Title: Quantifying the peak physical match-play demands of professional soccer substitutes following pitch-entry: Assessing contextual influences

Running head: Peak demands of soccer substitutes

Abstract

Purpose: To quantify the peak post-pitch-entry physical responses of soccer substitutes, while assessing contextual influences. Peak responses may be important performance indicators for substitutes introduced to provide a physical impact.

Method: Thirty-three professional substitutes wore Microelectromechanical Systems during 44 matches (4±3 observations·player^{-1}). Post-pitch-entry relative peak total and high-speed (>5.5 m·s^{-1}) distances, average acceleration, and PlayerLoad™ were calculated using rolling averages over 60-s to 600-s. Linear mixed models assessed contextual influences (position, substitution timing, scoreline, and location).

Results: Substitutes introduced during the final ~15 min of match-play covered less high-speed distance than first-half substitutes (~2.8-3.1 m·min^{-1}) over 480-s to 600-s epochs, and less than 60:00-74:59 min substitutes (~1.7-1.8 m·min^{-1}) during 540-s and 600-s epochs. Average acceleration during all except 180-s epochs was lower for 75:00+ min substitutes compared with first-half replacements (~0.27-0.43 m·s^{-2}), and lower than 60:00-74:59 min substitutes during 60-s epochs (~0.13 m·s^{-2}). Substitutes introduced when their team was winning recorded greater distances over 120-s to 600-s epochs (~6.2-7.7 m·min^{-1}), and higher PlayerLoad™ values during 120-s, 180-s, 300-s, and 480-s epochs (~2.7-3.6 arbitrary units·min^{-1}), compared with when scores were level at pitch-entry. Irrespective of substitution timing, substitute midfielders exceeded the total distance of substitute attackers (~5.9-16.2 m·min^{-1}) for all except 360-s and 600-s epochs, and defenders (~13.3-26.7 m·min^{-1}) during epochs <300-s.

Conclusions: This study provides benchmark data for practitioners tailoring training and recovery protocols, particularly 'top-up' conditioning, based upon the competitive demands of soccer substitutes. Knowing how contextual factors influence substitutes' peak match-play responses may also help managers/coaches to assess the efficacy of substitution strategies.

Key Words: Football; monitoring; fatigue; substitution.

Purpose

The strategic introduction of substitutes represents a means by which team management staff can attempt to influence the outcome of soccer matches. Acknowledging that contextual factors such as playing position or match scoreline may influence substitution timing (Hills et al., 2019; Hills et al., 2020b; Hills et al., 2018; Myers, 2012), substitutes are typically introduced at half-time or during the second-half of match-play (Bradley et al., 2014; Hills et al., 2020b; Hills et al., 2018; Myers, 2012). Whilst other motivations exist (e.g. decisions to replace injured or underperforming players, or to provide playing time to youth players or those returning from injury), and noting that a substitution may be made with either offensive or defensive objectives, a substitute's ability to provide a physical impetus or to facilitate changes in team tactics often represent substantial motivations for the use of substitutions in professional soccer (Hills et al., 2020c). Accordingly, markers of physical performance such as a player's high-speed running (HSR) responses following pitch-entry, are often considered to be key performance indicators for substitutes during match-play (Hills et al., 2020c).

Although partial-match players typically experience lower absolute match-play demands compared with the ~10-12 km covered by individuals who complete 90 min (Di Salvo et al., 2007; Hills et al., 2020b; Mohr et al., 2003), substitutes may record greater relative (i.e. per min played) running distances than players who start a match (Bradley et al., 2014; Hills et al., 2018). However, whilst reporting movement responses on a whole-match or whole-bout basis is useful to help increase the understanding of a player's overall physical loading, such data do not indicate the demands associated with the most intense periods of play (i.e. 'peak demands'). Many decisive moments of a match involve explosive or high-speed actions such as HSR, sprinting, changes of direction, and/or the execution of soccer-specific skills (Faude et al., 2012). Knowing the peak demands of match-play may be useful for practitioners when designing training programs to better prepare players for these crucial periods of competition (Whitehead et al., 2018). When considered alongside a substitute's absolute match-day demands, such information may help to inform the design of 'top-up' conditioning sessions to ensure that their limited match-play exposure does not compromise ongoing loading patterns and thus adaptive responses for partial-match players (Anderson et al., 2016a;

