bf}	193 ± 14^{bf}	184 ± 15^{b}	CM, STR, WD and WM > CD and WNG; WNG > CD
	Slope	−0.17 ± 0.06	−0.17 ± 0.03^{e}	−0.18 ± 0.03^{e}	−0.18 ± 0.04^{e}	−0.16 ± 0.03	−0.18 ± 0.04^{e}	
AveAcc (m·s^{-2})	Intercept	0.79 ± 0.05	0.78 ± 0.06	0.78 ± 0.06	0.86 ± 0.05^{abcef}	0.79 ± 0.06	0.82 ± 0.06^{abce}	WD > ALL; WNG > CD and STR
	Slope	−0.17 ± 0.03	−0.17 ± 0.03	−0.18 ± 0.03	−0.17 ± 0.03	−0.17 ± 0.03	−0.18 ± 0.03^{de}	
P_{met} (W·kg^{-1})	Intercept	17.8 ± 1.2^{b}	16.1 ± 1.2	17.8 ± 1.3^{bf}	18.3 ± 1.5^{abcef}	17.6 ± 1.3^{b}	17.4 ± 1.5^{b}	ALL > CD
	Slope	−0.18 ± 0.07^{b}	−0.19 ± 0.03^{e}	−0.19 ± 0.03^{e}	−0.20 ± 0.04^{e}	−0.18 ± 0.03	−0.20 ± 0.04^{e}	
HS Relative Distance (m·min^{-1})	Intercept	51 ± 16	45 ± 14	61 ± 15^{abef}	62 ± 16^{abef}	48 ± 16	55 ± 16^{bf}	STR and WD > CM; CD, WD and WNG > CD
	Slope	−0.18 ± 0.07	−0.19 ± 0.03^{e}	−0.19 ± 0.03^{e}	−0.2 ± 0.04^{e}	−0.18 ± 0.03	−0.2 ± 0.04^{e}	

CM: central midfield; CD: central defender; STR: striker; WD: wide defender; WM: wide midfield; WNG: winger; ALL: all other positions; AveAcc: average acceleration/deceleration. Differences were considered real if they were > 75% chance of being greater than the smallest worthwhile difference, calculated as 0.2 × between subject SD. [a] greater than CM; [b] greater than CD; [c] greater than STR; [d] greater than WD; [e] greater than WM; [f] greater than WNG.

Discussion

Using power law, this study has presented a novel method of modelling the running intensity of professional soccer competition as a function of time, providing coaches with a new level of flexibility when monitoring the demands of training relative to peak match intensity. It is well established that the running intensity of soccer experiences declines at various stages throughout a match, most likely due to fatigue or related to specific match situations (Mohr et al. 2005; Edwards and Noakes 2009; Carling and Dupont 2011; Bendiksen et al. 2012); however, this study was the first to establish a duration-specific profile of the peak running periods of professional soccer. Importantly, knowledge of the peak intensities attained during competition allows coaches to adequately prepare athlete for these demands through appropriate training methodologies. Furthermore, this study provides insight into the rate of decline in peak running intensity (i.e., slope) amongst these players, which was similar across positions. This may indicate that players are not only limited by fatigue in maintaining running intensity, but stoppages when the ball is not in play could limit the running intensity sustained by all players simultaneously.

Knowledge of the most demanding periods players are exposed to during competition allows coaches to prepare their athletes appropriately. This study observed that as time approached zero, relative distance peaked at ~170–200 $m \cdot min^{-1}$, depending on position. This is substantially higher than the values of ~100–120 $m \cdot min^{-1}$ that are typically reported over a half of a match (Bradley and Noakes 2013), which suggests that prescribing training based on "match intensity" must be done so using the peak running profile of competition, as using whole-match values will not adequately prepare athletes for the rigors of competition. As such, using the calculations presented in this study, coaches may determine "match speed" for any given value of time (i.e., the duration of the drill in question) and monitor these intensity of training drills relative to these values. However, it is important to note that the peak relative distances covered in this study equate to running speeds of 2.8–3.3 $m \cdot s^{-1}$, well below the maximal aerobic speed typically reported amongst professional soccer players (~4.4 $m \cdot s^{-1}$) (Wong et al. 2010). As soccer is stochastic in nature (Barrett et al. 2015), it is clear that the running requirements of competition fluctuate, and therefore, it may also be beneficial to quantify the peak periods of high-intensity running.

