Estimating Postmatch Fatigue in Soccer: The Effect of Individualization of Speed Thresholds on Perceived Recovery

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Estimating post-match fatigue in soccer: The effect of individualization of speed thresholds on perceived recovery

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ABSTRACT

Purpose: This study investigates the effectiveness of different individualization methods of speed zones during match-play to estimate post-match perceptual recovery in soccer. **Methods**: Twelve under 19 players undertook field-based assessments to determine their maximal aerobic speed (MAS) and maximal sprint speed (MSS). External load (extracted from 10 Hz GPS over 10 official matches) was measured and classified into four categories: 1) low-speed running; 2) moderate-speed running; 3) high-speed running (HSR) and 4) sprinting. Match running distribution into different speed zones were categorized using either: 1) MAS; 2) MSS; 3) MAS and MSS as measures of locomotor capacities (LOCO); and 4) using absolute values (ABS). Players perceived recovery status (PRS) was recorded post (Post), 24 (G+24H) and 48-hours after each game (G+48H). **Results**: Different individualization methods resulted in distinct match outputs within each locomotor category. The PRS was lower (p<0001) at Post (3.8±1.32, 95%CI = 3.6-4.2), G+24H (5.2±1.48, 95%CI = 4.9-5.6) and G+48h (6.0±1.22, 95%CI = 5.7-6.3) compared to pre-match values (7.1±1.05, 95%CI = 6.8-7.3). The absolute PRS score was better associated with HSR using LOCO method at Post (Beta = -1.7, 95%CI = -3.2, -0.22, p=0.027), G+24H (Beta = -2.08, 95%CI = -3.22, -0.95, p=0.001) and G+48H (Beta = -1.32, 95%CI = -2.2, -0.4, p=0.004) compared with other individualization methods. **Conclusions**: Our results suggest that LOCO may better characterize the match intensity distribution (particularly for the HSR and sprinting categories) and should be preferred over MAS and MSS to estimate perceived recovery.

Keywords: external load; GPS; perceptual measures; soccer match; youth players.

INTRODUCTION

The monitoring of the training load has been considered by practitioners as an important strategy to assist athletes to enhance performance and to reduce injury risk in a variety of sports. Within this context, research has previously established that the development of fatigue during training and competitive phases impact player's responses to training and competition demands [1]. Moreover, excessive fatigue may also compromise the capacity of the players to tolerate and to recover from high training loads, and consequently increase the odds of injury [1,2]. Accordingly, elite soccer clubs should seek to implement a fatigue monitoring system and effective strategies to aid player's recovery as part of the training process and overall practice organization [3].

Athlete self-reported measures (ASRM) are "paper-based or electronic records of an athlete's perceived physical, psychological, and/or social well-being, completed on a regular, often daily basis"[4]. Research has recognized that ASRM present the triple advantage of being easy to use, cost effective and sensitive [3,5]. Recently, studies reported that specific ASRM such as wellness questionnaires were effective to estimate the capacity of team-sport players to perform during training and competition [6-8]. As such, subjective measures have been generally supported as the most efficient instrument to monitor player's fatigue/recovery status in team-sport setting [6,7,8] compared to objective measures. This suggests that subjective measures may be more appropriate or more sensitive to assess the stress imposed by training and competition [5]. Specifically, perceptual ratings (e.g. recovery, fatigue and soreness) collected subsequently to the match (e.g. 24- and 48-hours post-match) may present a more holistic appraisal of the internal stress (e.g. oxidative stress, muscle micro-trauma) induced by the previous match and reflect on the extent of residual fatigue [9].

Alternatively, external output during match-play and training practices have been associated with acute and residual changes in specific fatigue-related markers such as muscle damage, neuromuscular readiness and perceptual state [10]. Within this context, the use of arbitrary and absolute thresholds for quantifying running speed during training and competition have been predominantly applied [11-13]. This approach has also been adopted by previous investigations to describe the impact of external load on post-match fatigue and recovery time-course [10,14,15]. However, it is important to consider that running speed thresholds tailored (e.g. maximal aerobic speed) to each player may better identify the relative physiological and neuromuscular demands/load experienced during training and competition [16,17]. It is reasonable to assume therefore, that a tailored approach to external load quantification may be appropriate to inform decisions on training load management, as well as the time-course of training-induced adaptions and recovery status [3,10,16,18]. Accordingly, the external load individualization method has been commonly applied to "reassess" the competitive demands in soccer [16,17,19,20]. This individualization approach is performed through the use of different physiological attributes such as maximal aerobic speed (MAS) or maximal sprinting speed (MSS) [19,20], or through a combination of MAS, MSS and anaerobic speed reserve (ASR) [19-21].