Buchheit, 2019; Hills et al., 2020a; Morgans et al., 2018). Moreover, recognising many managers' desire for replacements to make a physical impact upon a match (Hills et al., 2020c), quantifying a substitute's peak match-play 'intensity' could represent a valuable metric in helping to assess the efficacy of this substitution strategy. In support, practitioners have previously expressed a wish for further research to be conducted in relation to the physical responses of substitutes following their entry onto the pitch (Hills et al., 2020c).

To identify the peak demands of team sports, researchers often divide matches into discrete 'fixed' epochs, typically 5-15 min in length (Hills et al., 2019; Mohr et al., 2003; Whitehead et al., 2018). However, as fixed time-periods lack sampling resolution and thus underestimate the most demanding periods of team sport match-play by up to ~25% (Cunningham et al., 2018; Doncaster et al., 2020; Fereday et al., 2019; Varley et al., 2012a), rolling averages have been increasingly used for this purpose (Delaney et al., 2018b; Fereday et al., 2019; Whitehead et al., 2018). Amongst English Championship soccer players who started a match, relative total distance (TD) and HSR peaked at ~190 $m \cdot min^{-1}$ and ~60 $m \cdot min^{-1}$, respectively, over a 60-s period, with relative values decreasing as rolling epochs increased in length (Fereday et al., 2019). In contrast to the relative responses typically observed across their entire playing bout (Bradley et al., 2014; Hills et al., 2018), substitutes covered less TD over epochs of 180-s to 600-s compared with starting players (Fereday et al., 2019). Unfortunately, these data relate solely to locomotor demands, and neglect consideration of important factors such as substitution timing or match scoreline which could directly or indirectly influence a substitute's post-pitch-entry responses (Ferraz et al., 2018; Hills et al., 2020b; Waldron & Highton, 2014). Therefore, over epochs of 60-s to 600-s in length, this study aimed to determine the duration-specific peak physical demands of professional soccer substitutes, whilst assessing contextual influences. In addition to having potential value for managers and coaches when assessing and addressing their substitution strategies, such information may assist practitioners in providing training specificity for this bespoke population of soccer players. For example, any discrepancies in match-play demands between substitutes and whole-match players may help to inform the design of tailored recovery and/or 'top-up' conditioning strategies. It was hypothesized that contextual factors would influence the peak physical responses of soccer substitutes across all epoch durations, but that greater influences would be observed for the longest epochs assessed. Specifically, it was anticipated that midfielders and substitutes introduced later in the match would achieve the greatest peak responses while comparatively smaller influences would be exerted by match location and scoreline.

Method

Following receipt of institutional ethical approval, outfield players from a professional soccer club (n = 33, age: 26 ± 4 years, stature: 1.82 ± 0.07 m, mass: 77.6 ± 7.3 kg) were monitored during English Championship matches in which they entered the pitch as substitutes. Data-collection took place during the 2018-2019 and 2019-2020 seasons, and 121 individual substitute observations (4 ± 3 observations·player^{-1}, range: 1-11 observations·player^{-1}) were yielded from 44 matches. Data were only included from substitutes who played at least five min (i.e. including stoppage time) of any given match, and the sample consisted of 15 midfielders, nine attackers, and nine defenders. All players were fully briefed about the risks and benefits of participation prior to providing their written informed consent in advance of data-collection. Given the observational nature of the study, no attempt was made to influence players' responses.

