

Training load monitoring in football

Application of field systems in professional male players

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Academic dissertation submitted with the purpose of obtaining a doctoral degree in Sport Sciences, organised by the Centre of Research, Education, Innovation and Intervention in Sports (CIFI²D), Faculty of Sports, University of Porto, according to the Decree-Law 76/2006 of March 24th.

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Porto, 2019

Rago, V. (2019). Training load monitoring in football – Application of field systems in professional male players. Porto: V. Rago. Doctoral Thesis in Sport Sciences submitted to the Faculty of Sports, University of Porto.

Keywords: Physiology; Performance; Fitness; Fatigue; Testing.

Funding and support

The present research was funded by an individual doctoral grant awarded by *Fundação para a Ciência e Tecnologia* (SFRH/BD/129324/2017).

FCT Fundação para a Ciência e a Tecnologia

MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E ENSINO SUPERIOR



The present work was supported by: the Centre of Research, Education, Innovation and Intervention in Sports, Faculty of Sports, University of Porto; the Department of Sports Science and Clinical Biomechanics, Faculty of Health Sciences, University of Southern Denmark, Odense, Denmark; the Portugal Football School, Portuguese Football Federation, Oeiras, Portugal.



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Acknowledgements

The supervising team: professor António Rebelo, for his patience and valuable quality of his supervision throughout the development of this work; professor Peter Krstrup, for offering me the possibility of improving my research-related skills within a top-level research group; professor Daniel Barreira, for his support and for all the comments that improved the quality of this thesis. Additionally, I will always be in debt to professor Magni Mohr for the opportunity to work with data from a top-level league.

All the colleagues from the Health and Performance Unit and from the Portugal Football School, Portuguese Football Federation: in particular, João Brito for inviting me into an incredible work environment that provided me the privilege of developing my research in a world-class setting, Pedro Figueiredo for the priceless assistance with statistical analyses, as well as Rodrigo Abreu, Júlio Costa and André Seabra.

All the colleagues from Unione Sportiva Salernitana 1919 for their outstanding assistance with data collection, in particular: Gianluca Angelicchio, Italo Leo, Domenico Melino and Christian Ferrante.

Friends and colleagues from the Faculty of Sport, University of Porto (FADEUP), in particular Maickel Padilha, João Ribeiro, Thiago Carvalho, Gilberto Tozo, Tiago Fernandes, Rafael Bagatin and Sara Pereira for wordless enthusiasm and invaluable support, as well as from the University of Southern Denmark: Rasmus Cyril Ellegaard, Morten Randers, Malte Nejst Larsen, Mads Madsen and Jeppe-Foged Vigh-Larsen for the cooperation and the shared ideas. In particular, I thank Federico Pizzuto and Georgios Ermidis the endless support and good time.

Professors from the FADEUP: professor Fernando Tavares for offering me space in his department and the good company; professor Júlio Garganta for the valuable knowledge shared in the context of the research seminar in Sports Training; professor José Maia for the priceless tips with preparing the application for research funding and the possibility to build “some” data analysis skills.

João Renato Silva for the support and the valuable research contribution throughout the PhD, and Teresa Marinho for the assistance with English editing.

The Centre of Research, Education, Innovation and Intervention in Sports, FADEUP, for hosting my research; the University of Southern Denmark for accepting me as guest PhD student and the Portugal Football School for furtherly supporting my research.

My woman Estefanía for the tireless support, and all my family members: my parents, grandparents, uncles and aunts, and my brothers Michelangelo and Emanuele.

Table of contents

List of figures	IX
List of tables	XI
List of appendixes	XIII
Abstract	XV
Resumo	XVII
Abstrakt	XIX
List of abbreviations	XXI
Chapter 1 – Introduction	1
1.1. Overview	3
1.2. Building a monitoring system	4
1.3. Physical and physiological demands of football	6
1.4. Field measurements	7
1.4.1. Physical fitness	7
1.4.2. Training and match load quantification	9
1.5. Aim	10
1.6. List of original studies	10
Chapter 2 – Original studies	13
Study 1. Contextual variables and training load throughout a competitive period in a top-level male soccer team	15
Study 2. Training load and submaximal heart rate testing throughout a competitive period in a top-level male football team	31
Study 3. Application of individualized speed zones to quantify external training load in professional soccer	47
Study 4. Relationship between external load and perceptual responses to training in professional football: effects of quantification method	63

Chapter 3 – General discussion and conclusions	79
3.1. Synthesis of main findings	81
3.2. The training process: confounding factors and outcomes	81
3.3. Individual capacity as training load guidance	83
3.4. Limitations and suggestions for future research	84
3.5. Conclusions	87
References	89
Appendixes	XXII
Supplementary study 1. Differences in strength and speed demands between 4v4 and 8v8 small-sided football games	XXIV
Supplementary study 2. Influence of opponent standard on activity pattern and fatigue development during preseasonal friendly football matches: a team study	XXXVI
Supplementary study 3. The <i>Arrowhead</i> agility test: reliability, minimum detectable change and practical applications in soccer players	L

List of figures

Chapter 1 – Introduction

Figure 1. 1. Theoretical framework of the training process.	4
Figure 1. 2. The modelled fitness and fatigue response to a) a single bout and b) a sequence of training bouts.	5

Chapter 2 – Original studies

Figure 2. 1. Fluctuations in training load throughout a competitive period.	23
Figure 2. 2. Effect of opponent standard on weekly training load in a professional soccer team.	24
Figure 2. 3. Effect of game location on weekly training load in a professional soccer team.	25
Figure 2. 4. Effect of game outcome on weekly training load in a professional soccer team.	26
Figure 2. 5. Timeline of the study.	36
Figure 2. 6. Changes in Yo-Yo IR1 _{SUB} throughout a 4-month competitive period in a professional football team.	40
Figure 2. 7. Relationship between accumulated total distance covered during training between E1 and E4 and relative changes in Yo-Yo IR1 _{SUB} .	41
Figure 2. 8. Relationship between cardiorespiratory fitness and match performance given by a) total distance and b) sprinting distance.	41
Figure 2. 9. Graphical representation of arbitrary and individualized speed zone of each player.	56
Figure 2. 10. Within-weekly external training load distribution quantified using two different methods.	57
Figure 2. 11. Within-subject correlations between distance covered in arbitrary and individualized speed zones.	58
Figure 2. 12. Differences between distance covered using arbitrary and individualized speed zones.	58

Figure 2. 13. Weekly perceptual responses to training throughout a typical microcycle during a competitive period in professional football.	73
Figure 2. 14. Weekly external training load during a competitive period in professional football quantified using a) arbitrary and b) individualised speed zones.	73

Chapter 3 – General discussion and conclusions

Figure 3. 1. Modified theoretical framework of the training process proposed by Impellizzeri et al. (2005), when external training load quantification is based on individual fitness characteristics (e.g. maximal aerobic speed, maximal sprinting speed, anaerobic speed reserve).	83
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Appendixes

Figure A. 1. Changes in physical performance throughout 4v4 + GK and 8v8 + GK small-sided games.	XXX
Figure A. 2. Differences in physical demands (A, overall match activities and B, decreases in physical performance) between different opponent' standard.	XLIV
Figure A. 3. Flowchart of the research progress.	LIV
Figure A. 4. Layout of the <i>Arrowhead</i> agility test.	LV
Figure A. 5. Bland-Altman plot of the <i>Arrowhead</i> agility test and retest.	LVIII
Figure A. 6. Relationship between <i>Arrowhead</i> agility test performance and other neuromuscular capacities.	LIX
Figure A. 7. Differences in <i>Arrowhead</i> agility test performance according to competitive level and age-groups.	LX

List of tables

Chapter 1 – Introduction

Table 1. 1. Studies investigating the relationship between objective and subjective training load quantification in adult male football players.	11
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Chapter 2 – Original studies

Table 2. 1. Training load throughout a 3-month competitive period in a professional football team.	40
Table 2. 2. External training load quantified using two different quantification methods.	57
Table 2. 3. Weekly training characterisation in an Italian <i>Serie B</i> team.	70
Table 2. 4. Relationship between RPE-based parameters and distance covered in each speed zone over an 8-week competitive period in professional male football players.	75

Appendixes

Table A. 1. Overall comparison of 4v4 + GK versus 8v8 + GK small-sided games reported as distance covered per minute.	XXIX
Table A. 2. Comparison of neuromuscular performance between baseline values and post small-sided games.	XXX
Table A. 3. Relationship between physical performance during small-sided games and neuromuscular performance post small-sided games.	XXXI
Table A. 4. Physical performance according to various opponent' standard.	XLII
Table A. 5. Physical performance across three stages of the match.	XLIII
Table A. 6. Reliability and capacity to detect changes of the <i>Arrowhead</i> agility test.	LVI
Table A. 7. Changes in physical capacity throughout the game.	LVI
Table A. 8. Descriptive values of <i>Arrowhead</i> agility test performance.	LVII

List of appendixes

Supplementary study 1. Differences in strength and speed demands between 4v4 and 8v8 small-sided football games	XXIV
Supplementary study 2. Influence of opponent standard on activity pattern and fatigue development during preseasonal friendly football matches: a team study	XXXVI
Supplementary study 3. The <i>Arrowhead</i> agility test: reliability, minimum detectable change and practical applications in soccer players	L

Abstract

This dissertation examined the application of a monitoring system in football (soccer). An observational design was adopted to analyse training load (TL) and physical fitness measurements of two professional male football teams during their regular training and match routines. During the competitive period, a higher training volume was observed before and after playing against top-level opponents (1st to 5th in the league rank), and after losing a match. Additionally, the amount of high-intensity activity performed during training was higher when preparing a game against a top-level opponent. Regarding TL-induced effects on physical fitness, training volume was associated to a reduction of heart rate response during the submaximal Yo-Yo Intermittent Recovery Test – level 1, indicating improved cardiorespiratory fitness. Regarding the proper choice of external TL quantification method, the use of arbitrary or individualised speed-based intensity zones adjusted to player's physical fitness (maximal aerobic speed and maximal sprinting speed) showed similar sensitivity in the estimation of external TL magnitude (based on correlation) but differed at their absolute level (based on measurement bias). Notwithstanding, when external TL was adjusted to individual physical fitness, it revealed slightly stronger associations with perceptual responses to training, rather than when calculated using arbitrary intensity zones. Additionally, reporting external TL values as percentage values of distance does not inform about player's perceptual responses to training. The present findings can be considered by coaching and medical departments, and anyone involved with fitness testing and TL monitoring in football players.

Keywords: Physiology; Performance; Fitness; Fatigue; Testing

Resumo

Na presente dissertação foi examinada a aplicação de um sistema de avaliação e controlo do treino em futebol. Os dados de carga de treino (CT) e a aptidão física foram recolhidos em duas equipas de futebol masculino profissional no âmbito das rotinas de treino e de jogo. Durante o período competitivo foi observado um volume de treino mais elevado nas semanas antes e depois da competição contra adversários de topo (entre as primeiras 5 equipas da classificação da liga) e depois dos jogos cujo resultado final foi a derrota. Adicionalmente, o volume de atividade intensa durante o treino foi mais elevado nas semanas antecedentes aos jogos contra adversários de topo. O volume de treino mostrou-se associado à redução na resposta da frequência cardíaca na versão submáxima do teste *Yo-Yo Intermittent Recovery Test – level 1*, sugerindo uma melhor aptidão cardiorrespiratória. Relativamente aos cuidados a ter na escolha do método de quantificação da CT externa (CTE), a utilização de zonas de intensidade baseadas em velocidades determinadas de forma arbitrária ou individualizada (ajustadas à aptidão física [velocidade aeróbia máxima e velocidade máxima do jogador]) mostrou sensibilidade semelhante com o cálculo da magnitude da CTE (estudo da correlação), mas diferiu em termos de cálculo absoluto da CTE (estudo do viés de medição). A perceção da intensidade da sessão associou-se mais fortemente com a CTE ajustada á aptidão física individual do que quantificada com zonas de intensidade arbitrária. Além disto, a interpretação da CTE baseada em percentagens de distância não informou acerca da perceção da carga em resposta ao treino. Estes resultados podem ser considerados por profissionais envolvidos na área da avaliação física e fisiológica do jogador de futebol.

Palavras chave: Fisiologia, Desempenho, Aptidão física, Fadiga, Avaliação.

Abstrakt

Denne afhandling undersøgte anvendelsen af et trackingsystem i mandlig elitefodbold. Et observationelt design blev anvendt til at beskrive målinger af træningsbelastning (TB) og målinger af fysisk præstation hos to professionelle fodboldhold i en periode med normale trænings- og kamprutiner. Hvad angår den ugentlige træningsperiodisering i løbet af sæsonen blev en højere træningsbelastning observeret før og efter kampe mod tophold (1. til 5. plads i ligaen) samt efter nederlag. Derudover var mængden af høj-intense aktiviteter i træningen højere under forberedelsen til kampe mod tophold. I forhold til effekter induceret af TB på fysisk præstation var træningsvolumen associeret med en reduktion i pulsfrekvens under den submaksimale *Yo-Yo Intermittent Recovery – level 1*, som en indikation af en forbedret kardiovaskulær fitness. Hvad angår valget af metoder til at bestemme den eksterne TB, viste brugen af arbitrære eller individualiserede hastighedsbaserede intensitetszoner tilpasset spillerens fysisk præstation (maksimal aerob løbehastighed og maksimal sprinthastighed) samme sensitivitet i estimeringen af størrelsen af den eksterne TB (baseret på korrelationer), men adskilte sig i deres beregning af det absolutte niveau (baseret på målingsafvigelse). På trods af dette var associationen mellem ekstern TB tilpasset individuel fysisk præstation og selvopfattet træningsrespons var dog en anelse stærkere end ved anvendelsen af arbitrære intensitetszoner. Derudover var rapportering af ekstern TB som procentværdier af distancen ikke i stand til at informere om spillernes selvopfattede oplevelse af belastning under træning. Indeværende fund kan bruges af alle der arbejder med monitorering af elitefodboldspillere under træning og kamp, og kan tillige bruges af træner- og sundhedsstab i forbindelse med træningsplanlægning for mandlige elitefodboldspillere.

Nøgleord: Fysiologi; Præstation; Fitness; Træthed; Testning.

List of abbreviations

ASR	Anaerobic speed reserve;
ETL	External training load;
GPS	Global positioning system;
HR	Heart rate;
HR _{max}	Maximum heart rate;
ITL	Internal training load;
MAS	Maximal aerobic speed;
MSS	Maximal sprinting speed;
RPE	Rating of perceived exertion;
SSG	Small-sided games;
TL	Training load;
Yo-Yo IR1	Yo-Yo intermittent recovery test – level 1;
Yo-Yo IR1 _{SUB}	Submaximal Yo-Yo intermittent recovery test – level 1.

Introduction

1.1. Overview

Over the past three decades, football (soccer) teams have been gradually receiving systematic support from sports science (Bangsbo, 1994; Reilly, 1997), which is partially caused by the increase in physical and physiological demands of the sports (e.g. increased number of sprints during the match, and frequency of competitive fixtures; Barnes et al., 2014; Carling et al., 2015). This requires players to train harder and recover quicker than in the past. Therefore, it is important that coaches receive information about whether players are responding and adapting themselves to the training programme.

The player' monitoring has become one of the most critical areas of contemporary sports science, and it is commonly employed to improve / maintain physical performance, accelerate recovery and reduce injury risk. Indeed, players have become more familiar with regular assessments, wearable training load (TL)¹ monitoring technology incorporating global positioning systems (GPS) or heart rate (HR) monitors, as well as self-reported questionnaires (e.g. post-session rating of perceived exertion; RPE). Such advances are of undeniable value for information accessing; for instance, inappropriate training progressions can be identified, consequently attempting to educate coaches on suitable alternatives (Brink and Frencken, 2018). However, such easy access to a huge diversity of player' monitoring tools has caused confusion about the training dose-player' response to which different data are expected to be associated (Vanrenteghem et al. 2017). Additionally, the usefulness of the equipment used, the lack of consensus on analysis, the validity² and reliability³ of assessments are perceived as main perceived barriers to the effectiveness of a monitoring system in professional football (Akenhead and Nassis, 2016b). Furthermore, main of the inherent data of professional football players are collected and interpreted internally within clubs, most of the times remaining unpublished (Halsen, 2014).

¹ Training load: the input variable that is manipulated to elicit the desired training response (Coutts et al. 2018).

² Validity: the extent to which an assessment measures what it is designed to measure (Payne and Harvey, 2010).

³ Reliability: the consistency of measurements, or of an individual's performance on a test (Atkinson and Nevill, 1998).

1.2. Building a monitoring system

The first step to build a monitoring system is to ensure that a measurement tool is valid and reliable. Then, decisions around athletes may be based on small fluctuations, and thus, precision is extremely important to differentiate between real change and measurement error. Taken together, these assumptions can add scientific legitimacy and meaningfulness to the data expression to athletes and coaches (Hals0n, 2014; Robertson et al. 2017). Data from fitness tests provide an insight into players' capacity, and in conjunction with TL quantification can objectively inform about the training process. TL can be differentiated into external (ETL, the amount of work completed by the athlete) and internal TL (ITL, the associated physiological response experienced by the athlete). Despite ETL is the main determinant of ITL, other factors such as genetic, training background and starting fitness level could influence the exercise response imposed on the individual and consequently, the training outcome (Impellizzeri et al., 2005; **Fig. 1.1**). Indeed, athletes repeating the same exercise on different moments over time may maintain the same exercise output but experience different physiological and perceptual responses.

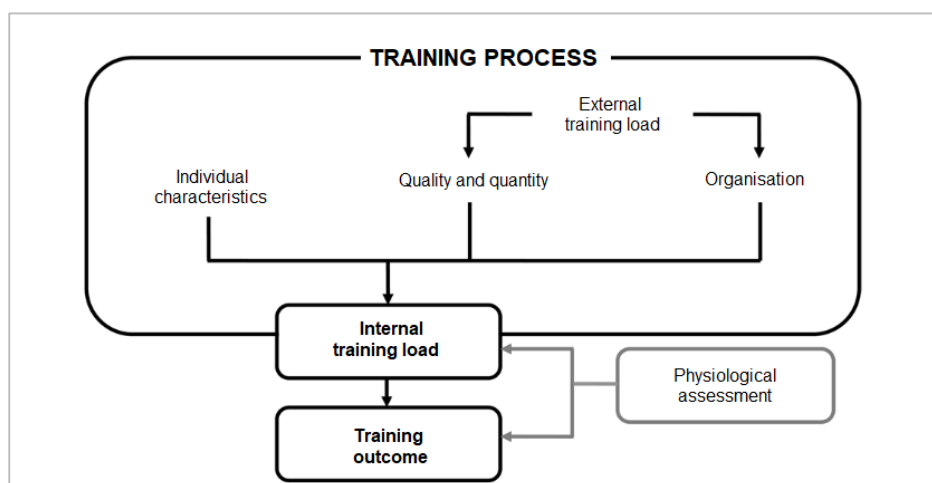


Figure 1. 1. Theoretical framework of the training process.⁴

Importantly, for positive training adaptations to occur, a careful balance between training dose and recovery is required (Matveyev, 1981). Thus, once

⁴ Adapted with kind permission from Impellizzeri et al. (2005).

acute fatigue⁵ has dissipated, improved performance is expected after a given period of time (Coutts et al. 2018; **Fig. 1.2**). However, the training process can result into improved (fitness) or impaired (fatigue) functional capacity (Banister et al. 1975; Kentta and Hassmen, 1998). Whereas this model appears simple to understand, football literature showed that it does not always apply. Higher training dose over time seem to be beneficial for isokinetic strength, trivial for body composition, whereas controversial results (either beneficial or harmful) have been reported for sprint, jump aerobic and anaerobic fitness (Jasper et al., 2017b). Therefore, the dose-response relationship between TL and training outcome requires further investigations.