In line with the basic principle of exposure-response relationship (i.e. workload-fatigue), a tailored approach to quantify training load is recommended. This may allow an accurate identification of the physiological strain experienced by each individual player during training and competition [3,17]. This approach may consequently benefit practitioners, particularly for programming daily training plan of each individual player or targeted groups (e.g. injured players returning to sports participation and/or competition following rehabilitation process)[22]. Recently, Scott & Lovell [9] observed that the individualization of speed thresholds was not sufficient to enhance the dose-response determination in female soccer players. It is important to highlight that the study [9] examined the dose-response relationship only during a training camp without including matches. According to the authors, the speed zone individualization may better elucidate the dose-response during matches[9] since match load (external and/or internal load during the competition) has been reported as a main determinant of a high weekly training load [23]. Consequently, it is still unclear which individualization method can be considered as optimal to estimate players' fatigue and recovery responses. As stated previously, the use of arbitrary and absolute thresholds have been applied to investigate the impact of external load metrics on perceptual recovery measures (total quality recovery scale, and brief assessment of mood) [14,15]. However, only one study has examined the efficiency of an individualized approach to quantified the dose-response to training (e.g. fatigue and soreness)[9]. To our knowledge there is currently a paucity of studies examining the PRS as an indicator of post-match fatigue and recovery. Moreover, this is the first study to examine the individualization of external load and its utility to estimate fatigue and recovery in male soccer players. Therefore, our objective was to investigate the effectiveness of different individualization methods of speed zones to estimate post-match perceptual recovery in soccer.

METHODS

Participants

Fourteen under 19 outfield male youth soccer players from a high-level youth academy from Qatar (Al Sadd Sports Club) participated in this study. Players' displayed on average 9 years of training experience. Data were collected during the competitive phase (10 official matches played between February and March) of the season 2016/2017. The inclusion criteria were: 1) a minimum of two matches per player where PRS and GPS match data were both recorded, and 2) ≥75-min of total match-play time. This resulted in a total of 78 individual match observations from 12 players (age 18.9 ± 0.8 years, height 174.4 ± 0.51 cm, weight 66.4 ± 10.44 Kg, body mass index 21.8 ± 2.4kg/m^2) belonging to different playing positions (four defenders, five midfielders and three forwards). All matches were played in 2 x 45 min with 15 min interval over an official natural soccer field (70m x 100m). Players played all the matches under the same tactical formation (4-3-3) throughout the period of the study. The temperature and humidity during the games were 24 ± 3.1^o C and 55 ± 11% respectively. The weekly micro-cycle during the competitive phase was comprised by one official match and 5 training sessions with a day off 24 hours after the match. Specifically, the post-match training routine was comprised by a passive recovery day 24 hours after the match (G+24H, day-off) and an active recovery training session 48 hours after the match (G+48H). This study has been approved by the ethical committee of St Mary's University, England, and followed the ethical recommendations suggested by the Declaration of Helsinki. Upon receiving the ethical approval, the club provided no objection to the study and all participants and their respective parents provided written informed consent.

Study Design

A cohort observational study design was used to investigate the effectiveness of different individualization methods of speed zones to estimate post-match perceptual recovery in soccer.

Physical testing battery

A physical testing battery was used to measure the status of the player's performance (MAS = 16.1 ±1.1 km/h, MSS = 31.6 ± 1 km/h, ASR = 15.5 ± 2.0 km/h) and to inform the individualized speed thresholds. The physical assessments included the 30-15 intermittent fitness test (IFT) and the 40 m straight line sprinting and were performed one week before the beginning of the data collection [24]. Following a debrief of the assessments and a standardized warming up, players started the 40 m sprinting test from a standing position with their front foot 0.5 m behind the first timing gate and were instructed to accelerate maximally until they cross the last timing gate (Race Time 2, Microgate S.r.I., Via Stradivari, 4, 39100 Bolzano – Italy). The players performed two trials with at least three min of a passive rest between repetitions to allow full recovery. Each split time (e.g. 10, 20 etc.) was measured to the nearest 0.01 s. Subsequently, MSS was defined as the fastest 10m split obtained during test [20]. The Intraclass Correlation Coefficient (ICC) values of the 40 m sprinting test have been observed to range between 0.94 - 0.99 [25]. Following a recovering period of approximately 10 min, players were required to perform the $30\text{-}15_{IFT}$. The speed attained during the last completed stage of the $30\text{-}15_{IFT}$ was taken as the final velocity (V_{IFT}) and MAS was estimated as 85% of the V_{IFT} ($MAS = 0.85 * V_{IFT}$) [26]. This test has been shown to have good test-retest reliability with a typical error of measurement of 0.3 km/h (ICC = 0.96), suggesting a potential difference of 1 stage or 0.5 km/h[24].