Substitutes' movements following pitch-entry were captured by Microelectromechanical Systems (MEMS; Optimeye S5, Catapult Sports, Melbourne, Australia) containing 10 Hz Global Positioning Systems (GPS) and 100 Hz accelerometers, which were worn between the scapulae and contained within a specifically designed vest designed to limit movement artefacts. Acceptable reliability (coefficient of variation; CV%: 2.0–5.3%) has been demonstrated when using GPS sampling at 10 Hz to measure instantaneous velocity (Varley et al., 2012b), and the accelerometers within the devices have also shown good intra (CV% = 0.9-1.1%) and inter-unit (CV% = 1.0-1.1) reliability (Boyd et al., 2011). In line with routine monitoring practices at the club, each player wore the same unit throughout the study to avoid inter-unit variation.

The MEMS devices were activated prior to the pre-match warm-up and according to the manufacturer's guidelines. Match-day data were downloaded post-match using proprietary software (Sprint 5.1.7, Catapult Innovations, Melbourne, Australia), trimmed according to a substitute's playing time, and exported in their raw format on an individual player basis. Each resulting file reflected time-series data representing the period between a substitute entering the pitch, and the end of match-play. The mean number of satellite connections during data collection was 13 ± 1 and the horizontal dilution of precision (HDOP) was 0.7 ± 0.2. Where instantaneous speed exceeded 10 $m \cdot s^{-1}$ or acceleration/deceleration exceeded 6/-6 $m \cdot s^{-2}$, these data-points were deemed to be erroneous based upon the playing population under investigation and were thus replaced with zeros as per previous research (Delaney et al., 2018b; Weston et al., 2015). A rolling average function was then separately applied to each dependent variable (*zoo* package, R Studio, v R-3.6.1.). Epochs were specified in 60-s increments to create rolling periods from 60-s to 600-s in length, from which the highest value achieved for each epoch duration was recorded. For substitutes who played less than 600-s, only data from completed epochs were included (e.g. a player who played for between eight and nine min only provided data for the 60-s to 480-s epochs).

Four dependant variables were analysed. From GPS data, doppler-shift-derived instantaneous speed allowed calculation of TD and HSR (>5.5 $m \cdot s^{-1}$), whilst 'average acceleration' ($m \cdot s^{-2}$) represented the absolute (i.e. when all made into positive values) value of all GPS acceleration and deceleration data when averaged over the defined period (Delaney et al., 2018a; Delaney et al., 2018b). This approach to quantifying acceleration and deceleration demands is well suited to time-series data and may offer increased reliability (CV% for average acceleration data sampled at 10 Hz: ~1-2% versus ~2-12% for pre-defined thresholds) compared with arbitrary categorisation of acceleration and deceleration activities according to pre-determined intensity bands (Delaney et al., 2018a). In addition, instantaneous PlayerLoad™ (PL) was determined from 100 Hz accelerometer data (Barrett et al., 2014). To allow comparison between rolling epochs of different lengths, dependent variables were expressed relative to epoch duration (i.e. per min). For each substitution, contextual information relating to playing position (i.e. 'midfielders', 'attackers', 'defenders'), match location (i.e. 'home', 'away'), match scoreline at the time of a substitute's pitch-entry (i.e., 'winning', 'drawing', 'losing'), and substitution timing (i.e. introduced; 'first-half', '45:00-59:59 min', '60:00-74:59 min', '75:00+ min') was also recorded.