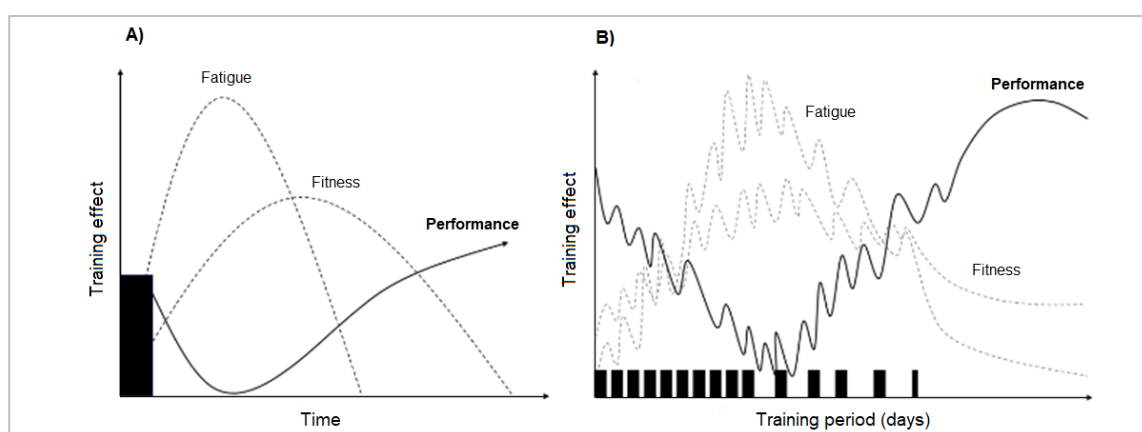


Figure 1. 2. The modelled fitness and fatigue response to a) a single bout and b) a sequence of training bouts⁶.

The training dose (e.g. ETL) can be easily quantified during analytic exercises, once exercise duration, running distance and recovery time between bouts are known, even though the ITL can vary between and within individuals. Nonetheless, quantifying ETL during skill- or game-based exercises is challenging, with variations in locomotor, physiological and perceptual responses during small-sided games (SSG) observed according to different external factors, such as pitch dimension, number of players, exercise regime, game rules etc. (Hill-Haas et al., 2011). However, little is known regarding acute neuromuscular responses after

⁵ Fatigue: inability to complete a task that was once achievable within a recent time frame (Pyne and Martin, 2011).

⁶ Adapted with kind permission from Coutts et al. (2018).

SSGs. Therefore, we compared the exercise and acute fatigue response between two different SSG formats (**Supplementary study 1**).

1.3. Physical and physiological demands of football

The key to develop football-specific training plans is to consider the specific demands imposed on players during competitive match-play. A football match is characterised by intermittent exercise that mixes short periods of maximal or submaximal effort requiring unpredictable and highly-complex motor patterns, separated by longer recovery periods (Bangsbo et al., 2006; Drust et al., 2007; Stølen et al., 2005). Therefore, football players are required to be proficient in, and able to maintain adequate fitness levels over the season, which includes a combination of capacities; primarily muscle strength and power, and cardiorespiratory fitness (Drust et al., 2007; Svensson and Drust, 2005).

Most likely due to fatigue, running intensity fluctuates during the game (Fransson et al. 2017; Mohr et al., 2005). Fatigue can be manifested temporarily after short-term intense periods and towards the end of the game (Akenhead et al. 2013; Fransson et al. 2017; Krstrup et al., 2006a; Mohr et al., 2003). However, it is accepted that intensity fluctuations are primarily dependent on external aspects (e.g. opponent standard, current match status) than on physiological determinants associated to the individual fitness level (Carling, 2013). One strategy based on external factors to prepare players for the competitive period is the appropriate organisation of pre-seasonal friendly matches based on the different demands associated to the opponent standard. Previous studies describing the opponent-induced effects on physical demands considered total match values, without attention to running intensity fluctuations. Thus, we analysed physical demands in relation to different opponent standards and stages of the game during pre-seasonal friendly matches (**Supplementary Study 2**).

When practice sessions are also considered, the entire football season presents higher TL during the preparatory period than the competitive period (Jeong et al., 2011). In addition, a tendency for TL to decrease has been observed as the season progressed (Brito et al., 2016; Malone et al., 2015). Whereas a TL pattern has been identified within a typical week of the competitive phase

(Akenhead et al., 2016; Malone et al., 2015), variations in TL could be observed between weeks. For instance, U19 male players perceived higher TL in the weeks after playing a home game, and after a loss or a draw compared to a win (Brito et al., 2016). However, players' perceptions of TL are not commonly in agreement with coaches' expectations (Brink et al., 2014, 2017). This could be due to the fact that physiological responses to training are influenced by a myriad of external factors, and therefore difficult to predict. In this context, the integration of objective TL measurements (e.g. GPS and HR) can aid in better explain the previous findings by Brito et al. (2016) using RPE-based ITL. Therefore, using wearable technology, we explored the effect of match-related contextual variables on weekly TL (**Study 1**).

1.4. Field measurements

1.4.1. Physical fitness

Once known the meaningful physical capacities required by football players, various physical tests have been developed or adopted. Muscle strength and power have been generally assessed by isokinetic tests, one-maximum repetition, jump and sprint tests (McCall et al., 2015; Svensson and Drust, 2005). Agility⁷ is also crucial for football performance. Despite various agility tests have been adopted in football, there is no current gold standard agility test for football players (Drust et al., 2007; Sheppard and Young, 2006). Therefore, we analysed the reliability of a novel football-specific agility test (**Supplementary study 3**). Sprint testing usually involves assessments over short distances (5–20 m) to replicate sprint length observed in official matches (Mendez-Villanueva and Buchheit, 2013). When sprint is tested over 30–40 m, players can be profiled by their maximal sprinting speed (MSS), enabling the quantification / prescription of the training dose as percentage of individual MSS (Buchheit and Laursen, 2013b).

Cardiorespiratory fitness has been commonly measured using incremental (e.g. time to exhaustion) continuous or intermittent tests (Jemni et al., 2018). Once exhaustion has been reached, test scores can be used to adjust ETL data by the

⁷ Agility: capacity to quickly change direction within confined spaces.

individual maximal aerobic speed (MAS)⁸. Hence, similarly to MSS, the training dose can be quantified or prescribed as percentage of individual MAS (Buchheit and Laursen, 2013a). Previous studies quantifying ETL through individual MAS, predominantly adopted direct cardiorespiratory measurements that were time-consuming, expensive and require access to unattainable equipment for lower-level clubs (Jemni et al. 2018). Therefore, field tests (e.g. the Yo-Yo Intermittent recovery test – level 1 [Yo-Yo IR1]; Bangsbo et al. 2008) are commonly prioritised over laboratory tests to assess prolonged intermittent exercise capacity, and subsequently estimate MAS and determine maximal HR (HR_{max}). It is important to consider that maximal tests are, most of the time, unsuitable during competitive periods, due to the high density of competitive fixtures. Non-exhaustive testing might be therefore preferable to assess athletes' training status, when functional capacity is limited (e.g. during reconditioning training following injury) or when frequent testing is required alongside competitive fixtures (Bangsbo et al., 2008). Observations in elite football players revealed that HR testing during the submaximal versions of the Yo-Yo tests is valid (in relation to maximal tests) and reliable (Bangsbo et al., 2008; Bradley et al., 2011; Krstrup et al., 2003, 2006b). Therefore, HR measurements during submaximal versions of the Yo-Yo tests seem to provide information about cardiorespiratory fitness, with the advantage that players do not have to work to exhaustion. However, information regarding cardiorespiratory fitness measured via submaximal testing in professional football players is unknown. Therefore, we examined HR testing during a submaximal version of Yo-Yo IR1 (Yo-Yo IR1_{SUB}), in relation to TL (**Study 2**).

Anaerobic fitness is also vital for football players, with various field tests available (Di Mascio et al., 2015; Rampinini et al., 2007). However, these are difficult to administer, especially during the competitive phase, due to the meaningful acute fatigue responses imposed by shuttle running at high speed (Akenhead et al., 2015; Morcillo et al., 2015), possibly compromising players' readiness for the next match. Once MSS and MAS have been obtained, the anaerobic capacity of the individual player can be profiled without performing these

⁸ The maximal aerobic speed is the lowest running speed at which maximum oxygen uptake occurs.

tests, using the anaerobic speed reserve (ASR)⁹ calculation. Taken together, information available from MSS, MAS and ASR can be used to adjust ETL and thus, offset the confounding effect of individual characteristics on the dose-response relationship between ETL and ITL, described in the conceptual model proposed by Impellizzeri et al. (2005; **Fig. 1.1**). Nonetheless, despite of the inherent advantages of an individual-based approach, ETL is commonly quantified using arbitrary (player-independent) speed zones (Akenhead and Nassis, 2016b). Therefore, we examined the interchangeability of two ETL quantification methods (arbitrary vs. individualised speed zones; **Study 3**).

1.4.2. Training and match load quantification

Either objective or subjective tools exist to quantify TL. Wearable technology incorporating GPS is the most commonly adopted tool to quantify ETL in professional football (Akenhead and Nassis, 2016b). Numerous validation studies have investigated the ability of GPS to measure distance and speed, reporting an improved accuracy with increased sampling frequency, without any benefits above 10-Hz (Scott et al., 2016). Notwithstanding, to provide a global TL picture of the session / match, ETL must be integrated into objective or subjective measures of ITL. Measurement of HR during exercise provides information about the aerobic contribution during either continuous or intermittent exercise (Dellal et al., 2012). However, all existent HR-based methods have been frequently questioned in relation to the intermittent nature of football and the inability to identify specific anaerobic-oriented efforts commonly observed during explosive actions (e.g. sudden attainment of peak speed; Dellal et al., 2012). Therefore, despite relying on a subjective assessment, RPE is commonly preferred by practitioners to HR measurements (Akenhead and Nassis, 2016b). This is also due to the ease of collection, versatility of use and negligible expense required to quantify the perception of exercise intensity (Fanchini et al. 2017; Impellizzeri et al. 2004). Importantly, RPE-based methods are valid in relation to objective

⁹ The ASR is based on different physiological demands to complete a task depending on the profile of the individual athlete. For instance, covering a given distance by sprinting compared to submaximal intensities (or vice-versa) could result in different physiological responses (Bundle et al. 2013). The ASR is given by the difference between MSS and MAS.

measurements of locomotor activity or HR during exercise (**Table 1.1**). Studies investigating the relationship between RPE and objective TL indicators over extended periods of time has been predominantly computed using HR-based ITL indicators based on individual HR_{max} (**Table 1.1**). However, studies considering ETL have adopted arbitrary speed-based intensity zones, with no attempts considering individual fitness level to adjust ETL. Therefore, we explored the relationship between RPE and ETL quantified using different methods (**Study 4**).

1.5. Aim

To examine the application of a monitoring system in professional male football, the present dissertation is based on four main studies conducted in non-experimental setting without interfere with coaching and medical departments (**Chapter 2**). Additionally, three supplementary studies that include supporting information for the main studies are included in the **Appendixes** section.

1.6. List of original studies

1. Contextual variables and training load throughout a competitive period in a top-level male soccer team. Ahead of print in the *Journal of Strength and Conditioning Research* (available on-line).
2. Training load and submaximal heart rate testing throughout a competitive period in a top-level male football team. Ahead of print in the *Journal of Sports Sciences* (available on-line).
3. Application of individualized speed zones to quantify external training load in professional soccer. Accepted in the *Journal of Human Kinetics* (under production).
4. Relationship between external load and perceptual responses to training in professional football: effects of quantification method. Published in *Sports* (available on-line).

Table 1. 1. Studies investigating the relationship between objective and subjective training load quantification in adult male football players.

Author	Participants	Competitive standard	Setting	Duration / period	Objective TL measurements associated to the rating of perceived exertion
Campos-Vázquez et al. (2015)	9 pro players	Spanish LaLiga	Full training sessions	10 months / CP	Edwards TL, Stagno ^o TRIMP, and time > 85%HR _{max}
Casamichana et al. (2013)	28 semi-pro players	Spanish 3 rd division	Full training sessions	4 months / CP	Edwards TL, TD and PlayerLoad
Casamichana and Castellano (2015)	14 semi-pro players	Spanish 3 rd division	SSG	27 SSGs / CP	HR _{mean} , TD, Distance covered within arbitrary speed zones and PlayerLoad
Coutts et al. (2009)	20 amateur players	Regional level	SSG	67 SSGs / CP	HR _{mean} , blood lactate concentrations
Fanchini et al. (2016)	19 pro players	Italian Serie A	Full training sessions	6 months / CP	Edwards TL
Gaudino et al. (2015)	22 pro players	English Premier League	Full training sessions	One full CP	TD, Distance covered / number of entries within arbitrary speed and acceleration zones
Gomez-Plriz et al. (2011)	22 pro players	Spanish LaLiga	Full training sessions	13 sessions / CP	Total body load
Kelly et al. (2016)	19 pro players	English Premier League	Full training sessions	One full CP	Edwards TL
Jasper et al. (2017a)	28 pro players	Dutch Eredivise	Full training sessions and competitive matches	Two full seasons / PP+CP	Distance covered within arbitrary speed, Acc and Dec zones, PlayerLoad, RHIE
Little and Williams (2007)	28 players	English championship	SSG	Not reported / CP	HR _{mean}

Acc, accelerations; CP, competitive period; Dec, decelerations; HR_{max}, maximum heart rate; HR_{mean}, mean heart rate; PP, preparatory period; RHIE, repeated high-intensity efforts; SSG, small-sided games; TD, total distance; TL, training load; TRIMP, training impulse.

Original studies

Contextual variables and training load throughout a competitive period in a top-level male soccer team

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Journal of Strength and Conditioning Research, ahead of print

DOI: 10.1519/JSC.00000000000003258

Keywords: Physiology; Heart rate; GPS; High-speed running.

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Abstract

The aim of the present study was to quantify the weekly training load (TL) according to different match-related contextual factors in a professional male football team ($n = 23$ players). TL was quantified using a 10-Hz global positioning system with integrated 100-Hz accelerometer and heart rate recordings over a 3-month competitive period. Total distance (TD) covered and high-speed running (HSR, $> 16 \text{ km} \cdot \text{h}^{-1}$) during training were higher in the week after playing against a bottom-level or top-level compared to a medium-level opponent ($P < 0.05$; *effect sizes*, $ES = 0.30\text{--}1.04$). TD was also higher when preparing for a match against a bottom-level opponent ($P < 0.05$; $ES = 0.39\text{--}0.76$). In addition, the relative HSR (expressed as percentage of TD) covered was higher after playing a bottom-level compared to a medium-level opponent ($P < 0.001$; $ES = 0.49 [0.27; 0.71]$). TD covered was higher in the week following a draw or a win, and higher before a loss compared to a draw ($P < 0.05$, $ES = 0.32\text{--}0.81$). Both absolute and relative HSR were higher before losing and winning a match compared to a draw ($P < 0.05$; $ES = 0.72\text{--}0.98$). Weekly TL seems to be slightly affected by match-related contextual variables, with special emphasis on the opponent standard and match outcome. Higher training volume was observed prior to and after playing against a top-level opponent, and after losing a match, while the volume of high-intensity training appears to be higher when preparing for a game against a top-level opponent. Future experimental research should clarify the interaction between match-related contextual variables (e.g. cause) and weekly TL (e.g. effect).

Introduction

TL monitoring, which has become one of the most critical areas of sports science support in contemporary soccer, aims to generate information concerning attainment of peak performance, to enable a certain level of protection against injury, and to provide an evidence-based and systematic approach to management decisions when prescribing training (Borresen and Lambert, 2008; Jaspers et al., 2017). The large amount of published studies, combined with available TL monitoring technologies on the market, has resulted in practitioners

having more choices than previously (Gabbett et al., 2017). Despite the inherent benefits of TL monitoring, there are meaningful challenges for practitioners in implementing monitoring strategies. For instance, coaches need to take into consideration the possible confounding effect of match-related parameters on TL interpretation (Brito et al., 2016; Nassis and Gabbett, 2017).

Contextual factors such as opponent standard, match location and match outcome have a meaningful impact on players' activity profile during competitive games (Aquino et al., 2017; Castellano et al., 2011; Folgado, et al., 2014; Rago et al., 2018). For instance, professional soccer players cover higher total distance (TD), high-speed running (HSR), acceleration/deceleration distance and attain peak speed values when playing against a stronger opponent (a top-five side; Aquino et al., 2017; Castellano et al., 2011; Folgado et al., 2014; Rago et al., 2018). In support of this, a recent study demonstrated that playing against a top-level team is perceived to be more demanding than playing against a bottom-level team (a bottom-five side; Barrett et al., 2018). Significant effects were also found regarding match location and match status, with higher TD covered during home games or when the reference team was losing (Castellano et al., 2011). While this information about contextual factors could assist match analysts, there is currently a lack of knowledge about TL. U19 professional soccer players perceived higher weekly TLs after a defeat or draw compared to a win, and when preparing to play against a medium-level team compared to a bottom- or a top-level team (Brito et al., 2016). Despite the inherent advantages offered by the RPE-based TL method, its accuracy is questionable due to the complex interaction of many factors that contribute to personal perception of effort. For example, concentrations of hormones and neurotransmitters, substrate levels, external factors (environment, spectators), psychological states, previous experience and memory may all limit the use of RPE in accurately quantifying training intensity (Abbiss et al. 2015; Borresen and Lambert, 2008; Nassis and Gabbett, 2017). In addition, players may be unwilling to report fatigue, as this might prevent them from being available for selection (Nassis and Gabbett, 2017). All these concerns should be taken into account when developing a strategy to assess TL.

Alongside the large amount of commercially available TL monitoring technologies, players and coaches have become more familiar with wearable micro-technology. For instance, GPS quantify the amount of activity performed by players based on a satellite navigation network that provides location and frame information for tracking devices (Malone et al., 2017). Conventional GPS-derived measures include TD, which is commonly used as a measure of overall training volume, and HSR, which is commonly used to quantify the amount of high-intensity activity (Buchheit and Simpson, 2017). However, because these measures are only quantified in two planes of movement (x and y), GPS devices commonly integrate accelerometers and gyroscopes enabling the quantification of events related to changes in speed (e.g. number of accelerations and decelerations). Recent GPS software also allows the direct integration of HR recordings by only integrating an HR sensor that is automatically detected by the GPS device. HR measurements allow the objective quantification of exercise intensity in response to the activity performed by the players (Dellal et al., 2012). Mean HR (HR_{mean}) during exercise is closely related to oxygen consumption during continuous exercise (when expressed as a percentage of HR_{max} and is commonly used to describe the load imposed on the aerobic system (Dellal et al., 2012).

As far as we know, one study has investigated the effect of match-related contextual variables on TL in young (U19) players employing subjective measures of TL (Brito et al., 2016). Therefore, information relating to older top-level players integrating objective TL measures might add worthwhile information for anyone involved in TL monitoring in soccer. Thus, the aim of the present study was to quantify the weekly TL according to different match-related contextual factors in a top-level male soccer team.

Method

Experimental approach to the problem

The TL was quantified over a 3-month competitive period from February to May. The generic training and competitive schedule completed by the soccer players involved in this study were supplied by the technical staff of the team, with

no input from the research team. Sixty-seven training sessions and 15 competitive matches were performed. Of these 67 training sessions, 24 included speed endurance training (e.g. repeated sprint activity) and 26 aerobic high-intensity training (e.g. interval training). The remaining training sessions mainly concerned ball-possession games and team-/opponent-based tactics. Individual / reconditioning sessions were excluded from the analysis. The final analysis included a total of 828 individual training sessions (median [range] = 35.5 [14; 45]). Three contextual variables were considered as previously described by Brito et al. (2016): opponent level (top, 1st to 6th in the current rankings; medium, 7th to 14th; and bottom, 15th to 20th); match location (home and away); and match outcome (win, draw and loss).

Subjects

During the second half of the 2017/18 season, 23 male outfield soccer players (mean \pm SD; age, 27.8 \pm 3.9 yrs; height, 177.9 \pm 6.4 cm; body mass, 72.7 \pm 11.9 kg), including 8 representing their respective national teams, competing in the top Spanish league (*LaLiga*) were regularly monitored in the context of their team routine. These data derived from routinely measured player activities over the course of the competitive season, so no informed consent was required (Winter and Maughan, 2009). At the end of the season, the club and the players verbally authorised the use of a dataset for research purposes whenever anonymity was ensured. During the data analysis, individual player identity was coded and presented anonymously. The Ethical Committee of the Faculty of Sports at the University of Porto approved and recorded the study under “CEFADE.08.2018”.