Data individualization methods

External load was measured with a 10 Hz GPS device (Optimeye S5, Catapult Innovations, Australia). The devices were allocated at the players' upper back between the scapulae housed in a tight-fitting garment to reduce movement artefact. The devices were turned on just before the warming up (~ 30 min) prior to the matches to enable acquisition of the satellite signals. During the period of data collection, players used the same GPS unit to reduce the measurement error [27]. The mean number of satellites during data collection was 13.9 ± 1.1 and the mean horizontal dilution of position was 0.7 ± 0.05. Following each match, GPS data was downloaded from Catapult Sprint v5.0.6 software. The raw data was then transferred to a personalized Microsoft Excel spreadsheet (Microsoft, Redmond, USA). As described in Table 1, match running intensity was classified into four categories: 1) low-speed running (LSR); 2) moderate-speed running (MSR); 3) high-speed running (HSR) and 4) Sprinting. Total high-speed running (THSR) was calculated as the sum of HSR and Sprinting. Match running distribution into different speeds zones were categorized either using relative or absolute methods as per the following: 1) individualized using MAS *per se*; 2) individualized using MSS *per se*; or 3) individualized using MAS and MSS as measures of locomotor capacities (LOCO); and 4) using absolute values (ABS). The criteria used to individualize speed thresholds is provided in Table 1 [20]. The individualization approach utilized by this study followed the procedures previously applied by Hunter et al. [20].

Insert Table 1 here

Perceived recovery scale

The Perceived Recovery Status (PRS) is a sport-specific ASRM that was developed as a convenient non-invasive marker with the primary goal to assess players recovery [4,28]. The straight-forward response nature [0-10 scale (11-point), 0 (very poorly recovered/extremely tired) to 10 (very well recovered/highly energetic)] favors the regular use of this empirical scale in soccer [4]. Additionally, the psychometric properties of the PRS (theoretical derived, a documented instrument development and validity) make it highly regarded and accepted in the literature [4]. Previous studies revealed that PRS is sensitive to detect changes in sprint running performance [28] and showed to be acutely associated with the hormonal (testosterone) and muscle damage (creatine kinase) responses to heavy resistance training [29]. The perceived recovery of the players was measured through the following approach: the PRS scale has been shown to each player followed by the question "how do you feel?". This approach was adopted approximately -30 minutes before starting the match (pre), 15 min after the match ends (Post), 24 hours (G+24H) and 48 hours (G+48H) after each single match. In case the 24 hours post-match measurement coincided with a day off, the PRS was self-reported via mobile phone and the respective result was added to the player profile. Players were familiarized with the PRS scale (e.g. at least 7-months of exposure to the scale) and reported procedure (e.g. during the off days) as part of the club fatigue monitoring protocol. PRS data was analyzed as absolute values, and percentage of change described by the following equation: ((Post-Pre)/Pre) *100.

Statistical Analysis

All data was continuous and presented as mean and standard deviation (mean ± SD). The data was screened and passed the test for normality using Shapiro-Wilk method. A linear mixed model analysis was performed separately to compare the low speed running, moderate speed running, high speed running, and sprinting using different individualization methods (MAS, MSS, LOCO, ABS). Same statistical method was used to compare PRS over time (Pre, Post, G24+H, G48+H). We adjusted for Bonferroni post-hoc pair-wise comparisons. Linear mixed model analysis was again performed to generate parameter estimates and coefficients to predict PRS at Post, G24+H, and G48+H separately using all individualization methods. The parameter estimates and AIC statistics were reported for all models with significant associations. Models with the lowest AIC was preferred and a more than two unit change in AIC should be considered as meaningful change. Threshold values for Cohen effect size (ES) were defined as trivial (< 0.2), small (0.2 – 0.6), moderate (0.6 – 1.2), large (1.2 – 2.0) and very large (< 2.0) [30]. A P-value at < 0.05 was considered as the threshold for statistical significance. Data was analyzed using SPSS software (version 21.0, IBM SPSS Statistics, Chicago, IL, USA).