Amongst professional soccer competition, several researchers have quantified the peak 5-min period of high-intensity running of match play using various high-speed thresholds between 4 and 5.5 $m \cdot s^{-1}$ (Mohr et al. 2003; Bradley and Noakes 2013; Carling et al. 2016). The present study observed that high-speed running peaked at ~50–65 $m \cdot min^{-1}$, depending on position. These data are above the ~45 $m \cdot min^{-1}$ above the same high-speed threshold reported across a 5-min period (Bradley and Noakes 2013), outlining an increased sensitivity to absolute peaks in the present study. Despite this, across all previous studies, there has been a consistent decrease reported in running intensity in the periods following the peak 5-min block that is suggestive of fatigue (Mohr et al. 2003; Bradley and Noakes 2013; Carling et al. 2016). This is consistent with the findings of the present study, where a negative, non-linear relationship was observed between the duration of the moving average applied, and high-speed relative distance achieved. Whilst the decline in running intensity observed in the present study may be a result of some level of fatigue, it is difficult to ascertain the exact physiological mechanism using only displacement data. Nonetheless, the power law method utilised in this study revealed that although the speed-based running requirements of competition are evidently high amongst WD and STR compared to other positions (indicated by the substantial differences in the intercept value), the rate of decline of these capacities was similar throughout the squad. The exact mechanism behind this is unclear, as differences in aerobic qualities between positions have been previously described (Stolen et al. 2005). Therefore, it may be that the similarity in the rate of decline amongst positions may be a function of all players receiving the same training stimulus, though this notion remains speculative as no measure of training load was considered in this study.

In addition to the observed differences between positions regarding speed-based movements, competitive soccer imposes varying acceleration demands on each position (Varley and Aughey 2013). Large between-unit variations have been observed using GPS to assess the number of acceleration (coefficient of variation [CV] = 10–43%) and deceleration (CV = 42–56%) efforts during a team-sport simulation protocol (Buchheit et al. 2014), which might be a result of the "count" technique employed (i.e., a non-substantial difference between units could lead to a substantially different result). The AveAcc measure used in this study avoids this issue, as all data points are considered regardless of their magnitude, and pilot data from our laboratory suggest this method possesses adequate reliability (CV = 5.7%; 4.5–7.8%). The findings of this study are in line with others (Varley and Aughey 2013), where the WD position had far greater acceleration requirements compared to other positions. Though these authors did not consider the WNG position as an isolated positional group, the present study found a similar increase in the acceleration/deceleration profile for this position compared to others. The WD positional group is regularly involved in attacking and defending duties, resulting in constant back and forth movements during match play. The WNG position also frequently accelerates into a wide position to have an attempt at goal or cross the ball into position for a goal attempt, which may explain the increased acceleratory demands of this group (Varley and Aughey 2013). Therefore, it would seem necessary that these players are exposed to the necessary stimulus in training to reflect the increased acceleration and deceleration requirements of competition.