Procedures

External training load. The amount of activity performed by the players was measured using a 10-Hz GPS (WIMU PRO ®; Realtrack Systems SL, Almeria, Spain) with a 3-axis accelerometer, gyroscope and magnetometer integrated sampling at 100 Hz. These devices (85 × 48 × 15 mm, 65 g) were fitted to the upper back of each player using adjustable harnesses (Rasán, Valencia, Spain). Data were analysed using the system-specific software (WIMU Software;

RealTrack Systems SL, Almeria, Spain). This system showed good accuracy for measures of running speed (Bastida-Castillo et al., 2018), acceleration and deceleration (Muyor et al. 2018) in relation to gold-standard measurements (Intraclass correlation coefficient = 0.93–0.97). All devices were always activated 15 min before data collection to allow acquisition of satellite signals in accordance with the manufacturer's instructions. Nonetheless, data were trimmed from the actual start of the session (start of field warm-up) to the end (prior to cool down exercises). To avoid inter-unit error, the players wore the same device for each training session (Gaudino et al., 2014). TD and HSR ($> 16 \text{ km}\cdot\text{h}^{-1}$) were calculated from instantaneous raw data for time, speed and distance available from the manufacturer's software, and the minimum effort duration was 0.2 s. The speed threshold of $> 16 \text{ km}\cdot\text{h}^{-1}$ is supposedly the average MAS in professional soccer players (Osngnach et al. 2010). To remove the effect of training volume, HSR was also expressed as percentage of TD within the training session. In addition, the number of intense accelerations (Acc3, $> 3 \text{ m}\cdot\text{s}^{-2}$) and intense decelerations (Dec3, $< -3 \text{ m}\cdot\text{s}^{-2}$) was retrieved from the accelerometer. ETL was reported as the amount of work performed (actual distance covered, in m) during the whole microcycle (one week of training sessions, previous to the next match). In addition, to remove the effect of the microcycle length, weekly ETL was normalized by the between-match duration, dividing the cumulative weekly distance (or number of efforts) by the number of training sessions.

Internal training load. Physiological responses to training were recorded every 5 s using a short-range telemetry system (WIMU PRO ®; RealTrack Systems; Almeria, Spain). This device has been shown to be valid in relation to gold standard measurements of HR during exercise ($r = 0.97$; Molina-Carmona et al., 2018). Weekly ITL was calculated using average daily values for HR_{mean} in a given microcycle, and expressed as percentage of HR_{max} ($193.8 \pm 5.2 \text{ bpm}$, determined by an incremental treadmill protocol at the start of the season).

Statistical analyses

Shapiro-Wilks test revealed that TL data were normally distributed within each microcycle ($P > 0.05$). Differences between contextual factors were analyzed

using a linear mixed model with unstructured covariance, taking into consideration the fact that the participants differed in respect of the number of training sessions in which they participated (Cnaan et al., 1997; Malone et al., 2015). The contextual factors were set as fixed effects, individual subjects were set as random effects, and TL was the dependent variable. When a significant effect was found, pairwise comparisons were analysed using a post-hoc *Bonferroni* test. The magnitudes of difference were subsequently quantified using *ES* according to Hopkins et al. (2009), namely trivial (*effect size*, $ES < 0.2$), small ($ES = 0.2–0.6$), moderate ($ES = 0.6–1.2$), large ($ES = 1.2–2.0$), very large ($ES = 2.0–4.0$) and extremely large ($ES > 4.0$). When 90%CI overlapped positive and negative values, the effect was deemed to be unclear. Otherwise, the effect was deemed to be the observed magnitude (Batterham and Hopkins, 2006). Statistical significance was set at $P \leq 0.05$. Data analysis was performed using Statistical Package for Social Sciences software (IBM Statistics, Chicago, USA).

Results

Overview of the weekly training load

Across the data collection period, the team played 15 competitive games, 4 of which were played against top-level teams, 6 against medium-level teams and 5 against bottom-level teams. 7 matches were played home and 8 matches were played away (median distance [range] from the home venue, 603 [64; 1166] km). Specifically, 7 out of 8 away fixtures were travelled by flight, whereas one by bus. The team won 2 matches, drew 5 matches, and lost 7 matches. Weekly TD and Acc3 during training decreased as the season progressed from the mid-season toward the end of the season ($P < 0.05$; **Fig. 2.1**). No seasonal changes were observed in HSR, Dec3 and HR_{mean} ($P > 0.05$; **Fig. 2.1**).

Main effect – opponent level

TD covered and HSR during training were slightly to largely higher in the week after playing against a bottom- and a top-level opponent compared a medium-level opponent ($P < 0.05$; TD, $ES = 0.30$ [0.08; 0.51] and 1.04 [0.63; 1.45]

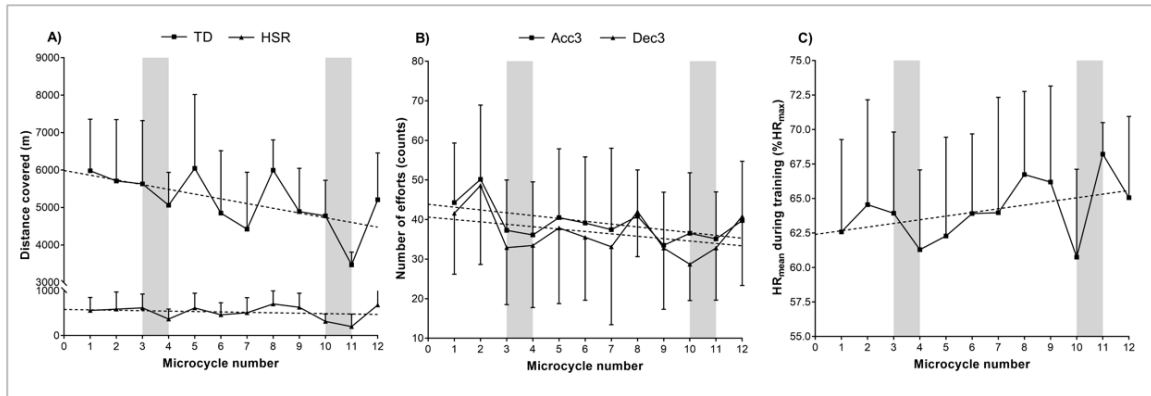


Figure 2. 1. Fluctuations in training load throughout a competitive period.

a) Total distance (TD) and high-speed running ($> 16 \text{ km} \cdot \text{h}^{-1}$; HSR, b) accelerations $> 3 \text{ m} \cdot \text{s}^{-2}$ (Acc3) and decelerations $< -3 \text{ m} \cdot \text{s}^{-2}$ (Dec3) and c) mean heart rate (HR_{mean}); HR_{max} , maximum heart rate; the grey-filled spaces indicate congested periods (≤ 3 days between matches).

respectively; HSR, $ES = 0.49$ [0.28; 0.71] and 0.89 [0.48; 1.30], respectively; **Fig. 2.2A**). TD was slightly to moderately higher before playing a bottom opponent compared to a medium- and a top-level opponent ($P < 0.05$; $ES = 0.39$ [0.16; 0.62] and 0.76 [0.46; 1.06]) whereas no significant differences were observed for HSR ($P > 0.05$) (**Fig. 2.2**). Similarly, the number of Acc3, Dec3 was higher in the week before playing against a bottom-level opponent compared to a medium-level opponent ($P < 0.05$; $ES = 0.56$ [0.33; 0.80] and 0.68 [0.44; 0.91], respectively; **Fig. 2.2B**). Regarding exercise intensity, the percentage of HSR covered during training was higher in the week after playing a bottom opponent compared to a medium opponent ($P < 0.01$; $ES = 0.49$ [0.27; 0.71]) whereas no opponent standard effect was observed for HR_{mean} during training ($P > 0.05$; **Fig. 2.8D**).

Main effect – match location

The number of Acc3 and Dec3 was slightly lower in the week after playing an away game compared to an away game ($P < 0.05$; $ES = 0.21$ [0.01; 0.42] and 0.32 [0.11; 0.53], respectively; **Fig. 2.3B**). No match location effect was observed for TD, HSR covered, percentage of HSR and HR_{mean} ($P > 0.05$; **Fig. 2.3**). Additionally, TD was slightly higher before losing a match compared to a draw ($P < 0.01$; $ES = 0.44$ [0.31; 0.77]). HSR was moderately higher in the week before losing a match, and before winning a match compared to a draw ($P < 0.05$; $ES = 0.81$ [0.57; 1.05] and 0.98 [0.66; 1.29], respectively; **Fig. 2.3A**).

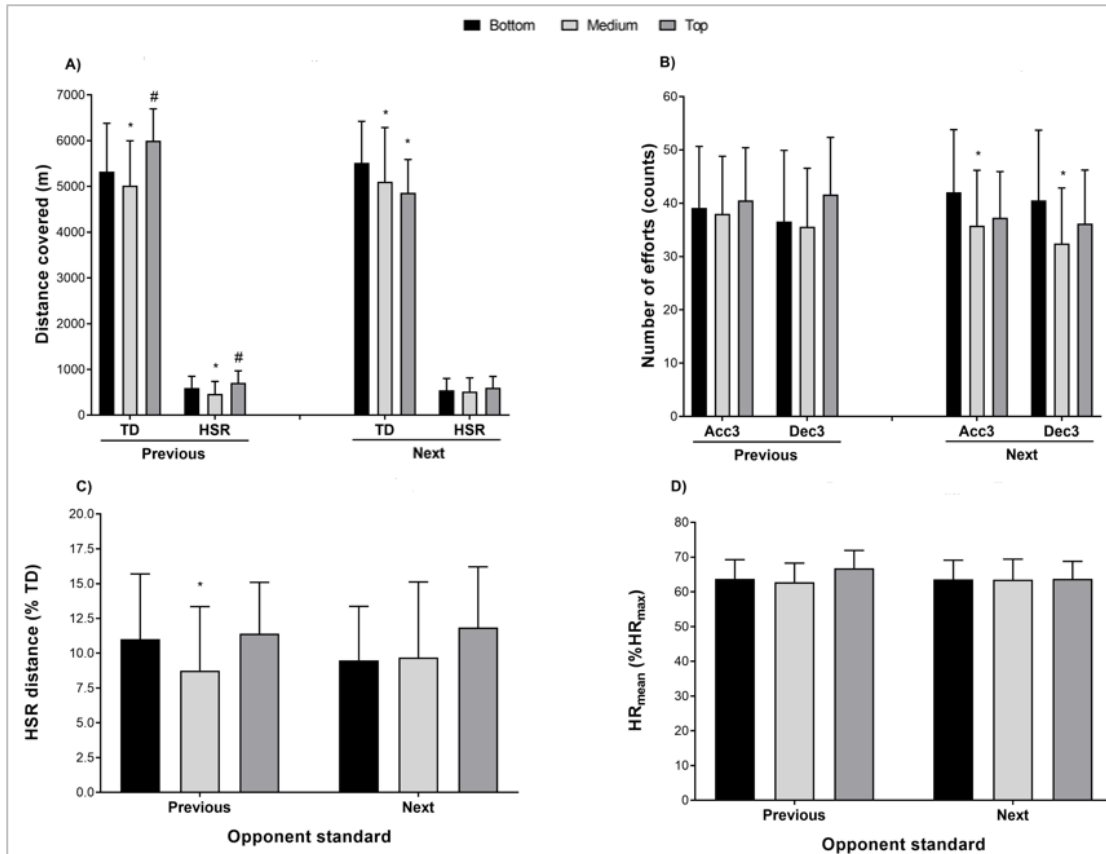


Figure 2. 2. Effect of opponent standard on weekly training load in a professional soccer team.

a) Total distance (TD) and high-speed running (HSR, $> 16 \text{ km} \cdot \text{h}^{-1}$); b) number of Acc3 (accelerations $> 3 \text{ m} \cdot \text{s}^{-2}$ and Dec3 (decelerations $< 3 \text{ m} \cdot \text{s}^{-2}$); c) percentage of TD and d) mean heart rate (HR_{mean}); HR_{max} , maximum heart rate; * denotes significant differences to "bottom" ($P < 0.05$), # denotes significant differences to "medium" ($P < 0.05$).

Main effect – match outcome

TD covered during training was higher in the week after losing a match compared to a draw or a win ($P < 0.05$; $ES = 0.37$ [0.14; 0.60] and 0.81 [0.50; 1.11]) and after a draw compared to a win ($P = 0.04$, $ES = 0.32$ [0.02; 0.62]; **Fig. 2.4A**). The number of Acc3 and Dec3 was higher after losing a match compared to a draw and a win ($P < 0.05$; Acc3, $ES = 0.44$ [0.21; 0.67] and 0.74 [0.44; 0.1.04], respectively; Dec3, 0.45 [0.22; 0.69] and 0.85 [0.55; 1.16]) and after a draw compared to a win ($P < 0.05$; Acc3, $ES = 0.39$ [0.09; 0.69]; Dec3, $ES = 0.46$ [0.16; 0.76]; **Fig. 2.4B**). The percentage of HSR covered during training was moderately higher before a loss and a win compared to a draw ($P < 0.05$; $ES = 0.72$ [0.49; 0.96] and 0.90 [0.59; 1.22], respectively; **Fig. 2.4C**). HR_{mean} during training was moderately higher in the week before a win compared to a loss or a draw ($P < 0.05$; $ES = 0.65$ [0.33; 0.97] and 0.65 [0.32; 0.98], respectively; **Fig. 2.4D**).

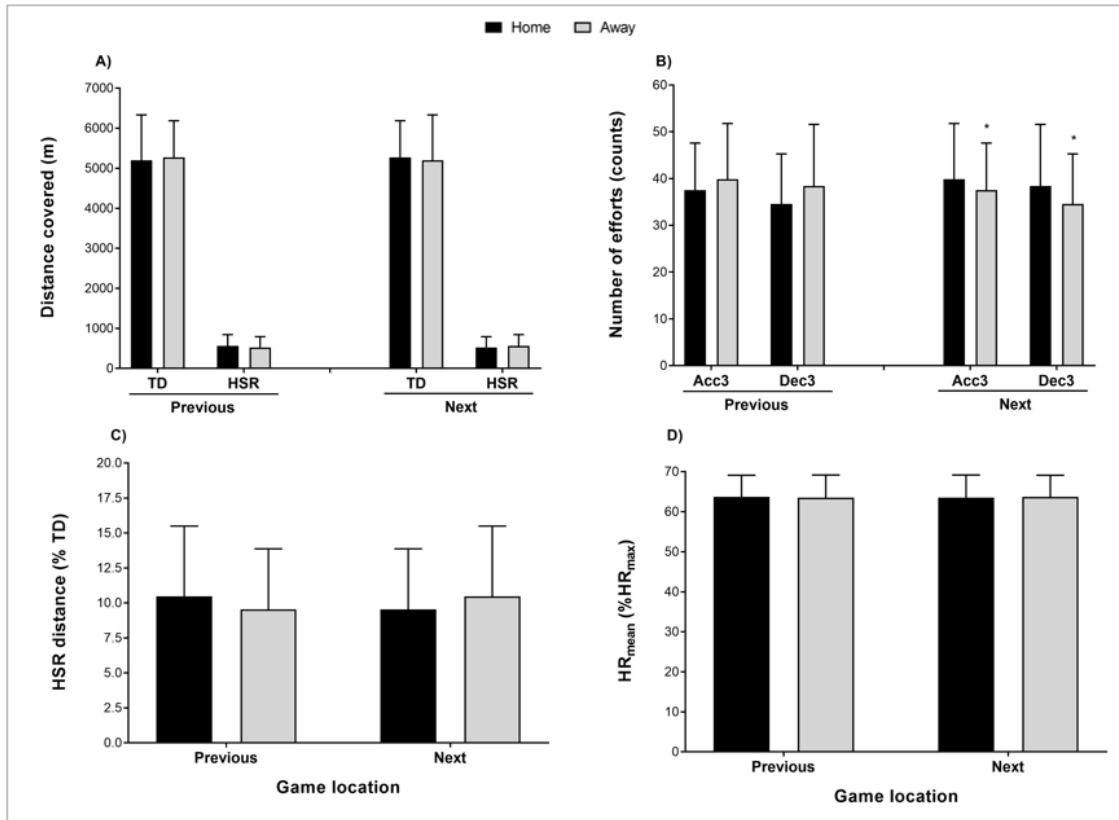


Figure 2. 3. Effect of game location on weekly training load in a professional soccer team.

a) distance covered; b) number of accelerations / decelerations; c) percentage of TD and d) mean heart rate; Acc3, accelerations $>3\text{m}\cdot\text{s}^{-2}$; Dec3, decelerations $<3\text{m}\cdot\text{s}^{-2}$; HR_{max}, maximum heart rate; HR_{mean}, mean heart rate; HSR, high-speed running ($> 16\text{ km}\cdot\text{h}^{-1}$); TD, total distance; * denotes significant differences to "home" ($P < 0.05$).

Discussion

The main finding of this study was that weekly TLs in a professional soccer team seem to be affected by match-related contextual variables. In particular, these effects appear more evident in the standard of the opponent, and the results of the previous and following games, rather than the game location. Overall, higher training volume was observed in the week after playing against a top-level opponent, and after losing a game. Game location appears scarcely influent on weekly TL, showing decreased mechanical work (Acc3 and Dec3) in the week before playing an away game, with no effect on the remaining variables. Additionally, a higher amount of high-intensity training was observed in the week after playing against a bottom-level opponent. Curiously, exercise intensity and physiological responses to training appear higher before winning a game. These findings add evidence to the single previous study investigating the influence of

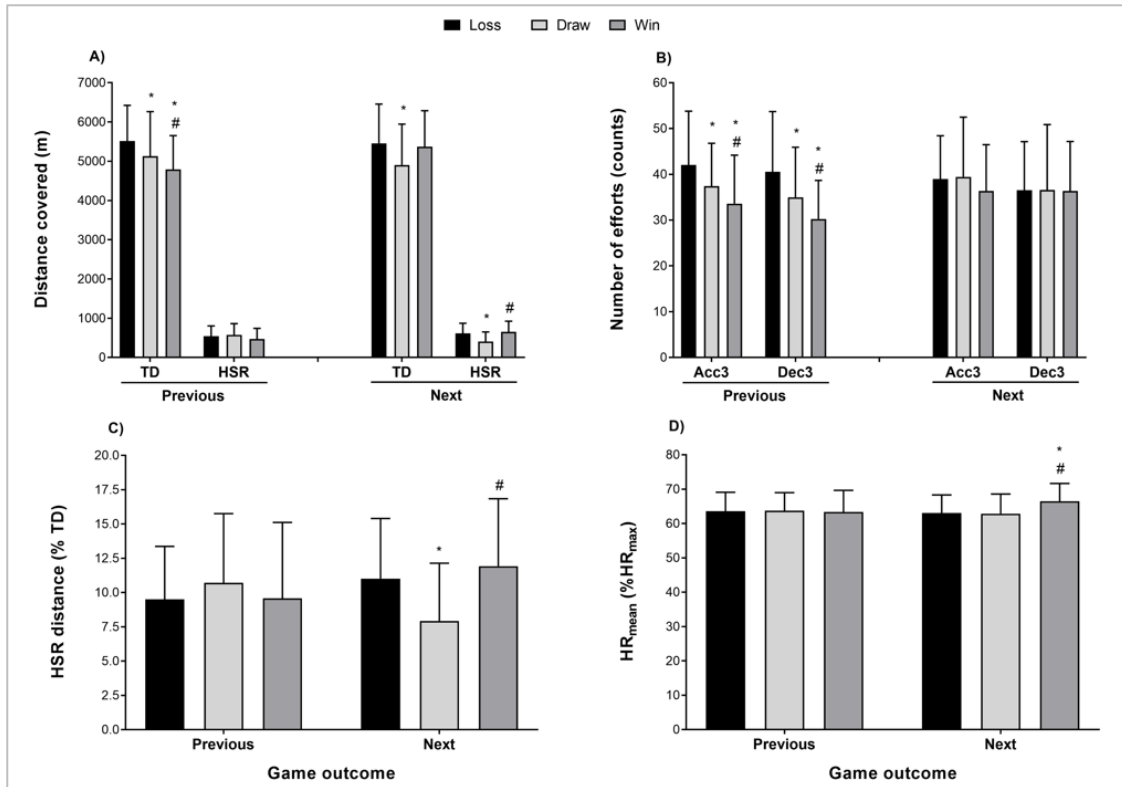


Figure 2. 4. Effect of game outcome on weekly training load in a professional soccer team.

a) distance covered; b) number of accelerations / decelerations; c) percentage of TD and d) mean heart rate; Acc3, accelerations $>3\text{m}\cdot\text{s}^{-2}$; Dec3, decelerations $<3\text{m}\cdot\text{s}^{-2}$; HR_{max} , maximum heart rate; HR_{mean} , mean heart rate; HSR, high-speed running ($>16\text{ km}\cdot\text{h}^{-1}$); TD, total distance; * denotes significant differences to "loss" ($P < 0.05$); # denotes significant differences to "draw" ($P < 0.05$).

match-related contextual factors on weekly TLs using players' subjective ratings (Brito et al., 2016). In an attempt to address the limitations of subjective measures of TLs, we therefore integrated objective indicators of ETL and ITL. Acknowledging the observational nature of the present study, future research is warranted to clarify whether a true cause-effect exists between match-related contextual variables and weekly TL.