RESULTS

Match Load according to individualization methods

The different individualization methods resulted in distinct match outputs within each locomotor category (Table 2). LSR and MSR was lower when using the MAS and LOCO individualization methods vs MSS (p<0.001, ES = 1.0 and 1.6 for LSR and MSR, respectively) and ABS (p<0.001, ES= 0.6 and 0.7 for LSR and MSR, respectively). In addition, a significant greater distance in LSR and MSR was quantified by the MSS compared to ABS method (p<0.001, ES = 0.4 and 2.1, respectively). The different individualization methods resulted in distinct match outputs for HSR (p<0.001, ES = 2.6 for MAS vs. ABS, ES = 1.6 for MAS vs. MSS, ES = 0.8 for MSS vs. ABS, ES = 0.9 for MSS vs. LOCO and ES = 0.6 for MAS vs. LOCO). Sprinting distance was lower when using ABS and MSS than when adopting the MAS (p<0.001, ES = 1.3 and 1.4, respectively) and LOCO quantification (p<0.001, ES = 2.6 and 2.8, respectively). Additionally, lower sprinting distance was covered when using MAS vs. LOCO (p<0.001, ES = 1.0).

Insert Table 2 here

Time-course of PRS

The PRS was lower ($p<0.001$) at Post (3.8 ± 1.32, 95% CI = 3.6 to 4.2, ES = 3.1), G+24H (5.2 ± 1.48, 95% CI = 4.9 to 5.6, ES = 1.8) and G+48h (6.0 ± 1.22, 95% CI = 5.7 to 6.3, ES = 1.0) compared to before the match (7.1 ± 1.05, 95% CI = 6.8 to7.3).

Estimating PRS using different quantification methods

PRS Immediately Post-match

At post-match, absolute scores of PRS were associated with the HSR individualized to MSS and LOCO methods. Using MSS method, the perceived recovery post-match was positively associated (Table 3) with the total distance of sprinting ($Sprint_{MSS}$, Beta = - 1.53, 95% CI = 0.08 to 2.98, p = 0.039). Using LOCO method, the perceived recovery at post-match was negatively associated (Table 3) with high-speed running distance (HSR_{LOCO}, Beta = - 1.73, 95% CI = - 3.22 to - 0.23, p = 0.027). LOCO was the best method with the lowest AIC. At post-match, the percentage change in PRS was not associated with any of the individualization methods.

Insert Table 3 here

PRS 24 hours Post-match

There was a negative association between match HSR individualized for MAS (HSR_{MAS}, Beta = -1.74, 95% CI = - 3.22 to - 0.26, p = 0.022) and LOCO (Beta = - 2.37, 95% CI = - 3.86 to - 0.89, p = 0.003), with the absolute PRS score (Table 3) at 24-hours post-match recovery period. This outcome was also negatively associated with the THSR individualized for LOCO ($THSR_{LOCO}$, Beta = - 2.08, 95% CI = - 3.22 to - 0.95, p = 0.001). HSR_{LOCO} was found to be the preferred method due to the lowest AIC compared to HSR_{MAS} and $THSR_{LOCO}$.

There was negative association between HSR_{MAS} (Beta = - 0.26, 95% CI = - 0.47 to - 0.04, p = 0.019), HSR_{LOCO} (Beta = - 0.27, 95% CI = - 0.48 to - 0.05, p = 0.016), $THSR_{LOCO}$ (Beta = - 0.21, 95% CI = - 0.36 to - 0.06, p = 0.009) with the percentage of change of PRS scores at G+24H (Table 3). $THSR_{LOCO}$ was the best fit compared to HSR_{MAS} and HSR_{LOCO} to estimate variations in PRS at G+24H.