Statistical analyses

Linear mixed models were used to account for the repeated measurement of the same individuals over multiple matches and the unbalanced number of observations from each player. Separate models were constructed for each dependent variable at every epoch duration (i.e. 60-s to 600-s) to assess the influence of several contextual factors on the physical responses observed. Prior to constructing the main models, variance components analysis was conducted for all variables across all epoch lengths (Table 1) to calculate the intraclass correlation coefficients for the random factors of 'player' and 'match', and determine whether they accounted for a significant proportion of the total variance within the model (Doncaster et al., 2020; Jones et al., 2019). 'Player' was specified as a random effect in all subsequent models due to the non-independence of repeated measurements amongst players, whilst 'match' was also included if it demonstrated a significant ICC and its presence improved the overall model fit when assessed via a likelihood ratio test. Random intercepts were modelled throughout to ensure model convergence, whilst parameters were estimated via the maximum likelihood method. For the main analyses, position (i.e. 'midfielders', 'attackers', 'defenders'), match location (i.e. 'home', 'away'), match scoreline at the time of a substitute's pitch-entry (i.e., 'winning', 'drawing', 'losing'), and substitution timing (i.e. a substitute being introduced; 'first-half', '45:00-59:59 min', '60:00-74:59 min', '75:00+ min') were modelled as fixed effects to assess the influence of these variables on the peak demands recorded. As per previous substitute research, substitute midfielders were used as the reference category for the fixed effect of position (Hills et al., 2019; Hills et al., 2020b), while 'home' matches, 'winning', and instances in which a substitute was introduced at '75:00+ min' in the match, were used as the comparators for the location, scoreline at the time of pitch-entry, and substitution timing variables, respectively (Hills et al., 2019; Hills et al., 2020b). Further comparisons between levels of the categorical fixed effects were made using Bonferroni-adjusted least squares means tests and standardized effect sizes (ES), which were interpreted as: 0.00-

0.19, *trivial*; 0.20-0.59, *small*; 0.60-1.20, *moderate*; 1.21–2.0, *large*; and >2.01, *very large* effects (Hopkins et al., 2009). Analyses were conducted in R Studio statistical software (V 3.6.1) using the *lme4*, *lmerTest*, and *emmeans* packages. Descriptive statistics are presented as mean ± standard deviation (SD), whereas ES are presented with 90% confidence intervals (CI).

****INSERT TABLE 1 HERE****

Results

Table 2 provides descriptive statistics for peak physical demands in relation to each dependant variable at every epoch duration. Although interactions between contextual factors were not assessed, the number of individual player observations when grouped by playing position and substitution timing are displayed in Table 3. Irrespective of playing position, match scoreline, and match location, substitutes introduced during the first-half recorded more TD during 480-s epochs (p = 0.031, ES: 0.59 [-0.27-1.45], *small*), and more HSR during 480-s to 600-s epochs (all p ≤0.05, ES: 0.62-0.63, *moderate*), compared with substitutes entering the pitch at 75:00+ min (Figure 1). Players introduced between 60:00-74:59 min also performed more HSR than 75:00+ min substitutes during 540-s (p = 0.024, ES: 0.33 [0.00-0.66], *small*) and 600-s (p = 0.036, ES: 0.20 [-0.31-0.70], *small*) epochs. Compared with 75:00+ min substitutes, players introduced between 60:00-74:59 min returned higher average acceleration values during 60-s epochs (p = 0.027, ES: 0.40 [-0.11-0.90], *small*), while first-half substitutes exceeded the average acceleration responses of 75:00+ min substitutes for all except for 180-s epochs (all p ≤0.05, ES: 0.92-1.21, *moderate-large*). Although PL values over 120-s and 180-s were greater for substitutes introduced between 60:00-74:59 min compared with 75:00+ min substitutes (both p ≤0.05), *trivial* ES were observed (ES: 0.10-0.12).

****INSERT TABLE 2 HERE****

****INSERT TABLE 3 HERE****

****INSERT FIGURE 1 HERE****

Match location did not influence a substitute's peak match-play demands, whereas match scoreline at the time of pitch-entry affected TD and PL responses (Figure 2). Substitutes entering the pitch when the reference team was leading in the match recorded greater TD over 120-s to 600-s epochs (all $p \leq 0.05$, ES: 0.41-0.51, *small*), and higher PL values during 120-s, 180-s, 300-s, and 480-s epochs (all $p \leq 0.05$, ES: 0.30-0.37, *small*), compared with when the scores were level at the time of pitch-entry. Moreover, substitutes entering the pitch in winning scenarios produced greater PL responses during 120-s ($p = 0.047$, ES: 0.33 [-0.04-0.69], *small*) and 180-s ($p = 0.042$, ES: 0.38 [0.02-0.75], *small*) epochs compared with when the team was losing at the time of pitch-entry.