The decrease in training volume (e.g. TD) and mechanical work (accelerations and decelerations) performed throughout the season may have been related to changes in training activities prescribed by the technical staff as consequence of cumulative seasonal TL. Notably, the players included in this analysis were highly exposed to competitive fixtures, and the volume of training decreased as the season progressed. On the other hand, HSR, Dec3 and HR loading during training remained stable toward the end of the season, indicating that the amount of high-intensity training and exercise intensity were maintained.

This is in contrast to previous findings showing a decrease in ITL self-reported by top-level U19 male players (Brito et al., 2016). A seasonal decrease in ITL previously documented (Brito et al., 2016) could be associated with improved cardiorespiratory fitness in this cohort of athletes (**Study 3**), and a consequent lower physiological response to training of the fittest athletes (Mann et al., 2013).

Higher TD and HSR were observed in the present study after playing a match against a top-level opponent. Higher training volume may have been observed simply as result of increased amount of high-intensity training within the training session. This is surprising given the higher work rate and degree of fatigue commonly observed during matches against stronger teams (Aquino et al., 2017; Castellano et al., 2011; Folgado et al., 2014; Rago et al., 2018). It is therefore expected that coaches decrease weekly TLs of starting players as recovery strategy due to the opponent-induced match load. Otherwise, players might increase their work rate with a view to match selection. Collectively, it is difficult to draw conclusions about the cause-effect between match-related contextual variables and changes in the volume of activity performed by the players. Additionally, no differences in the weekly ITL were observed according to the previous or next opponent. Our findings are therefore in contrast to previous findings in U19 players showing lower session-RPE (s-RPE) after playing against a top-level opponent (Brito et al., 2016). The relationship between the amount of HSR and s-RPE has been documented in highly-trained soccer players (Gaudino et al., 2015). Therefore, high perceptual responses to training could therefore have been found in our study, following playing against a stronger opponent. However, this cannot be confirmed since in the present study the technical staff had no input from the research team and RPE data were not collected. Therefore, future studies investigating the effect of match-related contextual variables should include either subjective and objective training load indicators. On the other hand, higher amount of intense mechanical work (e.g. Acc3 and Dec3) has been found when preparing a game against a bottom opponent. It is possible that coaches decrease the amount of high-intensity activity for tactical preparation (e.g. corner kicks, free kicks or game-specific single situations) against top-level opponents, simply to reduce muscle damage (Howatson and Milak, 2009) while focusing on other

components such as psychological preparation. This could possibly explain the higher rate of mechanical work when preparing for a game against a weaker team. Alternatively, increased work rate with stable physiological responses might indicate improved cardiorespiratory fitness and readiness to train and compete (Mann et al., 2013).

A game-location effect has been only found in Acc3 and Dec3 when preparing away game. A possible explanation for decreased muscle work imposed by the coaches, or possibly induced by the players' pacing strategy, could be an expected impaired recovery (e.g. team travels, impaired sleep) when travelling for away matches (Costa et al., 2018). However, our findings are in contrast to that of Brito et al. (2016), who observed higher s-RPE after playing an away match. This could be explained by the fact that players still had residual fatigue when rating TL. Consequently, training intensity could be perceived higher as a result of cumulative loads over the previous days. On the other hand, given that soccer teams normally alternate home and away matches, the amount of high-intensity activity was higher when preparing for an away game compared to a home game. This could be explained by the possibility of improving recovery strategy (e.g. no travel) after home games and consequently increasing weekly training stimulus.

Our analysis of match outcome revealed higher weekly training volume after losing a match. This is partially supported by higher weekly training load scores reported after a loss or draw compared to a win in U19 players over an entire season (Brito et al., 2016). However, caution should be exercised when generalizing our findings. Indeed, during the data collection period the team had two wins, five draws and six losses over less than half a season. A major limitation of the present study is that our dataset only included training sessions ($n = 828$) from the beginning of the second half of the season (February) to the end of the season (May). Previous data, i.e. for pre-season and the first half of the competitive period, were not available due to an early coach dismissal. Future studies investigating the effect of match-related contextual variables should be conducted over an entire season or multiple teams and seasons.

It is important to denote various limitations inherent to the present research, with the most important concerning the impossibility of obtaining a cause-effect

relationship from observational studies. First, given the reduced sample size (e.g. team study) we have not account for the starting status. For instance, if the weekly TL was reduced for starter players, non-starters players might have experienced higher weekly TLs than advised. Second, it was not possible to adjust TL to individual threshold based on players' capacity. Therefore, future studies are warranted to address the aforementioned concerns, considering that variations in training loads are therefore likely to be, firstly, a direct function of coaching decisions and, secondly, the actual short-term contextual variables of previous and following matches (Brito et al., 2016).

In summary, this is the first study to quantify the weekly TLs according to different match-related contextual variables using objective TL indicators. Our findings complemented previous research investigating the effect of match-related contextual variables on subjective perceptions of training (Brito et al., 2016) and could be considered with caution by practitioners involved with TL monitoring in top-level soccer. Opponent standard and game outcome appear to be the major influencers of weekly training, rather than game location. Notwithstanding this, the present study included two congested periods with limited time for recovery between competitive matches. On the other hand, during typical weeks (5 to 7 days between competitive matches) coaches commonly opt to concentrate the most intense training sessions in the middle of the weekly cycle to prevent excessive loading on the days immediate before and after competitive matches (Brito et al., 2016). Nonetheless, we adjusted our analysis by normalizing TL data by the number of weekly training sessions. The observed effect of match-related contextual variables on TL in the present study was of small to moderate magnitudes, compelling the identification of further factors influencing weekly TL in professional soccer.

Practical applications

Weekly TLs seem to slightly vary (based on the magnitude of differences) according to the standard of the opponent, the location of a game, and the results of the previous and following matches. Overall, higher training volume was observed before and after playing against a top-ranking opponent, and after losing

a match. Moreover, the amount of high-intensity training appears to decrease before and after playing against a top-ranking opponent, and to increase after a home game (or when preparing for an away game). Thus, when planning training sessions, soccer coaches need to consider the interplay of the numerous variables that influence the amount of prescribed training (e.g. ETL) and the actual training responses in each individual player. However, given the observational nature of the present study, future research is warranted to clarify cause-effect between match-related contextual variables and weekly TL.

Acknowledgments

The authors would like to express their appreciation for the outstanding efforts and positive attitude of the participants, their coaches and club. In particular, the technical assistance of Felix Martinez and Julio Hernando is greatly appreciated. Vincenzo Rago was supported by an individual doctoral grant awarded by *Fundação para a Ciência e Tecnologia* (SFRH/BD/129324/2017).

Training load and submaximal heart rate testing throughout a competitive period in a top-level male football team

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2019

Journal of Sports Sciences, ahead of print

DOI: 10.1080/02640414.2019.1618534

Keywords: Performance; Physiology; Monitoring; GPS; Assessment

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Abstract

The aim of this study was to investigate training load and cardiorespiratory fitness in a professional Spanish (*LaLiga*) football team ($n = 17$). The submaximal Yo-Yo intermittent recovery test level 1 (Yo-Yo IR1_{SUB}) was performed in four moments of the competitive period from early February (E1) to early May (E4). Training load was quantified using a 10-Hz global positioning system and heart rate (HR) recording ($n = 837$ individual training sessions), while match load was quantified using semi-automated cameras ($n = 216$ individual match observations). Cardiorespiratory fitness moderately improved as the season progressed ($P < 0.05$; *effect sizes* = 0.85–1.02). Cumulative total distance covered during training between E1 and E4 was negatively correlated with percentage of changes in mean HR during the last 30 s of Yo-Yo IR1_{SUB} ($P = 0.049$; $r = -0.47$ [-0.71; -0.14]). HR during the last 30 s of Yo-Yo IR1_{SUB} was negatively correlated to total distance covered during the match ($P = 0.024$; $r = -0.56$ [-0.80; -0.17]). Yo-Yo IR_{SUB} can be used to monitor seasonal changes in cardiorespiratory fitness without the need to have players work until exhaustion. Cardiorespiratory fitness given by mean HR during the last 30 s of the test seems meaningful in relation to match performance.

Introduction

The impact of football training and competition on the cardiorespiratory system is well-known (Stølen et al., 2005). For instance, outfield players' average exercise intensity locates in the range of 60–80% of their HR_{max} during training sessions (increasing from the start of the week toward the mid-week and decreasing from the mid-week toward the match), and 80–90% HR_{max} in a competitive game (Bangsbo et al. 2006; Malone et al., 2015; Stølen et al., 2005). Consequently, cardiorespiratory performance decreases throughout a competitive game (Rebelo et al., 1998). Extensive research has shown positive associations between cardiorespiratory fitness and physical performance (e.g. distance covered by high speed) during competitive male football matches (Bangsbo et al., 2008; Bradley et al., 2011; Krstrup et al., 2003; Rampinini et al., 2007). Yet, a recent study revealed that players with higher intermittent cardiorespiratory fitness

better tolerated acute TLs, than less-conditioned players (Malone et al., 2018). Thus, cardiorespiratory fitness is of importance in professional football players.

Cardiorespiratory fitness is commonly measured using maximal (e.g. time to exhaustion) tests. However, most of the time these tests are unsuitable during competitive periods due to the high density of competitive fixtures. Non-exhaustive testing is therefore preferable to assess athletes' training status when functional capacity is limited during rehabilitation from injury or when frequent testing is required (Bangsbo et al., 2008). As elite football clubs often limit the number of occasions they evaluate players due to heavy fixture schedules, submaximal tests have been proposed as an alternative to maximal testing (Svensson and Drust, 2005). Observations in elite football players revealed that mean heart rate (HR_{mean}) obtained after 6 min of the Yo-Yo IR1 or the Yo-Yo intermittent endurance test – level 2 were correlated to performance in various maximal tests and highly reproducible in professional football players (Bangsbo et al., 2008; Bradley et al., 2011; Krstrup et al., 2003). Therefore, HR measurements during submaximal intermittent tests may provide information about the fitness of a football player, with the advantage that the players do not have to work to exhaustion.

Physiological adaptations to training are the goal of systematic and repetitive exposure to training load over time (Mujika, 2017). The use of wearable technology incorporating GPS or HR monitors has markedly increased over the last decade in top-level football settings. However, research focusing on the association between TL and cardiorespiratory fitness during the competitive period in professional football players has predominantly focused on exposure time to competition (Silva et al., 2011) and RPE (Campos-Vázquez et al., 2017), with no attempts to consider GPS or HR indicators. On the other hand, research considering HR-derived TL indices has been predominantly conducted during the preseason (Castagna et al., 2011; Castagna et al., 2013; Manzi et al., 2013). Only one study has investigated the association between HR-based TL and cardiorespiratory adaptations in football players across the competitive period, showing a moderate correlation ($r = 0.67$) between training impulse and improved aerobic threshold in young (~17-yrs-old) football players (Akubat et al., 2012). Further attempts to investigate the associations between TL and training

adaptations have focused on measures of neuromuscular function, observing contradictory results (Jaspers et al., 2017). With this evidence in mind, information regarding TL and cardiorespiratory fitness obtained via submaximal tests in top-level football players during the competitive period is unknown. The aims of this study were to investigate, in a sample of professional football players: (i) changes in cardiorespiratory fitness throughout a competitive period; (ii) possible associations between these changes and cumulative TLs; and (iii) the associations between cardiorespiratory fitness and match physical performance.

Methods and material

Participants

During the second half of 2017/18 season, all outfield players competing in the same team of the top Spanish male league (*LaLiga*) were regularly monitored in the context of their team routine. Following exclusion of six players who did not take part in all the evaluations due to injury, 17 players (mean \pm SD; age, 27.8 \pm 3.9 yrs; height, 177.9 \pm 6.4 cm; body mass, 72.7 \pm 11.9 kg) were considered for analysis. 8 out of these 17 represented their respective national teams. These data arose as a routinely-measured player players' activities over the course of the competitive season, without any input from the research team; therefore, no informed consent was required to the players (Winter and Maughan, 2009). The Ethical Committee of the Faculty of Sports at the University of Porto approved and recorded the study under "CEFADE.08.2018".

Experimental overview

Cardiorespiratory fitness was assessed at four time points over a 3-month competitive period during the second part of the season (between mid-season and the end of the season) as follows: first (E1)—early February; second (E2)—early March; third (E3)—early April; and fourth (E4)—early May (**Fig. 2.5**). All tests were performed at 10.30 in the morning after eating a standardised breakfast. Players were asked to note what they ate prior to E1 and to replicate the meal prior to E2–4. Additionally, the players' TL between each time point was quantified, including

substitute players and individual sessions. The final analysis included a total of 837 individual training sessions (player' median [range] = 36 [5; 46]) and 216 individual competitive matches (player median [range] = 11 [1; 17]). Measuring fitness at different time points throughout the season allowed analysis of seasonal fitness alterations and the association between TL and training outcomes (e.g. cardiorespiratory fitness; Jaspers et al., 2017; Silva et al., 2011). To remove the effect of match-induced fatigue, thus ensuring freshness and focusing on training adaptations, cardiorespiratory fitness was assessed on the third day post-match. As a secondary purpose, the association between cardiorespiratory fitness and match performance was analysed considering only those players who completed the full 90 min at least once. In this specific analysis, the best (lowest HR during the last 30 s) of the four Yo-Yo IR1_{SUB} results was considered as the most representative of the player's cardiorespiratory profile.

The generic training and competitive schedule completed by the football players involved in this study was supplied by the technical staff of the team. As can be seen from the timeline (**Fig. 2.5**), 67 training sessions and 15 competitive matches were performed between E1 and E4. Of these 67 training sessions, 24 included speed endurance training (e.g. long sprints, repeated sprints) and 26 aerobic high-intensity training (e.g. interval training, medium-to-large sized games). The remaining training sessions mainly concerned ball-possession games and team/opponent tactics.

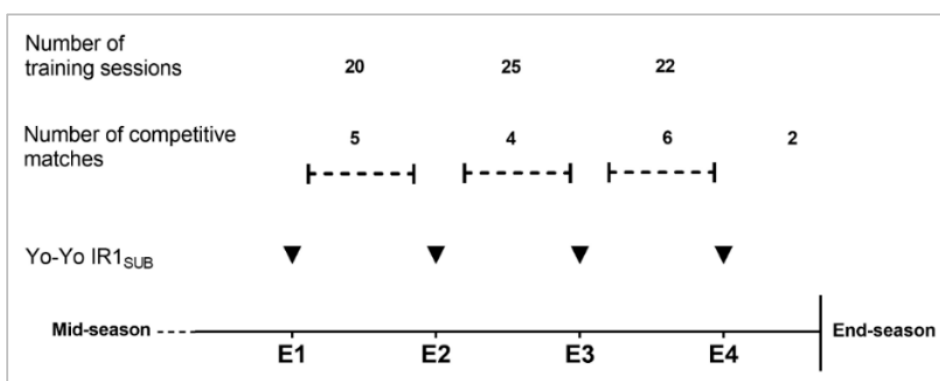


Figure 2. 5. Timeline of the study.

The dotted lines delimitate accumulated training load calculations; E1, evaluation moment 1; E2, evaluation moment 2; E3, evaluation moment 3; E4, evaluation moment 4; Yo-YoIR1_{SUB}, Submaximal Yo-Yo intermittent recovery test level 1.

Procedures

External training load. The players' movements during training were measured using a 10-Hz GPS (WIMU PRO ®; Realtrack Systems SL, Almeria, Spain) with a 3-axis accelerometer, gyroscope and magnetometer integrated sampling at 100 Hz. These devices (85 × 48 × 15 mm, 65 g) were fitted to the upper back of each player using adjustable harnesses (Rasán, Valencia, Spain). Data were analysed using the system-specific software (WIMU Software; Realtrack Systems SL, Almeria, Spain). This system showed acceptable accuracy for measures of running speed, acceleration and deceleration (Muñoz-López et al., 2017). All devices were always activated 15 min before data collection to allow acquisition of satellite signals in accordance with the manufacturer's instructions. To avoid inter-unit error, the players wore the same device for each training session (Gaudino et al., 2014). Total distance (TD) and distance covered in each speed zone were calculated, using a custom Excel spreadsheet, from instantaneous raw data for time, speed and distance available from the manufacturer's software, and the minimum effort duration was 0.5 s. Speed, acceleration and deceleration zones were defined according to Osgnach et al. (2010). The speed thresholds adopted were: high-speed running (HSR, distance covered above 16 km·h⁻¹, that is supposedly the average MAS in professional football players) and sprinting (distance covered above 21 km·h⁻¹, that is supposedly the 60–70% of MSS (Osgnach et al., 2010). The number of intense accelerations (number of entries above 3 m·s⁻²) and decelerations (below -3 m·s⁻²) was also quantified.

Internal training load. HR was recorded every 5 s using a short-range telemetry system (WIMU PRO ® RealTrack Systems). The physiological intensity of all training sessions was indicated in relative terms (i.e. the corresponding percentage of HR_{max}). The players' HR_{max} was 193.8 ± 5.2 bpm, determined by an incremental treadmill protocol at the start of the season. The ITL of all training sessions was evaluated by HR_{mean}.

Match performance. Match physical data were made available by Mediacoach (MediaPro, Madrid, Spain). The movements of all outfield players were recorded during the entire game by sixteen stable synchronised cameras

positioned at the top of each stadium. From the stored data, TD covered, and the distance covered above 21 km·h⁻¹ were provided by the default. The tracking system (OPTA Client System) was tested for acceptable inter-operator reliability (intra-class correlation coefficients = 0.88–1.00; Liu et al., 2013). Match data were adjusted to GPS data using a calibration equation described elsewhere, that allows the integration of different tracking systems (Buchheit et al., 2014). Match data were summed to training data to calculate cumulative loads and subsequently, to compute the associations with cardiorespiratory adaptations.

Testing. The Yo-Yo IR1_{SUB} was performed on natural grass on the training ground of the participating team. After a familiarisation trial, the first test was performed in early February. Players were advised to refrain from caffeine before testing and maintain their habitual nutritional habits prescribed by the team certified dietitian. According to the traditional version of the test (e.g. maximal Yo-Yo IR1), the Yo-Yo IR1_{SUB} required repeated 2 × 20-m runs (shuttles), separated by a 10-s rest period, between the start and finish line at progressively increased speeds controlled by audio bleeps from a tape recorder (Bangsbo et al., 2008). However, in contrast with the traditional version of the test (in which subjects aim to perform as many shuttles as possible), the Yo-Yo IR1_{SUB} was stopped at the last shuttle of the seventh level, corresponding to a speed of 14.5 km·h⁻¹ and an accumulated distance of 800 m (6 min, 51 s). This ensured that the physiological intensity was submaximal. The validity of this test has been previously documented by an inverse correlation between HR during the last 30 s of the first 6 min of the Yo-Yo IR1_{SUB} and performance in the Yo-Yo IR1 ($r = -0.81$; Krstrup et al., 2003). Additionally, HR responses during Yo-Yo IR1_{SUB} have shown acceptable reproducibility (coefficient of variation, CV = 3–7%; Krstrup et al., 2003). HR was recorded throughout the test, and HR_{mean} during the last 30 s was retained as an indicator of cardiorespiratory fitness (Buchheit, 2014; Krstrup et al., 2003).