The P_{met} method represents a theoretical model for assessing the estimated energetic cost of team sports activity, where both accelerated and constant speed running are accounted for (Osgnach et al. 2010). Recently, this metric has been challenged as a valid indicator of metabolic load during non-locomotor activities such as jumping and kicking (Buchheit et al. 2015; Brown et al. 2016) and for quantifying the energetic cost of sprints with changes of direction (Hader et al. 2016). However, with these limitations in mind, 10 Hz GPS units possess the ability to accurately assess these demands, with a strong relationship with the criterion (laser device; typical error = 2.4%; 2.1–2.9%) (Rampinini et al. 2015). Therefore, this technique represents an accurate measure for the assessment of the external running demands of team-sport activity, where high-intensity efforts at both high and low speed are incorporated. In this study, the CD positional group exhibited the lowest P_{met} intercept of any position (ES = 1.01–1.65), indicating a lower peak P_{met} of this position. During competition, the tactical requirements of the CD consist of primarily defending the goal area, resulting in the activity profile of this position often being limited by the movements of opposing players. The CD is generally involved in more body contacts and other soccer-specific actions such as jumping and heading rather than necessarily a high running-based activity profile (Varley and Aughey 2013). Nonetheless, the peak P_{met} achieved by soccer players is similar to rugby league (Delaney et al. 2016), despite a substantially lower acceleration requirement. This finding demonstrates the application of the P_{met} metric as an overall indication of the running profile of competition. However, information regarding the mechanism of the acquired load (i.e., acceleration/deceleration of high-speed running) is important when prescribing training with a specific physical adaptation in mind, and therefore, it is recommended that this metric be used in tandem with other measures.

The peaks in running intensity increased as the length of the moving average decreased in our study and were substantially higher compared to previous research where pre-defined blocks were analysed (Mohr et al. 2005; Bradley and Noakes 2013; Barrett et al. 2015). In addition, using the power law (Katz and Katz 1994), this study was able to establish the relationship between running intensity and moving average duration for each metric. By applying the theory of the power law often applied in sports such as running, cycling and swimming (Katz and Katz 1994), we have provided coaches and practitioners with a method for estimating peak "match intensity" for any given duration. It is conceded that a number of external factors such as match status, location and opposition strength might influence the running intensity achieved during team sports competition (Kempton and Coutts 2015; Paul et al. 2015), a phenomenon that is less prevalent in individual sports. However, the almost perfect relationship between log-transformed running intensity and log-transformed time would indicate little unexplained variance in the model, and therefore, it can be suggested that this method is appropriate for estimating the peak demands of high-level soccer.

Practical Implications

This study has presented a strong framework for the prescription and monitoring of specific training methodologies. Recent rule changes (*Amendments to the Laws of the Game–2015/2016*) have permitted the use of GPS technology during matches, allowing teams to directly compare match and training data accurately. By retrospectively analysing competitive matches, a series of simple calculations have been proposed which allow training drills to be assessed relative to the peak running intensities achieved during competition. For example, when prescribing a 5-min training drill aimed at replicating the demands of competition, using the values given in Table 1, match intensity (i.e., relative distance) for a CD could be calculated as a function of time, as:

$$i = 173t^{-0.17} \quad (3)$$

This results in an estimated match intensity of 132 m·min^{-1} for the 5-min drill, which can then be compared to the individual player's output during training. Commonly, coaches are faced with the challenge of providing an environment where physical, technical and psychological and competitive skills can be developed concurrently (Charlesworth 1994). The techniques presented in the current study allow the intensity of training drills to be assessed over time, which permits coaches to tactically prescribe and periodise sport-specific drills more precisely, relative to the peak match intensity athletes are required to reach during competition. Furthermore, if a player is unable to maintain the required running intensity of competition during soccer-specific training drills, they may benefit from the inclusion of traditional running drills to develop their running capacities (Helgerud et al. 2001) before they are able to perform in a competitive setting. Whilst it is important to expose athletes to the peak running intensities of competition, it is vitally important that this is done so safely, as part of an appropriately periodised preparation program.

What are the main findings?

- Using power law, the peak running demands of professional soccer competition can now be predicted as a function of time.
- A series of simple equations have been presented which can be built into a team's monitoring system, for accurate comparisons between training and the most demanding periods of play.
- Positional differences exist in terms of the peak running capacities achieved, outlining the need to individualise training relative to the match demands.
- The rate of decline in running intensity is much more alike across positions, indicating all positions' running intensity declines at similar rates during match play.

Disclosure statement

No potential conflict of interest was reported by the authors.

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