****INSERT FIGURE 2 HERE****

Irrespective of substitution timing, Figure 3 shows that substitute midfielders covered greater TD than substitute attackers during all except for 360-s and 600-s epochs (all $p \leq 0.05$, ES: 0.39-0.85, *small-moderate*), and more TD than substitute defenders during epochs shorter than 300-s (all $p \leq 0.05$, ES: 0.90-1.37, *moderate-large*). Substitute midfielders also exceeded the PL of substitute attackers during 60-s to 240-s epochs (all $p \leq 0.05$, ES: 0.42-0.55, *small*), and recorded higher PL values than substitute defenders during all epoch durations (all $p \leq 0.05$, ES: 0.97-1.76, *moderate-large*).

****INSERT FIGURE 3 HERE****

Discussion

This study assessed the peak post-pitch-entry movement demands of professional soccer substitutes over rolling 60-s to 600-s epochs, while highlighting the influence of playing position, the match scoreline at the time of pitch-entry, match location, and substitution timing. Although the peak demands of professional soccer match-play have previously been assessed (Delaney et al., 2018b; Fereday et al., 2019), the current study provides novel data concerning the unique responses of substitutes. Knowing the highest demands experienced during match-play may assist practitioners when designing training and recovery protocols for this bespoke population of soccer players, whilst knowledge of contextual influences could help to inform and/or evaluate substitution strategies. Although direct comparisons could not be made in the current study, practitioners may need to consider whether substitutes experience equivalent peak demands relative to members of the starting team. Indeed, as match-play may represent a substantial and important contributor to a squad's overall physical loading during a competitive season (Anderson et al., 2016a; Anderson et al., 2016b; Morgans et al., 2018), such information could be useful for the design of 'top-up' conditioning sessions aiming to compensate for deficits in the volume and/or intensity of match-play activity performed by partial- versus whole-match players (Buchheit, 2019; Hills et al., 2020a). Moreover, when substitutions are made with the aim of providing a physical impact (Hills et al., 2020c), quantifying the peak responses of those individuals entering the pitch may provide the opportunity for management staff to 'assess then address' substitution strategies.

Depending on epoch duration, peak TD and HSR ranged from ~119-188 $m \cdot min^{-1}$ and ~12-50 $m \cdot min^{-1}$, respectively. Notably, this study observed rolling average-derived peak five min values that exceeded the relative responses reported previously during the five min period immediately following a substitute's pitch-entry (Hills et al., 2019; Hills et al., 2020b). Whereas similar peak TD has been recorded amongst starting players over 60-s to 600-s of English Championship and Australian A-League soccer (Delaney et al., 2018b; Fereday et al., 2019), the current study observed generally lower HSR values for substitutes compared with existing published observations from whole-match players, particularly for defenders (Delaney et al., 2018b; Fereday et al., 2019). Such findings may seem surprising given that on a 'whole-bout' basis substitutes typically cover greater relative running distances compared with players who start a match (Bradley et al., 2014; Hills et al., 2018). However, it should be noted that the opening ~10-15 min following kick-off may elicit the highest running responses of any period of match-play (Bradley & Noakes, 2013; Mohr et al., 2003). Whilst substitutes have also demonstrated relatively heightened movement demands immediately after pitch-entry (Hills et al., 2019; Hills et al., 2020b), the exact time-course of such responses remains to be determined for substitutes. When one considers that an individual's peak demands are likely to reflect the 'fastest' period of play to which they are exposed, and may be influenced by contextual factors such as those assessed in the current study and whether a player is required to operate primarily in an 'offensive' or 'defensive' capacity, it seems plausible that their shorter overall playing time (i.e. compared with starting players) may provide limited opportunities for substitutes to experience many of the most demanding phases of a match (e.g. periods occurring during the first-half).