Statistical analyses

Shapiro-Wilk test revealed that HR_{mean} during the last 30 s of Yo-Yo IR1_{SUB} was normally distributed at all evaluation moments ($P > 0.05$). One-way analysis

of variance with repeated measures was used to analyse changes in Yo-Yo IR1_{SUB} throughout the competitive period. When a significant effect was found, pairwise comparisons were analysed using a post-hoc *Bonferroni* test. The magnitudes of difference were subsequently quantified using *effect sizes* (*ES*) according to Hopkins et al. (2009), trivial (*ES* < 0.2), small (*ES* = 0.2–0.6), moderate (*ES* = 0.6–1.2), large (*ES* = 1.2–2.0), very large (*ES* = 2.0–4.0) and extremely large (*ES* > 4.0). Paired sample correlations were computed to analyse the associations between accumulated TL and percentages of changes in Yo-Yo IR1_{SUB}. To interpret the magnitudes of correlation, the following criteria were adopted: trivial ($r \leq 0.1$), small ($r = 0.1–0.3$), moderate ($r = 0.3–0.5$), large ($r = 0.5–0.7$), very large ($r = 0.7–0.9$) and almost perfect ($r \geq 0.9$) (Hopkins et al., 2009). For both differences and correlations, associated 90% CIs were calculated. When 90% CIs overlapped positive and negative values, the effect was deemed to be unclear. Otherwise, the effect was deemed to be the observed magnitude (Batterham and Hopkins, 2006). Quantitative probabilities were evaluated qualitatively as *almost certainly not* (< 1%), *very unlikely* (1–5%), *unlikely* (5–25%), *possibly* (25–75%), *likely* (75–95%), *very likely* (95–99%) and *almost certainly* (> 99%) (Batterham and Hopkins, 2006). If the probabilities of the effect being higher or lower than the smallest worthwhile difference were simultaneously > 5%, the effect was deemed to be unclear. In order to provide practical indications of changes in cardiorespiratory fitness, the smallest worthwhile change (SWC) was calculated by multiplying 0.3 by the between-subjects' CV (Hopkins et al., 2009). Statistical significance was set at $P \leq 0.05$. Data analysis was performed using Statistical Package for Social Sciences software (IBM Statistics, Chicago, USA).

Results

A detailed description of TL is reported in **Table 2.1**. The SWC for submaximal HR_{mean} during the last 30 s of Yo-Yo IR1_{SUB} was 1.28 %HR_{max}. Cardiorespiratory fitness improved as the season progressed; specifically, HR_{mean} during the last 30 s of Yo-Yo IR1_{SUB} was moderately lower in E3 and E4 compared to E1 ($P < 0.05$; *ES* = 1.02 [0.47; 1.57] and 1.25 [0.68; 1.82], both *almost certainly*) and E2 ($P < 0.05$; *ES* = 0.85 [0.31; 1.40] and 1.06 [0.51; 1.62], both *very likely*)

(**Fig. 2.6**). Cumulative TD during training sessions between E1 and E4 was negatively correlated with percentage of changes in HR_{mean} during the last 30 s of Yo-Yo IR1_{SUB} ($P = 0.049$; $r = -0.47$ [-0.71; -0.14]; $n=17$; moderate; *likely* [1.1/5.1/93.7]; **Fig. 2.7**). However, two players did not experience meaningful changes in cardiorespiratory fitness between E1 and E4 (observed change < SWC; **Fig. 2.7**). No substantial correlations were observed between changes in HR_{mean} during the last 30 s of Yo-Yo IR1_{SUB} and all the remaining training and match load variables ($P > 0.05$). HR_{mean} during the last 30 s of Yo-Yo IR1_{SUB} was negatively correlated to TD covered during the match ($P = 0.024$; $r = -0.56$ [-0.80; -0.17]; $n = 16$; moderate; *very likely* [0.3/2.0/97.7]), but not to sprinting distance (**Fig. 2.8**).

Table 2. 1. Training load throughout a 3-month competitive period in a professional football team.

	Training sessions			Competitive matches		
	February	March	April	February	March	April
ET (min)	-	-	-	245 ± 155	164 ± 106	294 ± 195
TD (m)	41699 ± 9262	66749 ± 25307	43688 ± 14610	28210 ± 17537	18238 ± 11418	33872 ± 22243
HSR (m)	3221 ± 889	5037 ± 2178	3947 ± 1510	-	-	-
Sprinting (m)	1150 ± 513	2273 ± 953	1655 ± 672	1637 ± 1216	1026 ± 823	1977 ± 1534
THIA (m)	4352 ± 1305	7311 ± 3055	5603 ± 2128	-	-	-
Acc _{int} (counts)	316 ± 99	517 ± 249	290 ± 95	-	-	-
Dec _{int} (counts)	306 ± 94	470 ± 219	294 ± 104	-	-	-
HR_{mean} (% HR_{max})	63.1 ± 5.0	62.9 ± 8.8	65.8 ± 4.5			

Acc_{int}, intense accelerations (> 3 m·s⁻²); Acc_{int}, intense decelerations (< -3 m·s⁻²); ET, exposure time; HR_{max} , mean heart rate; HR_{mean} , mean heart rate; HSR, high-speed running (16–19 km·h⁻¹); THIA, total high-intensity activity (HSR + Sprinting [> 21 km·h⁻¹]); TD, total distance.

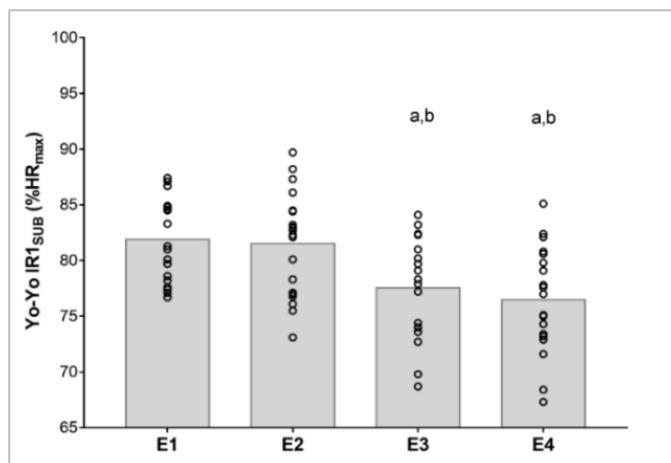


Figure 2. 6. Changes in Yo-Yo IR1_{SUB} throughout a 4-month competitive period in a professional football team.

E, evaluation moment; HR_{max} , maximum heart rate; Yo-Yo IR1_{SUB}, mean heart rate during the last 30 s of the submaximal Yo-Yo intermittent recovery test level 1; "a" denotes significant differences to E1; "b" denotes significant differences to E2.

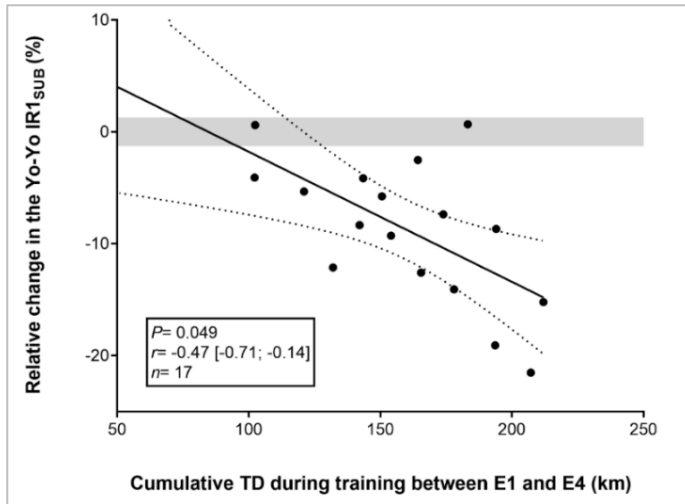


Figure 2. 7. Relationship between accumulated total distance covered during training between E1 and E4 and relative changes in Yo-Yo IR1_{SUB}.

E1, evaluation moment 1 (early February); E4, evaluation moment 4 (early May); TD, Total distance; Yo-Yo IR1_{SUB}, mean heart rate during the last 30 s of the submaximal Yo-Yo intermittent recovery test level 1. The grey-filled space denotes the smallest worthwhile change.

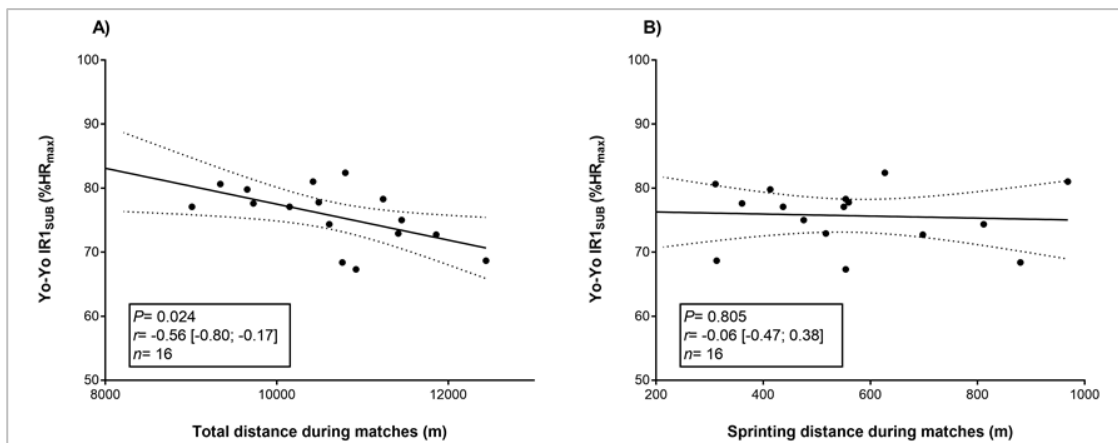


Figure 2. 8. Relationship between cardiorespiratory fitness and match performance given by a) total distance and b) sprinting distance.

HR_{max}, maximum heart rate; Yo-Yo IR1_{SUB}, submaximal Yo-Yo intermittent recovery level 1; the dotted lines are 90% confidence intervals.

Discussion

The present study is the first to monitor changes in cardiorespiratory fitness via a submaximal test and analyse their associations with cumulative training and match load throughout the competitive period in top-level football players. The major findings were that: (i) cardiorespiratory fitness improved as the season progressed; (ii) these changes were associated with the cumulative TD covered during training sessions; and (iii) cardiorespiratory fitness was associated with TD covered during the match.

Our data showed a decrease in HR_{mean} during the last 30 s of $YYIR1_{SUB}$ towards the end of the season, indicating improved cardiorespiratory fitness over time. As far as we know, this is the first study to use a submaximal test to monitor seasonal changes in cardiorespiratory fitness in elite players. Previous attempts to investigate seasonal variations in cardiorespiratory fitness in professional football players employed maximal field or laboratory testing at various points of the season (Castagna et al., 2011, 2013; Manzi et al., 2013; Meckel et al., 2018; Metaxas et al., 2006).

Irrespective of the methodology employed, our findings are in contrast to previous reports concerning professional football players. For instance, cardiorespiratory fitness data obtained from different assessments, such as various versions of the Yo-Yo intermittent tests (Manzi et al., 2013; Silva et al., 2011), the incremental treadmill test to exhaustion (Castagna et al., 2011, 2013; Metaxas et al., 2006) or the multistage shuttle running test (Meckel et al., 2018), revealed increased performance after the preseason followed by a decrease during the season. To the best of our knowledge, only one study assessed seasonal changes in Yo-Yo $IR1_{SUB}$, observing a tendency for improved cardiorespiratory fitness (lower HR_{mean} after 6 min) after the preseason period with stable performance from the start to the end of the competitive period (Krustrup et al., 2003). In the present study, the improved cardiorespiratory fitness towards the end of the season could be partially attributed to impaired performance, possibly observed following the mid-season winter break. Other studies investigating seasonal changes in cardiorespiratory fitness in professional football have predominantly found improved performance after the preseason with stable or decreased performance throughout the competitive period (Casajus, 2001; Fessi et al., 2016; Meckel et al., 2018). However, these studies only assessed physical fitness at two to four points in the season using maximal tests. Future attempts to longitudinally monitor cardiorespiratory fitness could use submaximal tests, saving time for training and providing the possibility to frequently test players, as was the case in the present study (monthly). However, future studies considering the entire season or multiple seasons are warranted.

Changes in cardiorespiratory fitness solely correlated to TD covered during training ($r = 0.49$). Curiously, cardiorespiratory adaptations did not show any significant association to the considered match parameters (e.g. exposure time, TD and number of sprints). Our findings corroborate those for Portuguese top-league players, which showed no significant correlations between distance covered in Yo-Yo Intermittent Endurance – level 2 and accumulated exposure time to competition (Silva et al., 2011). The associations between match load parameters and changes in physical fitness have been predominantly reported in muscle-related parameters such as countermovement jump height/power and isokinetic strength of the thigh muscles (Jaspers et al., 2017). Long-term (e.g. seasonal) studies are therefore recommended to clarify the impact of match load on the cardiorespiratory system.

Another unexpected finding of the present study was that mean HR during training failed to correlate to positive changes in cardiorespiratory fitness. This is somewhat curious given the well-documented effectiveness of high-intensity training for enhancing cardiorespiratory adaptations (Buchheit and Laursen, 2013; Iaia et al., 2009). However, the team studied did not use other HR-based training load indicators (e.g. amount of time in HR zones) that have related to cardiorespiratory adaptations. It seems that the higher the amount of training spent in high-intensity HR zones (i.e. $>90\%HR_{max}$), the better the relative changes in cardiorespiratory fitness. Previous studies showed that accumulated time spent above individual anaerobic thresholds during training resulted in positive cardiorespiratory adaptations, such as increased aerobic threshold and maximal oxygen uptake over the preseason period ($r = 0.65–0.84$; Castagna et al., 2011; Castagna et al., 2013). Moreover, improvements in intermittent cardiorespiratory fitness, obtained from distance covered in YYIR1, were also associated with i-TRIMP ($r = 0.69$; Manzi et al., 2013). Recently, however, changes in intermittent cardiorespiratory fitness during the preseason were associated with total exposure time to training, Edwards' TL and RPE ($r = 0.25–0.75$; Campos-Vázquez et al., 2017). These positive correlations between accumulated HR-derived TL and cardiorespiratory adaptations could be attributed to the fact that these studies were conducted during the preseason period. Training adaptations are easier to

observe after the preseason due to the frequently observed decline in physical capacities during the off-season (Silva et al., 2016). Conversely, during the competitive period, cardiorespiratory adaptations may be masked by the fact that professional players are already conditioned (Silva et al., 2016). No definitive conclusions can therefore be drawn in terms of the optimal amount of TL during the competitive period. Notwithstanding, our findings emphasise the fact that training volume (e.g. distance covered during training) may play a meaningful role in promoting positive cardiorespiratory adaptations over a prolonged training period. Caution should be exercised when generalising our findings and when using our SWC value. Indeed, the present research was a case study ($n = 17$) and five players did not display meaningful changes over time.

The analysis of associations between cardiorespiratory fitness and match physical performance revealed that HR_{mean} during the last 30 s of Yo-Yo IR1_{SUB} was negatively correlated to TD during the match. This indicates that players with better cardiorespiratory fitness also had higher volumes of activity during the match. Surprisingly, no significant association was observed between cardiorespiratory fitness and distance covered above $21 \text{ km}\cdot\text{h}^{-1}$ during competitive matches. Our findings are partially supported by previous research adopting exhaustive cardiorespiratory tests. For instance, Bradley et al. (2011) showed that distance covered in Yo-Yo Intermittent Endurance – level 2 was moderately correlated ($r = 0.55$) to TD covered in English Premier League players, while Rampinini et al. (2007) showed a positive correlation between peak speed during an incremental test and TD during the game ($r = 0.58$). However, research focusing on the association between cardiorespiratory fitness and match performance has predominantly focused on HSR distance (14.4 , 18 or $19.8 \text{ km}\cdot\text{h}^{-1}$). Moderate to large associations have been observed between performance in various maximal tests (e.g. Yo-Yo IR1, treadmill protocols) and HSR during professional top-level male games ($r = 0.34$ – 0.71 ; Bradley et al., 2011; Krstrup et al., 2003; Rampinini et al., 2007). As far as we know, only one study correlated cardiorespiratory fitness obtained via submaximal testing with physical performance during the game, showing that HR following 6 min of the submaximal Yo-Yo Intermittent Endurance – level 2 was negatively correlated to peak 5- and 15-min HSR during the match

(Bradley et al., 2011). However, our study possibly failed to show significant relationships between testing and performance due to the intensity threshold adopted ($21 \text{ km}\cdot\text{h}^{-1}$). Indeed, previous studies had lower speed thresholds (between 14 and $19 \text{ km}\cdot\text{h}^{-1}$) that closely relate to the MAS. It is therefore recommended that future studies should adopt lower thresholds comprised between 14 and 19 , to analyse the correlation between cardiorespiratory fitness obtained via submaximal testing and physical performance during the game.

Various limitations of the present study should be pointed out. First, the lack of further competitive match load parameters in addition to exposure time, TD and distance covered above $21 \text{ km}\cdot\text{h}^{-1}$ limited our longitudinal quantification of training load and the subsequent computation of association to our training outcome (e.g. cardiorespiratory adaptations). Second, whereas HR_{max} was obtained before the start of the study, it was not possible to conduct further assessment to obtain maximal individual capacities due to constraints associated with the team's schedule and technical staff decisions. For this reason, we used arbitrary (player-independent) speed zones. Despite the inherent information available from distance covered within arbitrary speed zones, this method is biased to the potential players' diversity within a team (e.g. fitness levels, age, training history, injury history, maturity offset), consequently masking individual capacities and thus neglecting the load imposed on the individual player. The use of individualised (player-dependent) speed zones has been proposed to quantify ETL, reducing the confounding effect of between-player variation in physical capacity (Hunter et al., 2015; Mendez-Villanueva et al., 2013). In this context, a recent study showed that time spent above individual MAS was better associated with changes in cardiorespiratory fitness ($R^2 = 0.59$) than time spent above $17 \text{ km}\cdot\text{h}^{-1}$ ($R^2 = 0.37$) in ~ 17 -yrs-old football players (Fitzpatrick et al., 2018). Nonetheless, performance responses to training are non-linear, influenced by a myriad of factors not related to training, and therefore difficult to accurately predict (Bourdon et al., 2017).

In summary, this study showed that cardiorespiratory fitness improved during the competitive season, as evaluated by HR measurements during a Yo-Yo IR_{SUB} test. It was also observed that the change in cardiorespiratory fitness is related to the cumulative training and match load during the competitive period in

top-level football players. In particular, TD covered during training showed a positive association with cardiorespiratory adaptations given by mean HR_{mean} during the last 30 s of Yo-Yo IR_{SUB} . The importance of exercise intensity for inducing training adaptations has been well documented in top-level football players (Castagna et al., 2011, 2013; Iaia et al., 2009; Jaspers et al., 2017; Manzi et al., 2013). However, the present finding possibly paves the way to further investigate the effect of training volume on training outcomes. In addition, considering that maximal tests are challenging to perform frequently during the competitive period in an elite setting, future studies are warranted to support our findings by investigating changes in cardiorespiratory fitness using submaximal tests.

Conclusions

This study showed changes in cardiorespiratory fitness throughout a 3-month competitive period in football players. The Yo-Yo IR_{SUB} can be used to monitor seasonal variations in cardiorespiratory fitness without the need to have players work until exhaustion. Cardiorespiratory fitness given by HR_{mean} during the last 30 s of the test also seems meaningful in relation to match performance given the association with total distance covered during competitive matches. The present data could assist in controlling training and competition loads and their impact on the cardiorespiratory system.

Acknowledgments

The authors would like to express their appreciation for the outstanding efforts and positive attitude of the participants, their coaches and club. In particular, the technical assistance of Felix Martinez and Julio Hernando is greatly appreciated. The assistance of Pedro Figueiredo with statistical analyses is also appreciated. Vincenzo Rago was supported by an individual doctoral grant awarded by *Fundação para a Ciência e Tecnologia* (SFRH/BD/129324/2017).

Application of individualized speed zones to quantify external training load in professional soccer

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Journal of Human Kinetics, under production

DOI: under registration

Keywords: Monitoring; GPS; Fitness, Performance, Testing

This is an accepted manuscript that is currently under production by the Journal of Human Kinetics.