PRS 48 hours Post-match

Among the different factors, HSR_{MAS} (Beta = - 1.68, 95% CI = - 2.90 to - 0.47, p = 0.008), HSR_{LOCO} (Beta = - 1.89, 95% CI = - 3.02 to - 0.75, p = 0.002), $THSR_{LOCO}$ (Beta = - 1.32, 95% CI = - 2.20 to - 0.44, p = 0.004) were negatively associated with the PRS scores at G+48H (Table 3). HSR_{LOCO} emerged as the best model compared to HSR_{MAS} and $THSR_{LOCO}$.

Other factors were also negatively associated with the percentage of change of PRS scores at G+48H (Table 3) such as, HSR_{MAS} (Beta = - 0.19, 95% CI = - 0.35 to - 0.04, p = 0.016), $Sprint_{LOCO}$ (Beta = - 0.34, 95% CI = - 0.6 to - 0.08, p = 0.004), $THSR_{LOCO}$ (Beta = - 0.013, 95% CI = - 0.24 to - 0.02, p = 0.017) and HSR_{ABS} (Beta = - 0.03, 95% CI = - 0.52 to - 0.05, p = 0.017). At this time point, $Sprint_{LOCO}$ provided the lowest AIC compared to HSR_{MAS}, $THSR_{LOCO}$ and HSR_{ABS} to estimate variations in PRS.

DISCUSSION

The aim of the study was to compare the sensitivity of different individualization methods of speed zones to estimate post-match perceptual recovery in soccer players. We found that different individualization methods resulted in distinct match outputs within each locomotor category. Moreover, independently of the outcomes analyzed, the LOCO quantification method showed to have strongest association and should be therefore primarily used to estimate players' perceived recovery. Among all the different individualization procedures, the HSR category was shown to reflect the external load metric with better associations across different combinations of PRS. Players performing higher HSR during the match showed lower PRS during the recovery period (24h and 48h). Nevertheless, a more comprehensive analyzes using HSR and Sprinting distance should be applied to estimate players perceived recovery at G+48H. We did not find any correlation between total distance, LSR and MSR with any other outcomes independent of the time point analyzed. In addition, the widely adopted ABS method did not better explain PRS response compared with other individualization approaches.

Previous studies have analyzed the external load in soccer training and competition using different approaches based on the individual's physical capacity to customize speed zones[16,19]. It has been suggested that the use of a combination of players' physical attributes should be preferred instead of the use of a single one [19,20]. The LOCO individualization method combines physical measures of MSS, MAS and ASR and have been shown to better represent the relative external load experienced by the player [19]. The MSS has been classified as the speed at which an athlete can no longer accelerate when performing an 'all out' sprinting and reflects the neuromuscular capacity[26]. On the other hand, MAS reflects the maximum aerobic capacity and combinesVO_2 max and running economy into a single factor [31]. Research has suggested the use of both MSS and MAS to determine individuals transition to HSR and sprinting, respectively, as well as to quantify external training load pattern in soccer players [19,20] .

It has been consistently shown that participation in a soccer match leads to acute (less than 3 hours post-match) and residual (still evident up to 72 h post-match) disturbances across different parameters including physical, metabolic, biochemical and perceptual [3,15]. As such, perceptual measures have been suggested to quantify mental fatigue, effort, stress, and motivation; all factors that seem to be important moderators of the relationship between performance and fatigue [36]. In our study, we found a significant decrease in players' perceptual recovery post-match. Moreover, it is important to highlight that the perceptual values remained lower up to 48h post-match. Previous research involving soccer players reported similar time course for recovery; however, these studies have adopted different perceptual scales (e.g. Hooper Index, DOMS, fatigue) [3,32]. Interestingly, the time course of the PRS observed in our study followed similar pattern of objective measures often reported in the literature, including biochemical (e.g. muscle micro-trauma and inflammatory markers) and neuromuscular (e.g. jump ability and eccentric muscle strength) variables [3]. Given previous research has also shown association between PRS and biochemical (e.g. CK) and neuromuscular responses to training (e.g. sprint running) [28,29], our results reinforce the importance of perceptual assessment following training and match and its applicability to monitor fatigue and recovery in soccer players.