Substitution timing influenced a substitute's peak physical demands following pitch-entry, particularly with an increase in epoch length. For example, HSR during 480-s to 600-s epochs was higher for players introduced prior to half-time compared with for individuals entering the pitch at 75:00 min or later in the match. Similar patterns were observed for players introduced between 60:00-74:59 min (540-s and 600-s epochs), who at times exceeded the peak HSR of 75:00+ min substitutes. These findings appear to contradict the established notion that a player's expectation of a shorter exercise duration may result in higher relative physical outputs compared with when a longer period of exercise is anticipated (Ferraz et al., 2018; Waldron & Highton, 2014). However, as members of the starting team typically experience progressive reductions in physical performance indicators during the latter stages of a match (Bradley & Noakes, 2013; Mohr et al., 2003; Waldron & Highton, 2014), a substitute's peak running responses may be modulated by the declining physical outputs of surrounding team members and opposition players. Alternatively, or in conjunction, the pre-pitch-entry preparations undertaken by substitutes could have affected their post-pitch-entry physical responses. Prolonged periods of inactivity following a pre-match warm-up may induce physiological processes (e.g. progressive decreases in body temperature) that limit physical performance during high-intensity exercise performed thereafter (Galazoulas et al., 2012; West et al., 2013). Notably, observations from professional soccer appear to suggest that players entering the pitch as second-half substitutes benefitted from increasing the amount of warm-up and rewarm-up activity performed prior to match-introduction, specifically during the pre-match and half-time periods (Hills et al., 2019; Hills et al., 2020b). Acknowledging that some rewarm-up activity was likely performed between kick-off and pitch-entry (Hills et al., 2019; Hills et al., 2020b; Hills et al., 2020c), if this was negligible in volume or intensity then the post-pitch-entry responses of substitutes introduced later in a match may have been further compromised by the length of time elapsing following cessation of the pre-match warm-up (Galazoulas et al., 2012; West et al., 2013). Irrespective of the underlying reasons, the responses observed in the current study suggest that the length of time remaining in a match may represent an important factor influencing the peak physical outputs of substitutes following entry onto the pitch. Indeed, practitioners have intimated that the amount of time remaining in the match, and the adequacy of pre-pitch-entry preparations, may each represent important factors modulating a substitute's ability to make a substantial positive impact (Hills et al., 2020c).

Compared with when the match scores were level, greater TD responses during epochs of 120-s or longer and higher PL values over 120-s, 180-s, 300-s, and 480-s epochs, were recorded when the reference team was winning at the time of a substitute's introduction into a match. Moreover, substitutes introduced in winning scenarios led to greater PL responses over 120-s and 180-s epochs compared with when the team was losing at the time of a substitution being made. These observations are in line with existing reports that substitutes may produce the greatest relative physical outputs when their team is leading in the match (Hills et al., 2019; Hills et al., 2020b). Although such responses may be attributable to factors such as differences in team tactics and/or dominance over fatiguing opposition players, it is likely that mangers typically value the role of substitutes more highly at times when their team is losing in the match compared with when the players already on the pitch have managed to produce a lead (Hills et al., 2020b; Myers, 2012). Acknowledging that substitutes may be made with offensive or defensive intentions and could also influence a match in other ways (e.g. technical and tactical contributions), it may be argued that for managers making replacements with the objective of providing physical impetus (i.e. and thereby potentially changing the 'momentum' of a match), it would be preferable for substitutes to record their greatest peak physical responses when introduced in losing rather than winning scenarios (Hills et al., 2020c).