Abstract

This study aimed to examine the interchangeability of two external training load (ETL) monitoring methods: arbitrary vs. individualized speed zones. Thirteen male outfield players from a professional football team were monitored during training sessions using 10-Hz GPS units over an 8-week competitive period ($n = 302$ individual observations). Low-speed activity (LSA), moderate-speed running (MSR), high-speed running (HSR) and sprinting were defined using arbitrary speed zones as <14.4 , $14.4\text{--}19.8$, $19.8\text{--}25.1$ and ≥ 25.2 $\text{km}\cdot\text{h}^{-1}$, and using individualised speed zones based on a combination of maximal aerobic speed (MAS, derived from the Yo-yo Intermittent recovery test level 1), maximal sprinting speed (MSS, derived from the maximal speed reached during training) and anaerobic speed reserve (ASR) as: $<80\%$ MAS, $80\text{--}100\%$ MAS, 100% MAS– 29% ASR and $\geq 30\%$ ASR. Distance covered in both arbitrary and individualised methods was almost certainly correlated in all speed zones ($P < 0.01$; $r = 0.67\text{--}0.78$). However, significant differences between methods were observed in all speed zones ($P < 0.01$). LSA was almost certainly higher when using the arbitrary method than when using the individualized method ($P < 0.01$; *effect size*, $ES = 5.47$ [5.18 ; 5.76], respectively). Conversely, MSR, HSR and sprinting speed were higher in the individualized method than in the arbitrary method ($P < 0.01$; $ES = 5.10$ [4.82 ; 5.37], 0.86 [0.72 ; 1.00] and 1.22 [1.08 ; 1.37], respectively). Arbitrary and individualised methods for ETL quantification based on speed zones showed similar sensitivity in depicting player locomotor demands. However, since these methods significantly differ at absolute level (based on measurement bias), arbitrary and individualised speed zones should not be used interchangeably.

Introduction

The use of GPS technologies for monitoring players' ETL has markedly increased over the last decade among soccer practitioners. A wide range of GPS metrics is currently available from which coaches can be objectively informed and subsequently adjust training programs. The amount of activity performed by the

players is commonly quantified using arbitrary (player-independent) speed zones (Akenhead and Nassis, 2016). Despite the inherent information available from distance covered within arbitrary speed zones, this method is biased by the potential players' diversity within a team (e.g. fitness, age, training experience, injury history), consequently masking individual capacities and thus neglecting ETL imposed on the individual player. The use of individualized (player-dependent) speed zones has recently therefore been proposed for quantifying ETL, reducing the confounding effect of between-player variation in physical capacity (Abbott et al., 2018; Hunter et al., 2015; Mendez-Villanueva et al., 2013).

Individualized speed zones rely on fitness test data, such as measures of cardiorespiratory fitness. Thus, recent studies have adopted incremental field tests to indirectly compute athletes' MAS (Abbott et al., 2017; Fitzpatrick et al., 2018). MAS is very strongly correlated to maximal oxygen uptake and, in conjunction with MSS, allows calculation of the ASR that accounts for the transition from HSR to sprinting (Hunter et al., 2015). However, direct measurements of cardiorespiratory fitness are time-consuming, expensive, require access to equipment uncommon for lower-level clubs and lack ecological validity (Abbott et al., 2018; Lovell and Abt, 2013). The Yo-Yo IR1 is widely employed by soccer practitioners to profile soccer players' prolonged intermittent exercise capacity and subsequently estimate MAS. In particular, the Yo-Yo IR1 involves an essential neuromuscular component imposed by shuttle running, thus better reflecting the physical demands of soccer (Castagna et al., 2006). However, to the best of our knowledge, only one study has attempted to individualize ETL data by deriving individual MAS from the Yo-Yo IR1 (Scott and Lovell, 2018). In addition, previous studies have predominantly used a single fitness component to adjust ETL data to individual fitness levels, with limited research using a combination of capacities (Abbott et al., 2017, 2018; Fitzpatrick et al., 2018). Considering MSS or MAS independently to analyze ETL data would result in a misunderstanding of TL data (Hunter et al., 2015). Indeed, a combined approach to quantifying ETL data that incorporates fitness data from field-based tests to estimate players' MAS and MSS provides a more accurate definition of speed zones than a single fitness component (Hunter et al., 2015).

Individualized ETL was shown to give a detailed insight into players' activity, but there is limited research regarding the validity of this method (Abbott et al., 2018; Hunter et al., 2015). In addition, information regarding the degree of association and agreement between individualized and arbitrary speed zones is still unknown. Previous agreement-type studies in professional soccer have focused on composite ETL variables such as metabolic power (Castagna et al., 2017; Gaudino et al., 2013). Differences between ETL using arbitrary and individualized thresholds have been previously documented using laboratory tests (Abbott et al., 2018; Hunter et al., 2015; Nakamura et al., 2017). Also, previous studies individualizing ETL data have been predominantly conducted in young athletes (Abt and Lovell, 2009; Hunter et al., 2015; Lovell and Abt, 2013; Mendez-Villanueva et al., 2013) with scarce information available for professional players. Moreover, the aforementioned studies focused on competition only and, to the best of our knowledge, only two studies analyzed individualized training ETL (Abbott et al., 2017, 2018). Beyond the well-established importance of accounting for individual capacities when interpreting ETL data, the actual superiority of individualized versus arbitrary ETL has yet to be investigated. With this in mind, it is appealing to analyze ETL in soccer practice sessions taking into consideration individual physical capacity. Therefore, we aimed to examine the interchangeability of two ETL monitoring methods (arbitrary vs. individualized speed zones) in a group of professional soccer players.

Method

The present study was conducted under non-experimental conditions as the technical staff and participants did not receive any input from the research team. Training contents were described according to the typical weekly training schedule and associated daily activities. Training contents were described according to the typical weekly training schedule and associated daily activities. For the description, we considered each training day according to its temporal distance from the match day (MD):

- MD+1 (Sunday): Static stretching and recovery training for starting players (>45 min game-time); dynamic stretching, SSGs (ball possession) and

cardiorespiratory endurance training for non-starting players (≤ 45 min match exposure).

- MD+2 (Monday). Day off.
- MD-4 (Tuesday): Technical skills warm-up, team tactics (e.g. 10v10 full-sized game), cardiorespiratory endurance exercises, continuous regime SSGs (pitch was commonly goal to halfway line as length and touchline to touchline as width).
- MD-3 (Wednesday): Dynamic stretching exercises, complex training, intermittent-regime small-sided games (commonly ball-possession without goalkeepers) with reduced pitch sizes (e.g. 3v3 to 5v5).
- MD-2 (Thursday): Technical skills warm-up, team tactics (e.g. 11v11 emphasizing specific and expected game situations), free-kicks.
- MD-1 (Friday): Dynamic stretching, corners, free-kicks and pre-match activation (e.g. short skipping session).
- MD (Saturday): Official match.

Participants

During the 2016/17 season, 13 professional male outfield soccer players (age, height, body mass and senior experience; mean \pm SD; 25.8 \pm 3.5 yrs old, 181.5 \pm 5.6 cm, 78.3 \pm 5.9 kg, 7.3 \pm 3.0 yrs) competing in Italy's second-tier league (*SerieBwin.it*) were regularly monitored in the context of their training routines. Sample consisted of 3 central defenders, 2 fullbacks, 3 central midfielders, 2 wingers and 3 strikers. Their estimated MAS and MSS were 17.7 \pm 0.6 km·h⁻¹ (based on distance covered in the Yo-Yo IR1 of 2289 \pm 384 m) and 31.1 \pm 0.9 km·h⁻¹, respectively. The Ethical Committee of the Faculty of Sports at the University of Porto approved and recorded the study under "CEFADE.08.2018".

Measures

Data collection was carried out over an 8-week period of the competitive season between January and March 2017. Physical testing was conducted in September 2016, corresponding to the start of the competitive period. Forty-five

training sessions (including three friendly matches) were analyzed, resulting in 302 individual observations (median = 24 [18; 28]. The quantification method was considered independent variable, while distance covered within given speed zones was the dependent variable.

Procedures

Testing. The Yo-Yo IR1 was performed on a natural grass pitch where the team usually performed training sessions. The test was chosen based on its representativeness of physical performance during official matches in professional soccer (Bangsbo et al. 2008). The Yo-Yo IR1 requires repeated 2x20-m runs (shuttles), separated by a 10-s rest period, at progressively increased speeds controlled by audio bleeps from a tape recorder (Bangsbo et al., 2008). The aim of the test is to perform as many shuttles as possible. The test ends when the player fail twice to reach the finish line in time. The distance covered in the test allows to estimate MAS using a generic prediction equation as proposed by Kuipers et al. (1985)¹⁰. The peak speed reached during training was assumed to be the MSS. Recent findings observed a large relationship ($r = 0.84$) and trivial bias ($\sim 0.30 \text{ km}\cdot\text{h}^{-1}$) between peak speed obtained by timing gates over a 40-m sprint and peak speed obtained by GPS devices (Massard et al., 2018). Additionally, it was found higher peak speeds during official matches than using timing gates for speed assessment, calling into question the use of sprint testing (Massard et al., 2018). MSS was therefore obtained from the GPS by extrapolating raw data for speed and the highest value (in $\text{km}\cdot\text{h}^{-1}$) recorded throughout the data collection period was retained as individual MSS. The ASR was subsequently determined as the difference between MSS and MAS, and expressed in $\text{km}\cdot\text{h}^{-1}$, as previously reported (Bundle et al., 2003; Mendez-Villanueva et al., 2013).

External training load monitoring. The ETL was monitored using unobtrusive portable 10-Hz GPS units (BT-Q1000 Ex, QStarz, Taiwan). The mean number of satellites during data collection was 14 ± 1 , and the mean horizontal dilution of position was 0.7 ± 0.1 . The system used the GPS Doppler data, and

¹⁰ MAS = speed at the last uncompleted stage ($\text{km}\cdot\text{h}^{-1}$) + $0.5 \times (n/8)$
where n = the number of runs completed in the last stage from $14.5 \text{ km}\cdot\text{h}^{-1}$.

distances were calculated from changes in position according to the integrated manufacturer's proprietary algorithm, to reduce measurement error. A vest was tightly fitted to each player to place the receiver between the scapulae. The accuracy of 10-Hz GPSs has been previously examined, giving an inter-unit coefficient of variation (CV) < 5% (Coutts and Duffield, 2010). All devices were activated 15 min before data collection to allow acquisition of satellite signals in accordance with the manufacturer's instructions. Also, to avoid inter-unit error, players wore the same GPS device for all training sessions (Gaudino et al., 2014). Total distance (TD) and distance covered in each speed zone were calculated using a custom Excel spreadsheet from instantaneous raw data for time, speed and distance, and the minimum effort duration was 0.2 s. This analysis process was repeated twice, once applying global speed thresholds and once applying individual speed thresholds. Arbitrary speed zones were defined in accordance with previous reports for professional soccer players (Akenhead and Nassis, 2016), whereas individualized speed zones were based on a combination of players' fitness components (Mendez-Villanueva et al., 2013). Four speed zones were established to describe ETL: low-speed activity (LSA; arbitrary, <14.4 km·h⁻¹; individualized, <80% MAS), moderate-speed running (MSR; arbitrary, 14.4–19.8 km·h⁻¹; individualized, 80–99.9% MAS), high-speed running (HSR; arbitrary, 19.9–25.1 km·h⁻¹; individualized 100% MAS–29% ASR) and sprinting (arbitrary, ≥25.2 km·h⁻¹; individualized, ≥30% ASR–100% MSS). The arbitrary >14.4 km·h⁻¹ is supposedly slightly below the average MAS in professional soccer players (~16 km·h⁻¹; Osgnach et al., 2010), consequently enabling a direct comparison with the individualized threshold of 80% MAS. To remove the effect of situations in which players were standing (e.g. receiving instructions from coaches, hydration break, static stretching exercises), ETL was reported as a percentage of TD covered during the training session.

Statistical analysis

To characterize the variability between participants, the CV was calculated by dividing the between subjects' SD by the mean and multiply by 100. In order to provide practical indications of changes in ETL metrics, the smallest worthwhile

change (SWC) was calculated by multiplying 0.2 by the between-subjects SD (Hopkins et al., 2009). Average biases were reported as absolute differences between values. Within-participant correlations and associated 90% CIs between ETL quantification methods were calculated to take into account the longitudinal nature of the study design removing the variation between subjects (Bland and Altman, 1995). The magnitudes of correlations were qualitatively considered as: trivial ($r \leq 0.1$), small ($r = 0.1-0.3$), moderate ($r = 0.3-0.5$), large ($r = 0.5-0.7$), very large ($r = 0.7-0.9$) and almost perfect ($r \geq 0.9$) (Hopkins et al., 2009). Differences between quantification methods were analyzed using a linear mixed model with unstructured covariance, taking into consideration the fact that the participants differed in respect of the number of training sessions in which they participated (Cnaan et al., 1997). The quantification methods were set as fixed effects, individual participants were set as random effects, training contents was set as covariate, and distance covered in each speed zone was the dependent variable. Differences between methods were quantified using effect sizes (*ES*) according to Hopkins et al. (2009), namely: trivial ($ES < 0.2$), small ($ES = 0.2-0.6$), moderate ($ES = 0.6-1.2$), large ($ES = 1.2-2.0$), very large ($ES = 2.0-4.0$) and extremely large ($ES > 4.0$). When 90% CIs overlapped positive and negative values, the effect was deemed to be unclear. Otherwise, the effect was deemed to be the observed magnitude (Batterham and Hopkins, 2006). Quantitative probabilities were evaluated qualitatively as *almost certainly not* ($< 1\%$), *very unlikely* (1–5%), *unlikely* (5–25%), *possibly* (25–75%), *likely* (75–95%), *very likely* (95–99%) and *almost certainly* ($> 99\%$) (Batterham and Hopkins, 2006). If the probabilities of the effect being higher or lower than the smallest worthwhile difference were simultaneously $> 5\%$, the effect was deemed to be unclear.

Descriptive data were reported as the mean \pm SD. Data analysis was performed using SPSS software (IBM Statistics, Chicago, USA) and a modified statistical spreadsheet (Hopkins, 2007).

Results

Players' estimated MAS was $17.7 \pm 0.6 \text{ km}\cdot\text{h}^{-1}$ based on distance covered in the Yo-Yo IR1 of $2289 \pm 384 \text{ m}$, and their MSS was $31.1 \pm 0.9 \text{ km}\cdot\text{h}^{-1}$. A detailed representation of individual players' speed zones is shown in **Fig. 2.9**. A representation of the within-weekly ETL distribution is shown in **Fig. 2.10**. Average TD covered during training was $6,598 \pm 1,136 \text{ m}$ (range: 3,801 to 9,585 m). In all variables, all measurement biases were higher than the SWC (**Table 2.2**). Distance covered in both arbitrary and individualized methods was almost certainly correlated in all speed zones ($P < 0.01$; $r = 0.67\text{--}0.78$; **Fig. 2.11**). There were no significant differences between the models with and without the effect of training contents for all ETL variables ($P > 0.05$). Significant differences between quantification methods were observed in all variables ($P < 0.01$). LSA was almost certainly higher when using the arbitrary method than when using the individualized method ($P < 0.01$; $ES = 5.47 [5.18; 5.76]$; **Fig. 2.12**). Conversely, MSR, HSR and sprinting were higher when using the individualized method than when using the arbitrary method ($P < 0.01$; $ES = 5.10 [4.82; 5.37]$, $0.86 [0.72; 1.00]$ and $1.22 [1.08; 1.37]$, respectively; **Fig. 2.13**).

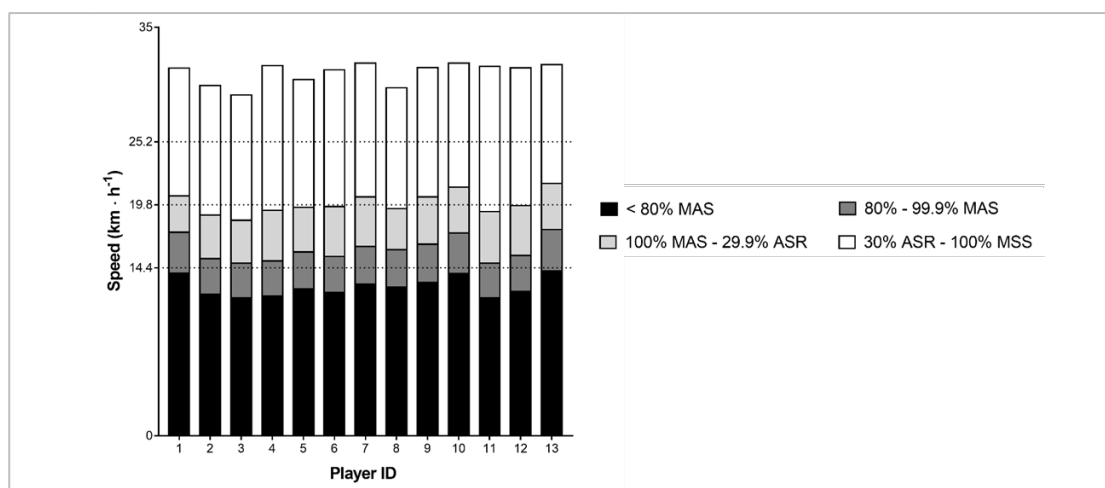


Figure 2. 9. Graphical representation of arbitrary and individualized speed zone of each player.

ASR, anaerobic speed reserve; MAS, maximal aerobic speed; MSS, maximal sprinting speed; the dotted lines delimitate arbitrary speed zones.

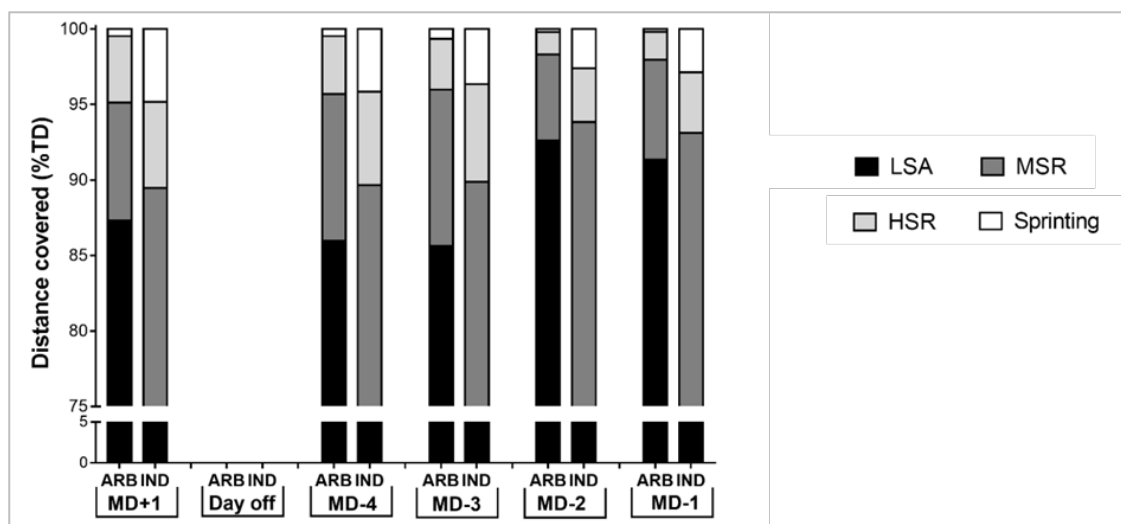


Figure 2. 10. Within-weekly external training load distribution quantified using two different methods.

ARB, arbitrary speed zones, IND, individualized speed zones, LSA, low-speed activity, MSR, moderate-speed running, HSR, high-speed running, MD, match-day, TD, total distance.

Table 2. 2. External training load quantified using two different quantification methods.

	Method	Mean \pm SD	Range	CV (%)	SWC
Low-speed activity	Arbitrary (%)	89.1 \pm 6.9	54.3; 99.7	7.83	1.4
	Individualized (%)	17.6 \pm 17.1	1.1; 84.8	96.93	3.4
	<i>Bias (95% CI)</i>	70.5 (44.4; 96.7)			
Moderate-speed running	Arbitrary (%)	7.9 \pm 4.2	0.2; 26.8	53.45	0.8
	Individualized (%)	77.2 \pm 18.7	14.2; 133.0	24.25	3.7
	<i>Bias (95% CI)</i>	69.2 (38.9; 99.5)			
High-speed running	Arbitrary (%)	2.6 \pm 2.5	0.0; 16.9	96.50	0.5
	Individualized (%)	4.9 \pm 2.8	0.1; 18.4	56.95	0.5
	<i>Bias (95% CI)</i>	2.3 (1.5; 6.2)			
Sprinting	Arbitrary (%)	0.3 \pm 0.7	0.0; 5.4	193.54	0.1
	Individualized (%)	2.8 \pm 2.7	0.0; 16.5	97.10	0.5
	<i>Bias (95% CI)</i>	2.4 (2.0; 6.9)			

CI, confidence intervals; CV, coefficient of variation; SWC, smallest worthwhile change.