We have identified a greater association between the LOCO method and players' perceived recovery at G+24H and G+48H. Our findings are supported by recent research involving male soccer players. According to Rago et al. [22], there is a moderate to large association between the session rating of perceived exertion and external training load when it is adjusted to individual fitness capacities. However, it is important to highlight that the reported correlation between internal load (e.g. RPE and heart-rate indices) and player's individualized external load has not been confirmed by other studies[9]. Within this context, it is paramount to understand whether specific match-play external load metrics reflect the acute and residual changes in post-match perceptual recovery. This may allow practitioners to optimize training load in order to improve performance and recovery capacity while minimize injury risk [10]. Despite the efficiency of self-report perceptual measures to quantify match-related load [3,5], only few studies have investigated such relationship [8,14,15]. To our knowledge, just one study has been developed in this line of research[9]. In this investigation similar within-player correlation coefficients were recorded between the individualization approaches, arbitrary speed threshold and subsequent day wellness ratings of fatigue and soreness[9]. The different results observed between the present and the aforementioned study may be associated to several methodological aspects. This includes differences in gender (male vs female), age (young vs adult), training scenarios (official matches during in-season period vs training camp without matches), perceptual measures (PRS vs fatigue and soreness), criteria used for entry the thresholds and different approaches adopted to characterize the external load data. Hence, future research is warranted.

We have identified that HSR displayed better association with players perceived recovery when the LOCO method was adopted. Although this association was evident throughout the recovery phase (post, G+24 H and G+48H), we observed higher association values at G+24 H. We did not find any correlation between the total distance covered, LSR and MSR amongst any outcome analyzed independently of the time point. The trend of our results followed a similar pattern of a recent systematic review with meta-analysis, which has reported strong correlation between HSR ($> 5.5\ m \cdot s^{-1}$) and both biochemical and neuromuscular fatigue-related makers [10]. According to the authors, CK activity increased by 30% for every 100 m of HSR running distance covered during a soccer match, while a decrement of 0.5% was observed for CMJ_{PPO} at G+24 H [13].

We also observed that HSR was significantly different across the individualization methods of speed zone, which might explain why LOCO exhibited better association compared to the other variables. In fact, the LOCO resulted in 27 and 47% more distance covered at HSR compared to MSS and ABS threshold respectively. On the other hand, it is important to highlight that the LOCO resulted in 16% less distance covered at HSR compared with MAS individualization method. The use of MSS *per se* may reduce the sensibility of external load individualization process as it produces lower associations with external load measures and erroneous interpretations of training load [9,19]. This was further confirmed by our study where we found a positive association between HSR_{MSS} and PRS (higher HRS_{MSS} resulted in a better perceived recovery post-match). On the other hand, as the LOCO method incorporates MAS (e.g. an aerobic and anatomical trait dependent physical attribute) and MSS (e.g. a measure of neuromuscular capacity), may allowed a better profiling of the player's phenotype; covering a higher spectrum of fitness determinants thus more representative of the body functional limits[20]. Subsequently, this may result in an improved ability of the LOCO method to determine the dose response relationship (external load reflecting the internal stress) in soccer matches compared to MAS *per se.*

It is important to highlight that the physical fitness of the players may have changed over the period of the present study and this is a limitation to consider. Nevertheless, improvement in physical qualities was not the central aim of the training program during the period of data collection (i.e. two months of competitive period). Another potential limitation of the study was the small sample size (i.e. players belong to a single team) which unable generalization of our results. Additionally, in order to estimate the degree of post-match fatigue, the inclusion of individual acceleration thresholds is also recommended. Finally, to increase the buy-in of the coaching staff and players we applied a sport-specific endurance test (e.g. intermittent nature). This option resulted in the estimation of MAS from the 30-15 test and this obviously is not the "gold standard" measure to assess MAS.

PRACTICAL APPLICATION

The current findings have direct application for practitioners involved in the area of training load monitoring in soccer. Our results suggest the utilization of customized speed zones to interpret players dose response. This approach may inform decision making on training load management and recovery state. Amongst different individualization methods, PRS showed better association with LOCO, particularly with external load metrics such as HSR and Sprinting. In addition, different individualization methods result in distinct match outputs with special evidence to the HSR. We also observed that a single physical capacity may overestimate or underestimate players external load responses. Finally, we suggest the utilization of the LOCO method for individualizing speed thresholds. It has also an advantage of being comprised by field-based measures only, resulting in higher ecological validity, economical and practical approach.

CONCLUSION

This is the first study that has assessed the dose-response relationship between a range of speed zones individualization methods and the PRS in youth soccer players. According to our results, the PRS is a cost-effective method to monitor perceptions of recovery and seems to be sensitive to detect changes in the time course response following a soccer match-play. Furthermore, the present study provides support for the utility of the LOCO quantification method and external load measures such as HSR and Sprinting to estimate players' perceived recovery. Finally, amongst the different individualization methods, LOCO showed to be more sensitive to characterize the match intensity distribution.