Midfielders typically cover the greatest match distances of any playing position (Di Salvo et al., 2007; Fereday et al., 2019; Mohr et al., 2003), and the current study indicates that this relationship may also exist for the peak demands of substitute players. In addition, substitute midfielders exceeded the PL responses of substitute defenders during all epoch lengths, and recorded higher PL values than substitute attackers during epochs shorter than 300-s. Acknowledging that certain match situations (e.g. a teammate's injury or poor positioning) may require a player to perform tasks atypical of their positional role, the distinct tactical and physical demands of each position suggest that a position-specific approach to training may at times be beneficial (Buchheit, 2019; Di Salvo et al., 2007). For substitutes, acknowledging that practical barriers may limit what can be safely achieved during the immediate post-match period (Hills et al., 2020a), practitioners may need to consider the diverging positional responses when determining the degree of 'topping-up' required during post-match conditioning sessions (Buchheit, 2019). It should be noted that substantial differences in tactical roles and/or playing 'style' may exist even amongst players categorised as 'midfielders', 'attackers' or 'defenders'. For example, whilst central defenders typically experience the lowest peak physical demands (Delaney et al., 2018b; Fereday et al., 2019), their frequent involvement in both attacking and defending means that wide defenders may record greater acceleration responses compared with any other position (Delaney et al., 2018b; Varley & Aughey, 2013). As sample size limitations prevented more in-depth analysis, it is possible that further differences between specific playing positions were obfuscated by the broad positional classifications adopted in the current investigation.

Accelerating and decelerating represent important actions during soccer match-play, and elicit greater metabolic demands compared with constant-speed running (Osgnach et al., 2010). Although combining acceleration and deceleration data into one metric may preclude identification of the specific component eliciting the loading (i.e. accelerating or decelerating), 'average acceleration' accounts for the neuromuscular cost of all changes in speed, regardless of their magnitude (Delaney et al., 2018a; Delaney et al., 2018b; Varley & Aughey, 2013). Whilst the 60-s peak average acceleration observed for substitutes in the current study (~0.89 $m \cdot s^{-2}$) exceeds published findings from an Australian A-League soccer team (~0.78-0.86 $m \cdot s^{-2}$), substitutes recorded slightly lower (~0.47 $m \cdot s^{-2}$ versus >0.50 $m \cdot s^{-2}$) 600-s values (Delaney et al., 2018b). In contrast to existing reports from players who started a match (Delaney et al., 2018b), no between-position differences in average acceleration were observed in the current investigation for substitutes. However, substitutes who entered the pitch during the final ~15 min of play typically produced lower peak acceleration responses compared with players introduced earlier in the match. Where circumstances allow, practitioners may thus benefit from considering the density of acceleration and deceleration activity performed during top-up conditioning sessions, particularly for substitutes introduced during the final ~15 min of match-play. Notably, to elicit a substantial acceleration and deceleration stimulus may require different training modalities (e.g. small-sided games), compared with the straight-line running drills that are often used to achieve HSR targets for partial-match players (Ade et al., 2014; Hills et al., 2020a).

Knowledge of a substitute's peak match-play demands is useful for practitioners individualising training and recovery practices, as well as managers seeking to assess then address their substitution strategies. However, because locomotor actions are not performed in isolation during a match, considering each performance variable separately may not fully capture the most physically demanding periods of match-play. For example, although HSR and average acceleration peaked at ~50 $m \cdot min^{-1}$ and ~0.9 $m \cdot s^{-2}$, respectively, these demands may not have occurred simultaneously. The inclusion of PL may somewhat offset this limitation, as PL encompasses three-dimensional measures of instantaneous rate of change in acceleration to produce an 'overall' external load (Barrett et al., 2014). Empirical observations suggest that PL is widely used by practitioners, and this metric has also demonstrated strong associations with heart rate and rating of perceived exertion-derived measures of internal training load (Scott et al., 2013). As such, monitoring PL responses alongside locomotor variables such as HSR, may allow comparison of match-play and training demands on a more holistic level. Notwithstanding, it would be beneficial for future research to investigate the interaction between different internal and external load variables when assessing the peak demands of soccer match-play. In addition, although a desire to increase the pace of play often represents an important objective for managers when making a substitution (Hills et al., 2020c), it is acknowledged that several other motivations may also at times be influential and that substitutes may be introduced as part of either an offensive or defensive tactical strategy. Such differences could influence a substitute's post-pitch-entry responses and further research investigating substitute performance (i.e. via indices of physical, technical, and tactical performance) with reference to the specific tactical rationale for making any given replacement may further benefit managers when evaluating the efficacy of substitution strategies. To assess whether substitutes are able to 'get into the game' straight away upon match-introduction, such studies may consider comparing data from the period immediately post-pitch-entry to the responses observed throughout a substitute's playing bout.