Discussion

In the current investigation, we evaluated the interchangeability of two ETL quantification methods in soccer, specifically arbitrary and individualized speed zones. The main findings were the significant correlation between distance covered in arbitrary and individualized speed zones, although significant measurement bias was found between methods. These results suggest that

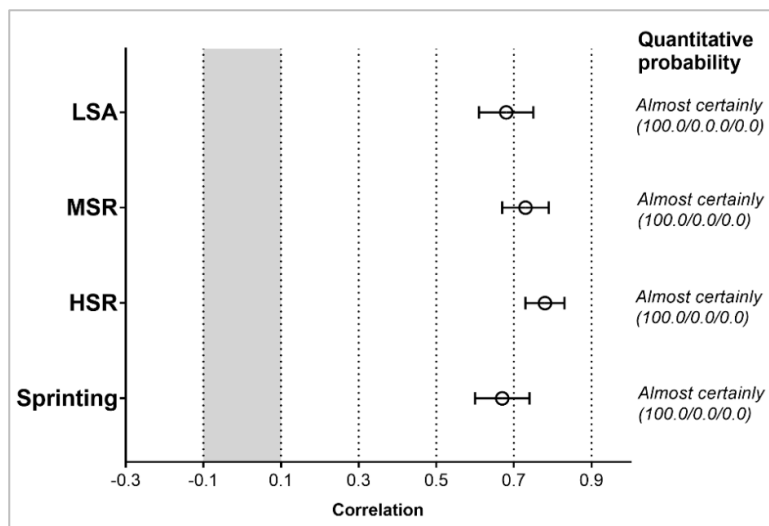


Figure 2. 11. Within-subject correlations between distance covered in arbitrary and individualized speed zones.

LSA, low-speed activity; MSR, moderate-speed running; HSR, high-speed running. The grey-filled space represents an unclear correlation ($P \leq 0.05$, $r < 0.1$). Dotted lines delineate the magnitude of correlations.

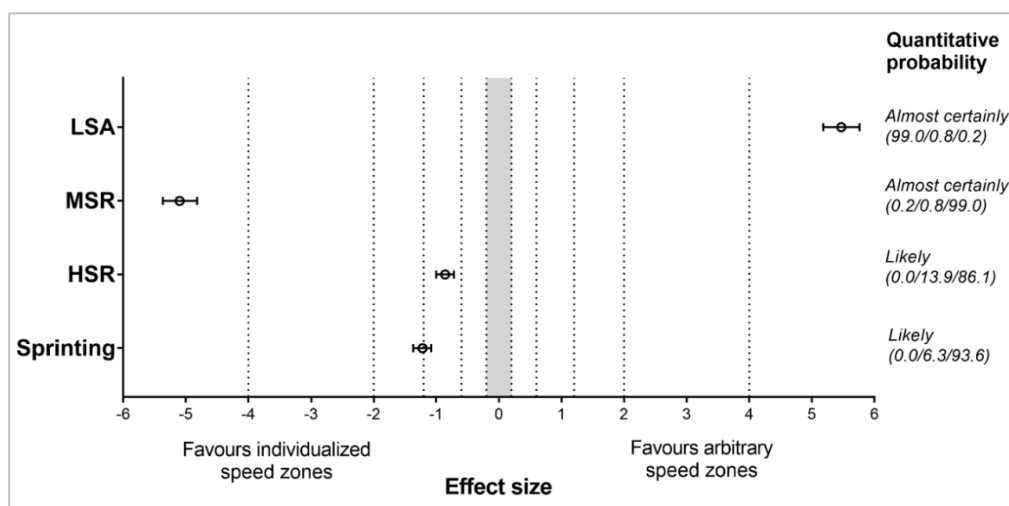


Figure 2. 12. Differences between distance covered using arbitrary and individualized speed zones.

HSR, high-speed running; LSA, low-speed activity; MSR, moderate-speed running; the grey-filled space indicates trivial differences ($P \leq 0.05$, $ES < 0.2$). Dotted lines delineate the magnitude of differences.

arbitrary and individualized methods are similarly sensitive in depicting players' locomotor profiles but differ when accounting for the amount of activity performed.

Explorative data analysis showed large relationships ($r = 0.67$ – 0.78) between distance covered within arbitrary and individualized speed zones, indicating the feasibility of interchanging the methods at relative level. However, significant measurement bias (-69 to 70%) was observed between these ETL

quantification methods. In fact, except for LSA ($< 14.4 \text{ km}\cdot\text{h}^{-1}$ and $< 80\%$ MAS), distance covered was always higher when calculated with the individualized compared to the arbitrary method. This is in line with previous research conducted in soccer and rugby players, despite the different methodologies adopted (Abbott et al., 2018; Abt and Lovell, 2009; Gabbett, 2015; Hunter et al., 2015; Lovell and Abt, 2013; Nakamura et al., 2017). For instance, Hunter et al. (2015) showed that arbitrary speed zones, with emphasis on sprinting distance, underestimated distance covered compared to individualized speed zones based on laboratory measurements of heart rate deflection point and MSS. Other studies employed laboratory measurements of MAS and ventilatory threshold to individualize ETL characterization (Abt and Lovell, 2009; Lovell and Abt, 2013). Individualized methods based on MAS would solely improve the dose-response relationship between ETL and cardiorespiratory adaptations (Fitzpatrick et al., 2018). Indeed, the authors showed that time spent above MAS was better associated with changes in MAS ($R^2 = 0.59$) than time spent above $17 \text{ km}\cdot\text{h}^{-1}$ ($R^2 = 0.37$) (Fitzpatrick et al., 2018). Laboratory assessments have the advantage of standardizing measurements conditions, improving their accuracy. However, their employability could be argued as they lack the real-world linkage, being not completely interpretable in relation to the specific physical demands of the sport modality (Foster et al., 2017). It should be also pointed out that the studies above considered MAS per se to adjust ETL data (Abt and Lovell, 2009; Lovell and Abt, 2013). The players' MAS does not take into account either the players' capacity to perform short, intense actions or the transition from moderate- to the high-intensity exercise domains. For instance, a powerful athlete (e.g. with high MSS) might not sustain high exercise intensity for long, as reflected by their intermittent endurance capacity. By contrast, MSS in isolation from sprint testing might not account for players' capacity to maintain high velocities for prolonged periods. Indeed, a less powerful athlete may show a comparatively higher intermittent endurance capacity that enables them to run intensively more frequently, enter high-speed zones and recover quicker. To address the limitation associated with considering one fitness component only, we adopted an integrated approach, combining MAS and MSS, as previously documented (Hunter et al., 2015; Mendez-Villanueva et al., 2013).

In this study, the differences detected between methods were more evident in MSR that represented a zone comprising between 14.4 and 19.8 km·h⁻¹ or 100% MAS and 29% ASR. Moreover, the results in sprinting suggest that arbitrary thresholds underestimate a significant proportion of distance covered by sprinting, which would represent a limitation when interpreting ETL data. This is supported by recent match-analysis reports in female soccer players, which observed a greater number of repeated sprint sequences using an individualized threshold of 90% MSS compared to an arbitrary threshold of 20 km·h⁻¹ (Nakamura et al., 2017). This is also supported by large associations between individualized sprinting time ($\geq 30\%$ ASR) and cardiorespiratory adaptations, compared to unclear associations when using an arbitrary threshold (21 km·h⁻¹; Fitzpatrick et al., 2018). Given that volume of sprinting has been linked to impaired muscle function (e.g. decreased isometric force, and increased creatinekinase activity and perceived muscle soreness; Howatson and Milak, 2009), accurate quantification of sprinting activity would be of importance for assisting neuromuscular recovery monitoring.

Various significant limitations of the current investigation must be pointed out. Firstly, the players could not have attained their actual MSS during training. Indeed, previous studies have evaluated MSS using the best (lower time) 10-m stretch across a 40-m straight sprint (Mendez-Villanueva et al., 2013; Nakamura et al., 2017), which is considered the gold standard for measuring MSS. The relevance of sprint testing in soccer has been questioned in favor of MSS determination using GPS data during matches (Massard et al., 2018). However, those studies failed to include match ETL due to club decisions not taken under control. Secondly, we analyzed a relatively small sample size ($n = 302$ training observations) compared to previous research adopting similar designs. For instance, a recent study by Abbott et al. (2018) compared ETL using arbitrary and individualized thresholds over 645 training sessions. Although a large-scale analysis such as one or multiple seasons would be necessary to generalize our findings, the results support previous findings showing that a significantly higher amount of high-intensity activity is accounted for when considering individualized speed zones (Abbott et al., 2018; Hunter et al., 2015). Moreover, it has been suggested that method agreement-type studies should involve at least 40

participants for adequate statistical accuracy (Atkinson et al., 2005). Despite the reduced sample size of this study ($n = 13$), repeated measurements on individual players increased statistical accuracy (Hopkins, 2000). Thirdly, neither arbitrary nor individualized speed zones account for the transition between speed zones, represented by accelerations and decelerations. This is of utmost importance given the significant physiological strain (e.g. increased blood lactate concentrations, mean heart rate and perception of effort, compared to constant-speed running) associated with changing speed (Akenhead et al., 2015). This provides justification for some previous agreement-type studies in professional soccer having focused on the validity of composite ETL variables (e.g. metabolic power), encompassing a combination of speed and accelerative efforts (Castagna et al., 2017; Gaudino et al., 2013). In this regard, it is a limitation of the current study that both arbitrary and individualized speed zones do not take into consideration efforts imposed by transition between speed zones.

TL monitoring is considered to be a pertinent construct in modern soccer. Besides the validity and reliability of ETL monitoring methods, accounting for the specific physical demands imposed on the individual player is vital for subsequent training prescription and recovery. The practical limitations of the use of arbitrary speed zones to calculate ETL were therefore underlined. However, a recent investigation of common training load monitoring practices revealed that arbitrary speed thresholds are still frequently adopted in professional soccer (Akenhead and Nassis, 2016). However, this approach masks the relative intensity imposed on the individual player (Hunter et al., 2015). This gap is furtherly emphasized when monitoring involves athletes with differing maturity offset (Abbott et al., 2018; Gabbett, 2015). In our view, adopting player-specific intensity zones can add value to the interpretation of GPS data, assisting coaches' decisions relating to subsequent training dose prescription based on individual capacity and needs, since this is of vital importance for optimizing performance and reducing injury risk. The practical limitations of the use of arbitrary speed zones to calculate ETL should be taken into consideration when planning monitoring strategies. Based on the significant relationship observed between the researched methods in respect of calculating distance covered, we admit that both methods show similar sensitivity

in depicting player profile on HSR. However, significant absolute measure differences found between methods indicate that they differ in their ability to account for the number of activities performed. Despite, arbitrary speed zones can be used to monitor seasonal fluctuations in ETL or to compare ETL between drills/sessions. In addition, individualized speed zones provide an insight into players' physical responses to training and enable comparisons between player profiles. Knowledge about player locomotor profile would help practitioners to understand the cause-effect relationship between the training dose and players' responses to training.

The present study investigated the interchangeability of two ETL quantification methods in soccer, specifically arbitrary and individualized (based on a combination of MAS and MSS). Our findings indicate that arbitrary and individualized speed thresholds can be interchanged at the relative rank (magnitude level) but not at the absolute rank (measurement error). The descriptive analysis of daily ETL distribution using both methods also provides novel information regarding the interpretation of distance covered in specific speed zones.

Acknowledgments

The authors would like to thank Italo Leo, Gianluca Angelicchio and Christian Ferrante for their cooperation. Vincenzo Rago was supported by an individual doctoral grant awarded by *Fundação para a Ciência e Tecnologia* (SFRH/BD/129324/2017).

Relationship between external load and perceptual responses to training in professional football: effects of quantification method

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2019

Sports, 7 (3): 68

DOI: 10.3390/sports7030068

Keywords: GPS; Monitoring; Maximal aerobic speed; Sprint; Testing.

This is a published manuscript that belongs to the Special Issue “Training Process in Soccer Players” of MDPI Sports, available online: <https://www.mdpi.com/2075-4663/7/3/68>

Abstract

We examined the within-player correlation between external training load (ETL) and perceptual responses to training in a professional male football team ($n = 13$ outfield players) over an 8-week competitive period. ETL was collected using 10-Hz global positioning system, whereas perceptual responses were accessed through rating of perceived exertion (RPE) questionnaires. Moderate-speed running (MSR), high-speed running (HSR) and sprinting were defined using arbitrary and individualised speed zones (based on maximal aerobic speed and maximal sprinting speed). When ETL was expressed as actual distance covered within the training session, perceptual responses were moderately correlated to MSR and HSR quantified using the arbitrary method ($P < 0.05$; $r = 0.53$ – 0.59). However, the magnitude of correlations tended to increase when the individualised method was used ($P < 0.05$; $r = 0.58$ – 0.67). Distance covered by sprinting was moderately correlated to perceptual responses only when the individualised method was used ($P < 0.05$; $r = 0.55$ [0.05; 0.83] and 0.53 [0.02; 0.82]). Perceptual responses were largely correlated to the sum of distance covered within all three speed running zones, irrespective of the quantification method ($P < 0.05$; $r = 0.58$ – 0.68). When ETL was expressed as percentage of total distance covered within the training session, no significant correlations were observed ($P > 0.05$). Perceptual responses to training load seem to be better associated with ETL, when the latter is adjusted to individual fitness capacities. Moreover, reporting ETL as actual values of distance covered within the training session instead of percentage values better inform about players' perceptual responses to training load.

Introduction

TL monitoring is extensively employed by football practitioners to enhance performance and reduce injury risk. Common parameters for quantifying training load in professional football include the RPE, distance covered in given speed zones derived from micro-technology incorporating GPS and exposure time to

training (Akenhead and Nassis, 2016). Despite the amount of activity performed (ETL) is the main determinant of individual physiological responses (ITL) (Impellizzeri et al., 2019), few studies have addressed the training dose-player' response relationship during professional football training (Gaudino et al., 2015; Scott and Lovell, 2018).

RPE is an easy, low-cost tool for measuring the perceived intensity of training sessions or matches. Despite being questionable for its subjective assessment, RPE has shown positive correlations with percentage of distance covered at high intensity (Rebelo et al., 2012) and with HR-based parameters such as Edwards' TL or training impulse during practice sessions (Impellizzeri et al., 2004; Rebelo et al., 2012). Moreover, Akenhead and Nassis (2016) showed that RPE is one of the top five ranked variables in monitoring TL adopted in professional football. Another advantage compared to HR measurement could therefore be attributed to the fact that RPE considers both psychological and physiological factors, possibly providing a more comprehensive evaluation of TL at individual level. Recent reports have shown progressive decreases in RPE towards the end of the season, with high between-players variability (coefficient of variation, CV = 4–48 %; Brito et al., 2016). This indicates that individual responses to training can vary markedly between players, consequently affecting coaches' interpretation of TL data. It is not therefore surprising that practitioners show a keen interest in methods to individualise TL.

The use of GPS technologies has markedly increased over the last decade, and a wide range of metrics is available from which technical staff can be objectively informed about the training process. Arbitrary speed zones independent of players' fitness levels seem to be commonly adopted (Akenhead and Nassis, 2016; Anderson et al., 2016a). However, the interpretation of arbitrary speed zones has the disadvantage of masking individual capacities, addressing TL interpretation of players' performance rather than the load imposed by the training session on the individual. An individualised approach to adjust ETL data by players' capacities would therefore be necessary.

Attempts to individualise ETL data have used player-dependent speed zones based on isolated fitness components, such as measures of

cardiorespiratory fitness including MAS (Abt and Lovell, 2009; Lovell and Abt, 2013). However, the players' MAS neither consider the players' capacity to perform short intense actions, nor the transition from the moderate- to the high-intensity exercise domain. For instance, a powerful athlete (e.g high MSS) cannot sustain high exercise intensity for long, as reflected by his intermittent-endurance capacity. Contrarily, MSS in isolation from sprint test does not account for players' capacity to maintain high velocities for prolonged periods. Indeed, a less powerful athlete may show a comparatively higher intermittent-endurance capacity, which enables him to intensively run more frequently, entering the high-speed zones, and recover quicker. To fulfil the limitation associated to considering one fitness component only, an integrated approach is needed, combining MAS and MSS (Abbott et al. 2018; Hunter et al., 2015; Mendez-Villanueva et al., 2013). MAS is very strongly correlated with maximal oxygen uptake and, in conjunction with MSS, allows calculation of the ASR (Bundle et al., 2003; Hunter et al., 2015). The combination of MAS and MSS is of importance because considering them independently to analyse ETL data would result in a misunderstanding of ETL data, neglecting the transition from an aerobic to an anaerobic regime (Hunter et al., 2015). A combined approach to quantifying ETL data that incorporates fitness data from field-based tests, therefore provides a more accurate definition of speed zones than a single fitness component.

To date, studies investigating the relationship between RPE and objective training load indicators in football have mainly involved sub-elite-level players (Alexiou and Coutts, 2008; Casamichana, et al., 2013; Impellizzeri et al., 2004). Recently, two studies have quantified the correlation between heart rate indices and RPE in elite football players undertaking various forms of field-based football-specific training over extended periods of time (Fanchini et al., 2016; Kelly et al., 2016). However, currently adopted training load monitoring practices revealed a more frequent use of GPS than HR in professional football. It could therefore be of interest to explore the longitudinal relationship between GPS-derived indicators using different quantification methods and RPE. In addition, previous studies individualising ETL data have been predominantly conducted in young athletes (Abt and Lovell, 2009), with scarce information available for professional players.

Moreover, the aforementioned studies focused on competition only and, to the best of our knowledge, only two studies analysed individualised training ETL (Abbott et al., 2017, 2018). The aim of this study was therefore to examine the within-player correlation between RPE and ETL quantified using arbitrary and individualised speed zones in a professional male football team.

Method and materials

Participants

During the 2016/17 season, 13 professional male outfield football players (age, height, body mass and senior experience; mean \pm SD; 25.8 \pm 3.5 yrs old, 181.5 \pm 5.6 cm, 78.3 \pm 5.9 kg, 7.3 \pm 3.0 yrs) competing in Italy's second-tier league (*SerieBwin.it*) were regularly monitored in the context of their training routines. Sample consisted of 3 central defenders, 2 fullbacks, 3 central midfielders, 2 wingers and 3 strikers. Their estimated MAS and MSS were 17.7 \pm 0.6 km·h⁻¹ (based on distance covered in the Yo-Yo IR1 of 2289 \pm 384 m) and 31.1 \pm 0.9 km·h⁻¹, respectively. The Ethical Committee of the Faculty of Sports at the University of Porto approved and recorded the study under "CEFADE.08.2018".

Experimental design

Arbitrary speed zones do not take into account individual capacity, possibly resulting in incorrect interpretation of ETL. It would therefore be intuitive to evaluate the athletes' GPS data in relation to player' fitness profile. Differences between arbitrary and individualised speed zones have been previously documented. However, it is not known whether RPE is associated with ETL, quantified using arbitrary or individualised speed zones, and with actual (m) or relative (%) distance covered. The arbitrary method is commonly employed in professional football to quantify ETL data (Anderson et al., 2016; Gaudino et al., 2013), whereas the use of the individualised method (Mendez-Villanueva et al., 2013) is currently growing. Data collection was carried out over an 8-week competitive period, between January and March 2017. Individual reconditioning sessions were not included for analysis. Players participated in 42 training

sessions and three friendly matches, resulting in 256 individual observations (median [range] = 20 [15; 25]). Training contents were described in **table 2.3**.