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Table 1. Classification of speed zones for different methods to determine the match-play intensity distribution**.**

	MAS	MSS	LOCO	ABS
LSR	< 79 % MAS	< 49 % MSS	< 79 % MAS	< 14.3 km/h
MSR	80 - 99 % MAS	50 - 59 % MSS	80 - 99 % MAS	14.4 – 19.7 km/h
HSR	100 - 139 % MAS	60 - 79 % MSS	100 % MAS – 29% ASR	19.8 – 25.1 km/h
Sprinting	≥ 140 % MAS	80 - 100 % MSS	30 % ASR - MSS	≥ 25.2 km/h
THSR	≥ 100 % MAS	≥ 60 % MSS	≥ 100 % MAS	≥ 19.8 km/h

LSR- low-speed running; MSR- moderate-speed running; HSR- high-speed running; THSR – total high speed running; MAS- maximal aerobic speed; MSS – maximal sprinting speed - MAS and MSS as measures of locomotor capacities; ABS- absolute

Table 2- Distances covered in meters (mean ± SD) by different speed zones and quantification methods during match-play.

	MAS	ABS	MSS	LOCO
LSR	6635 ± 888[b,c]	7141 ± 777[a,c,d]	7470 ± 837[a,b,d]	6635 ± 888[b,c]
MSR	1011 ± 208 [b,c]	1176 ± 268 [a,c,d]	677 ± 199 [a,b,d]	1011 ± 208 [b,c]
HSR	961 ± 242[b,c,d]	430 ± 161[a,c,d]	587 ± 234[a,b,d]	807 ± 257[a,b,c]
Sprinting	259 ± 148[b,c,d]	94 ± 59[a,c]	99 ± 64[a,c]	410 ± 142[a,b,c]
THSR		8839 ± 1008		

LSR- low-speed running; MSR- moderate-speed running; HSR- high-speed running; THSR – total high speed running; MAS: maximal aerobic speed; MSS: maximum sprint speed; ABS: absolute threshold; LOCO: locomotor speed zones incorporating MAS and MSS; a: significantly different from MAS ($p<0.05$); b: significantly different from ABS ($p<0.05$); c: significantly different from MSS ($p<0.05$); d: significantly different from LOCO ($p<0.05$)

Table 3 – Parameter estimates for predicting perceived recovery scale at post, 24h and 48h post-match using different quantification methods.

Distance covered (km) by quantification method	Perceived recovery scale					
	Absolute scores			Percentage of change		
	Post	**G+24H**	**G+48H**	**Post**	**G+24H**	**G+48H**
Maximal aerobic speed						
HSR$_{MAS}$		-1.74*	-1.68**		-25.5*	-19.2*
SPRINT$_{MAS}$						
AIC		*285.0*	*263.5*		*1.2*	*-32.3*
Absolute						
HSR$_{ABS}$						-2.9*
SPRINT$_{ABS}$						
AIC						*-33.1*
Maximal sprinting speed						
HSR$_{MSS}$	1.53*					
SPRINT$_{MSS}$						
AIC	*288.1*					
Locomotor Capacities						
HSR$_{LOCO}$	***-1.73****	***-2.37*****	***-1.89*****		-26.7*	
SPRINT$_{LOCO}$						***-34.4*****
AIC	*284.1*	*281.8*	*260.5*		*.5*	*-34.1*
Total high speed running (THSR)						
THSR$_{MAS}$						
THSR$_{LOCO}$		-2.08***	-1.32**		***-20.7*****	-1.3*
THSR$_{MSS}$						
THSR$_{ABS}$						
AIC		*290.9*	*262.9*		*.2*	*-31.5*

$^{*}p<0.05$; $^{**}p<0.01$; $^{***}p<0.001$ Dependent variable: PRS, Independent variables: HSR- high speed running; THSR -sum of HSR and sprinting; MAS- maximal aerobic speed**;** LOCO- locomotor capacities; MSS- maximal sprint speed; ABS- absolute. Bold parameter estimates represent best fit among the other quantification methods. Non-significant associations are not shown. AIC- Akaike's Information Criterion