Conclusions

This study assessed the peak physical match-play demands of professional soccer substitutes over 60-s to 600-s epochs. Peak TD and HSR distance ranged from ~119-188 m·min^{-1} and ~12-50 m·min^{-1}, respectively, with relative demands decreasing as epochs increased in length. Substitutes therefore recorded similar peak TD, but lower peak HSR responses compared with published reports from starting players in professional soccer (Delaney et al., 2018b; Fereday et al., 2019). Contextual factors influenced the peak physical responses of substitutes, with players entering the pitch during the final ~15 min of match-play typically recording the lowest peak HSR and acceleration demands. Similarly, greater TD and PL values were generally recorded for substitutes who entered the pitch when their team was winning in terms of match scoreline compared with when the scores were level, whilst substitute midfielders typically produced the highest TD and PL per epoch of any playing position.

What does this article add?

The data and methods presented in this study may assist applied practitioners when designing individualized training and recovery protocols for substitutes. Not only must players be prepared for the physical demands of match-play, 'top-up' training may be necessary to compensate for potential reductions in a substitute's peak intensity (i.e. in addition to considering the volume of activity performed on match-day) compared with whole-match players (Buchheit, 2019; Hills et al., 2020a). Likewise, conditioning sessions may need to account for the reduced peak HSR and acceleration values recorded by substitutes introduced later, versus earlier, in a match. Understanding contextual influences on a substitute's peak match-play responses may also help managers to evaluate their substitution strategies, particularly when making a physical impact is the primary objective. For example, perhaps due to lack of opportunity for involvement and/or the effects of prolonged periods of relative inactivity prior to pitch-entry (Hills et al., 2020c), it is possible that the length of time remaining and/or the match scoreline may each represent important factors influencing a substitute's ability to provide a substantial physical impact upon a match.

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Legends

Table 1: Intraclass correlation coefficients of each random factor in relation to each outcome variable across every epoch length.

Table 2: Descriptive statistics indicating the duration-specific peak physical demands of substitutes during match-play. Data are presented as mean ± standard deviation.

Table 3: Number of individual player observations grouped by playing position and substitution timing.

Figure 1: The influence of substitution timing on a substitute's peak total distance (panel A), high-speed running distance (panel B), average acceleration (panel C), and PlayerLoad™ (panel D) responses following pitch-entry.

[a]: Significant differences between substitutes introduced at 75:00+ min and substitutes introduced between 60:00-74:59 min of match-play, [b]: Significant differences between substitutes introduced at 75:00+ min and substitutes introduced during the first-half of match-play (all at the $p \leq 0.05$ level).

Figure 2: The influence of match scoreline at the time of pitch-entry on a substitute's peak total distance (panel A), high-speed running distance (panel B), average acceleration (panel C), and PlayerLoad™ (panel D) responses following pitch-entry.

[a]: Significant differences between substitutes introduced when the team was winning versus when the scores were level, [b]: Significant differences between substitutes introduced when the team was winning versus when losing (all at the $p \leq 0.001$ level).

Figure 3: The influence of playing position on a substitute's peak total distance (panel A), high-speed running distance (panel B), average acceleration (panel C), and PlayerLoad™ (panel D) responses following pitch-entry.

[a]: Significant differences between substitute midfielders and substitute attackers, [b]: Significant differences between substitute midfielders and substitute defenders (a single letter indicates

differences at the $p \leq 0.05$ level, whilst two of the same letter indicates differences at the $p \leq 0.001$ level).