Procedures

Testing. The Yo-Yo IR1 was performed on a natural grass pitch where the team usually performed training sessions. The test was chosen based on its representativeness of physical performance during official matches in professional football (Bangsbo et al. 2008). The Yo-Yo IR1 requires repeated 2 × 20-m runs (shuttles), separated by a 10-s rest period, at progressively increased speeds controlled by audio bleeps from a tape recorder (Bangsbo et al., 2008). The aim of the test is to perform as many shuttles as possible. The test ends when the player fail twice to reach the finish line in time. The distance covered in the test allows to estimate MAS using a generic prediction equation as proposed by Kuipers et al. (1985). The peak speed reached during training was assumed to be the MSS. Recent findings observed a large relationship ($r = 0.84$) and trivial bias ($\sim 0.30 \text{ km}\cdot\text{h}^{-1}$) between peak speed obtained by timing gates over a 40-m sprint and peak speed obtained by GPS (Massard et al., 2018). Additionally, it was found higher peak speeds during official matches than using timing gates for speed assessment, calling into question the use of sprint testing (Massard et al., 2018). MSS was therefore obtained from GPS by extrapolating raw data for speed and the highest value (in $\text{km}\cdot\text{h}^{-1}$) recorded throughout the data collection period was retained as individual MSS. The ASR was subsequently determined as the difference between MSS and MAS, and expressed in $\text{km}\cdot\text{h}^{-1}$ (Bundle et al., 2003; Mendez-Villanueva et al., 2013).

External training load monitoring. ETL was monitored using unobtrusive portable 10-Hz GPS units (BT-Q1000 Ex, QStarz, Taiwan). The mean number of satellites during data collection was 14 ± 1 , and the mean horizontal dilution of position was 0.7 ± 0.1 . The system used the GPS Doppler data, and distances were calculated from changes in position according to the integrated manufacturer's proprietary algorithm, to reduce measurement error. A vest was tightly fitted to each player to place the receiver between the scapulae. The

Table 2. 3. Weekly training characterisation in an Italian Serie Bwin.it team.

	MD+1	MD-5 (Day off)	MD-4	MD-3	MD-2	MD-1	MD
Day	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Duration	75 ± 30 min	-	120 ± 16 min	118 ± 15 min	98 ± 30 min	101 ± 12 min	~ 90 min
Time	Morning	-		Morning and afternoon	Afternoon	Afternoon	Afternoon
Warm-up	Static stretching for starters*, dynamic stretching for non-starters**.	-	Technical skills	Dynamic stretching	Technical skills	Dynamic stretching	-
Main contents	Recovery training for starting players; SSGs (ball possession) and cardiorespiratory endurance training for non-starting players	-	1) team tactics (e.g. 10v10 full-sized game); 2) cardiorespiratory endurance exercises (e.g. interval training); 3) continuous regime SSGs (pitch was commonly goal to halfway line as length and touchline to touchline as width)	1) complex training in the morning; 2) intermittent-regime SSGs (commonly ball-possession without GKs) with reduced pitch sizes (e.g. 3v3 to 5v5) in the afternoon.	1) team tactics (e.g. 11v11 emphasising specific and expected game situations) 2) free-kicks	1) Corners and free-kicks; 2) Pre-match activation (e.g. skipping and short sprints)	-

GKs, goalkeepers; MD, match day; SSGs, small-sided games *non-starters, players who participated in less than 45 min match-play on the previous day. **starters, players who participated at least 45 min match-play on the previous day.

accuracy of 10-Hz GPSs has been previously examined, giving an inter-unit CV < 5% (Coutts and Duffield, 2010). All devices were activated 15 min before data collection to allow acquisition of satellite signals in accordance with the manufacturer's instructions. Also, to avoid inter-unit error, players wore the same GPS device for all training sessions (Gaudino et al., 2014). TD and distance covered in each speed zone were calculated using a custom Excel spreadsheet from instantaneous raw data for time, speed and distance, and the minimum effort duration was 0.2 s. This process was repeated twice, once applying global speed thresholds and once applying individual speed thresholds. For describing ETL, three speed categories were established (moderate-speed running [MSR], high-speed running [HSR] and sprinting), and two different approaches were adopted. The arbitrary method was based on arbitrary (player-independent) speed categories: MSR, HSR and sprinting were set as 14.4–19.8, 19.9–25.1 and above 25.2 km·h⁻¹, as suggested for professional male players in previous studies (Anderson et al. 2016). In the individualised method, MSR, HSR were set as 80–99.9% MAS, 100% MAS, 29% ASR and ≥ 30% ASR (Mendez-Villanueva et al. 2013). In addition, total high-intensity activity (THIA) was given by the sum of MSR, HSR and sprinting. Firstly, data were reported as actual distance covered (m) within each zone using both ETL quantification methods. Secondly, to explore the possible effect of training volume, ETL was reported as a percentage of total distance covered within the training session. The technical staff decided to not use GPS during competitive matches.

Rating of perceived exertion. Throughout the season, the same fitness coach collected players' individual RPE after training sessions using a Borg's category ratio scale anchored from 0 (rest) to 10 (maximal effort). The players' RPE was collected in isolation to avoid the potential effects of peer pressure 15 to 30 min after each training session, ensuring that the perceived effort reflected the whole session, and not the recent exercise intensity (Impellizzeri et al., 2004). All players were familiarised the scale during the previous months. The overall TL was calculated by using s-RPE, that is calculated multiplying the RPE score (in arbitrary units) by the individual training duration (in min; Foster et al., 2001).

Statistical analyses

Descriptive data were reported as mean \pm SD. To characterise the intersession variability, the CV for THIA was calculated dividing the between-session SD by the mean and then multiply by 100. Within-participant correlations were calculated between RPE-derived parameters (RPE and s-RPE) and ETL (Bland and Altman, 1995). In repeated-measures studies, it is important to quantify within-subject correlations by modelling the longitudinal dataset as a whole and reducing the variation between subjects. This approach quantifies the correlation and associated 95%CI between a covariate and outcome while taking into account the within-participant nature of the study design, based on the correct degrees of freedom. The magnitudes of correlation were qualitatively interpreted using the following criteria: trivial ($r \leq 0.1$), small ($r = 0.1-0.3$), moderate ($r = 0.3-0.5$), large ($r = 0.5-0.7$), very large ($r = 0.7-0.9$) and almost perfect ($r \geq 0.9$) (Hopkins et al., 2009). When 95% CIs overlapped positive and negative values, the effect was deemed to be unclear. Otherwise, the correlation was interpreted as the observed magnitude. Significance was set at $P \leq 0.05$. Data analysis was performed using SPSS software (IBM Statistics, Chicago, USA).

Results

Overview of training load

Average exposure time, total distance (TD) covered within the training session, RPE and s-RPE were (Mean \pm SD) 105 \pm 23 min, 6384 \pm 1593 m, 3.6 \pm 1.8 AU and 411.0 \pm 266.9 AU. A description of the weekly RPE is reported in **Fig. 2.13**. The actual distance covered within training session was: MSR (arbitrary and individualised), 531 \pm 318 m and 5000 \pm 1767 m; HSR, 178 \pm 173 m and 332 \pm 208 m; and sprinting, 25 \pm 49 m and 190 \pm 183 m (**Fig. 2.14A**). The inter-session variability in the actual THIA ranged between 40 and 73%. The percentage of distance covered in a given speed was: MSR (arbitrary and individualised), 8.1 \pm 4.3% and 78.7 \pm 18.8 %; HSR, 2.7 \pm 2.6 % and 5.0 \pm 2.8 %; sprinting, 0.4 \pm 0.7 % and 3.0 \pm 2.9 % (**Fig. 2.14B**). The inter-session variability in the percentage of THIA ranged between 22 and 60%.

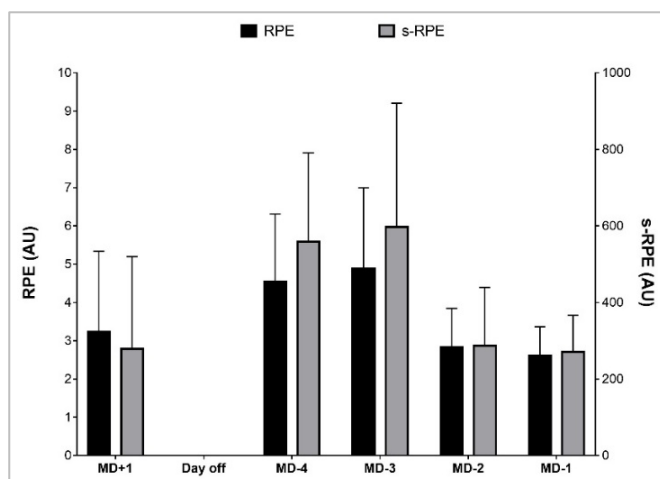


Figure 2. 13. Weekly perceptual responses to training throughout a typical microcycle during a competitive period in professional football.

AU, arbitrary units; RPE, rating of perceived exertion; s-RPE, session-RPE (RPE multiplied by training duration).

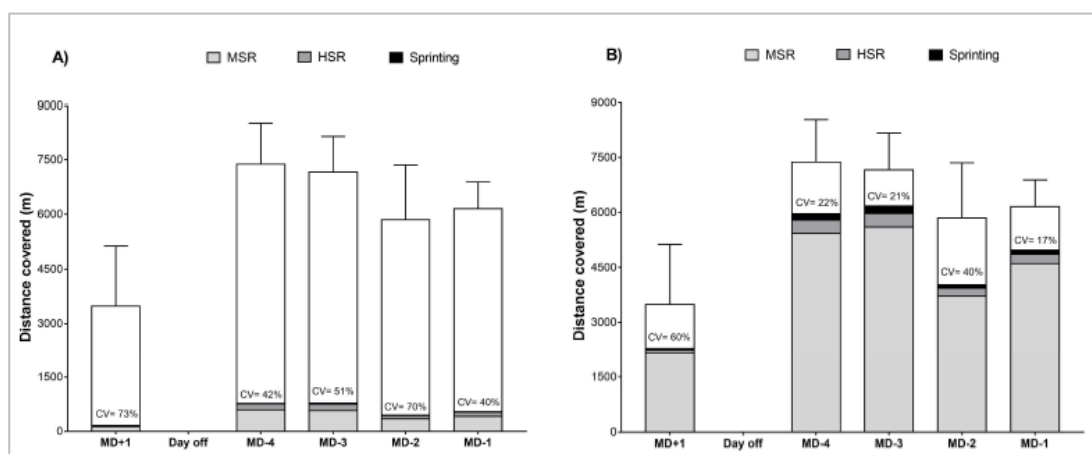


Figure 2. 14. Weekly external training load during a competitive period in professional football quantified using a) arbitrary and b) individualised speed zones.

HSR, high-speed running; MSR, moderate-speed running. The top of the bars indicate total distance covered. The coefficient of variation (CV) refers to the inter-session variability of total high-intensity activity (MSR + HSR + Sprinting).

Associations between external training load and perceptual responses

When ETL was expressed as actual distance covered, the RPE and s-RPE were moderately correlated to MSR and HSR quantified using the arbitrary method ($P < 0.05$; $r = 0.53$ – 0.59). However, the magnitude of correlations tended to increase when the individualised method was used ($P < 0.05$; $r = 0.58$ – 0.67). Distance covered by sprinting was moderately correlated to RPE and s-RPE, only when the individualised method was used ($P < 0.05$; 0.55 [0.05 ; 0.83] and 0.53 [0.02 ; 0.82], respectively). Both RPE parameters were largely correlated to THIA, irrespective of the quantification method adopted ($P < 0.05$; $r = 0.58$ – 0.68). When

ETL was expressed as percentage of TD covered within the training session, no significant correlations were observed ($P > 0.05$). A detailed description of the relationship between RPE parameters and ETL is reported in **table 2.4**.

Discussion

The aim of this study was to examine the within-player correlation between RPE and ETL using arbitrary and individualised speed zones in professional football. RPE and s-RPE seem to be better associated with ETL when speed zones are determined individually than when arbitrary speed zones are used, with special emphasis on sprinting distance. Notwithstanding, these correlations were only observed when ETL was expressed as actual values of distance covered, which suggests that quantifying distance covered in a given speed as portion of TD covered does not inform about the players' perceptual responses to training.

In the present research, RPE-derived parameters showed moderate correlations with distance covered by MSR and THSR ($r = 0.56$ – 0.67), calculated using both arbitrary and individualised methods. This is supported by previous studies performed across football players from different competitive standards. For instance, Gaudino et al. (2015) showed that the actual distance covered at $> 14.4 \text{ km}\cdot\text{h}^{-1}$, the number of impacts and the number of accelerations were largely correlated to s-RPE ($r = 0.61$ – 0.72) throughout the English Premier League season. Moreover, findings in young players showed moderate correlations between distance covered at $> 13 \text{ km}\cdot\text{h}^{-1}$ and RPE ($r = 0.43$ – 0.54 ; Rebelo et al., 2012). In addition, player load was found to be strongly associated with RPE across various SSG formats in semi-professional male Spanish players ($r = 0.70$; Casamichana et al., 2013). Regarding HSR, large correlations were observed only between RPE-derived parameters and individualised speed (100%MAS–29%ASR), possibly indicating that knowledge of individual MAS and ASR may better assist in understanding the effect of ETL on players' perception of TL than the use of arbitrary speed zones (14.4 – $19.8 \text{ km}\cdot\text{h}^{-1}$). In this context, recent findings in ~17-yr-old football players showed that training time spent above MAS would solely improve the dose-response relationship between ETL and cardiorespiratory adaptations (Fitzpatrick et al., 2018). Indeed, the authors showed that time spent

Table 2. 4. Relationship between RPE-based parameters and distance covered in each speed zone over an 8-week competitive period in professional male football players.

		Moderate-speed running			High-speed running			Sprinting			Total high-intensity activity		
		<i>P</i>	<i>r</i> (95% CIs)		<i>P</i>	<i>r</i> (95% CIs)		<i>P</i>	<i>r</i> (95% CIs)		<i>P</i>	<i>r</i> (95% CIs)	
Training volume (m)	RPE	ARB	0.002	0.56 (0.14; 0.84)	0.011	0.55 (0.05; 0.83)		0.184	0.34 (-0.25; 0.75)		0.005	0.58 (0.04; 0.85)	
		IND	0.005	0.58 (0.04; 0.85)	0.005	0.58 (0.04; 0.85)		0.011	0.55 (0.05; 0.83)		0.002	0.61 (0.08; 0.86)	
	s-RPE	ARB	0.004	0.59 (0.04; 0.85)	0.014	0.53 (0.02; 0.82)		0.221	0.32 (-0.28; 0.74)		0.004	0.59 (0.04; 0.85)	
		IND	< 0.001	0.67 (0.18; 0.89)	0.003	0.60 (0.07; 0.86)		0.014	0.53 (0.02; 0.82)		< 0.001	0.68 (0.20; 0.89)	
Training intensity (%TD)	RPE	ARB	0.050	0.46 (-0.12; 0.80)	0.063	0.44 (-0.14; 0.79)		0.273	0.29 (-0.31; 0.72)		0.036	0.48 (-0.09; 0.81)	
		IND	0.094	0.41 (-0.18; 0.78)	0.036	0.48 (-0.09; 0.81)		0.063	0.44 (-0.14; 0.79)		0.050	0.46 (-0.12; 0.80)	
	s-RPE	ARB	0.083	0.42 (-0.17; 0.78)	0.115	0.39 (-0.20; 0.77)		0.327	0.26 (-0.33; 0.70)		0.073	0.43 (-0.15; 0.79)	
		IND	0.115	0.39 (-0.20; 0.77)	0.063	0.44 (-0.14; 0.79)		0.125	0.38 (-0.21; 0.76)		0.073	0.43 (-0.15; 0.79)	

above MAS was better associated ($R^2 = 0.59$) with changes in MAS than time spent above $17 \text{ km}\cdot\text{h}^{-1}$ (Fitzpatrick et al., 2018). In addition, irrespective of the ETL quantification method adopted, perceptual responses to training were not correlated to distance covered by sprinting. This possibly indicates that cardiorespiratory fitness (e.g. MAS) is a stronger contributor of TL and associated perceptual responses, rather than explosive capacity (e.g. MSS). Recent match-analysis reports in female football players that found a greater number of repeated sprint sequences using a threshold of 90% MSS compared to an arbitrary one of $20 \text{ km}\cdot\text{h}^{-1}$ (Nakamura et al., 2017). Moreover, a recent study on ~17-yrs-old football players reported large associations between sprinting time ($\geq 30\%$ ASR) and cardiorespiratory adaptations, compared to unclear associations when using an arbitrary threshold of $21 \text{ km}\cdot\text{h}^{-1}$ (Fitzpatrick et al., 2018).

The aforementioned correlations were not observed when ETL was expressed as portion of TD covered within the training session. This possibly indicates that perceptions of training intensity (RPE) and load (s-RPE) are affected by training volume. Under controlled situations, RPE responses increase linearly over time, reaching maximal values at the end of exercise (Eston, 2012; Nicolo et al., 2016; Pires et al., 2011). However, football training is characterised by intermittent and spontaneous activities, and by increasing session / bout duration, the players may adopt a pacing strategy decreasing exercise intensity, or simply as a consequence of fatigue (Fanchini et al., 2011). Reports of amateur adult football players revealed that increasing bout duration from 2 to 6 min resulted in a decreased HR_{mean} during 3v3 SSG (Fanchini et al., 2011). Moreover, after 2v2 to 4v4 SSGs consisting of continuous regime (1 bouts \times 6 min duration) and short duration (6 bouts \times 2 min) higher RPE were observed, than after 3 bouts \times 4 min, or long 2 bouts \times 6 min (Koklu et al. 2017).

The usefulness of individualised speed zones has been previously documented in direct laboratory measurements (e.g. respiratory compensation threshold) that showed that a combination of MAS and MSS was more accurate in relation to gold standard measurements of heart rate deflection point and MSS, than a single fitness component per se (Hunter et al., 2015). Nonetheless, ETL is still nowadays commonly collected and interpreted on an absolute basis,

expressing players' workload as distances covered using player-independent speed zones (Akenhead and Nassis, 2016). Arbitrary speed thresholds allow comparison of physical performance between players or within the same individual player over time. However, the arbitrary approach masks the relative intensity imposed on the individual player (Hunter et al., 2015). This gap is furtherly emphasised when simultaneously monitoring athletes of different fitness levels and maturity offset (Gabbett, 2015). Nonetheless, various significant limitations of the current investigation must be pointed out. Firstly, the players could not have attained their actual MSS during training. Indeed, previous studies have evaluated MSS using the best (lower time) 10-m stretch across 40-m straight sprint (Mendez-Villanueva et al., 2013; Nakamura et al., 2017) by means of timing gates, which is considered the gold standard for measuring sprint performance. Recent reports in professional players showed a moderate correlation between MSS attained during training sessions and the measure of 40-m sprint time ($r = 0.52$) (Djaoui et al., 2017). An almost perfect correlation coefficient ($r \geq 0.90$) has been suggested to be necessary for the validity of measurements (Atkinson and Nevill, 1998). Secondly, we analysed a relatively small sample of training sessions ($n = 268$ training observations) compared to previous research adopting similar designs. For instance, a recent study by Abbott et al. (2018) compared ETL using arbitrary and individualised thresholds over 645 training sessions. Although a large-scale analysis such as one or multiple seasons would be necessary to generalise findings, the results of our study support previous findings showing that a significant amount of high-intensity activity is accounted for when considering individualised speed zones (Abbott et al., 2018; Hunter et al., 2015). Thirdly, neither arbitrary nor individualised speed zones account for the transition between speed zones, represented by accelerations and decelerations. This is of utmost importance given the significant physiological strain (e.g. increased blood lactate concentrations, HR_{mean} and RPE, compared to constant-speed running) associated with changing speed (Akenhead et al., 2015).

In summary, this is the first study to quantify the within-subject correlations between RPE and two different approaches to quantify ETL. We found that testing professional male football players individually can add value to external training

load monitoring and interpretation of data collected during training sessions. Specifically, using data from fitness tests to individualise speed zones appears to improve the relationship between player perceptual response to running-based TL, especially in relation to sprinting distance.

Conclusions

The present research analysed the within-subject correlations between running-based ETL parameters and RPE-derived parameters in professional football players. The magnitude of the relationships between external training load and RPE parameters appear to slightly strengthen when ETL are adjusted to individual fitness capacities, with special emphasis on cardiorespiratory fitness. However, when ETL are quantified as portion of total distance covered within the training session, these relationships were unclear. Practitioners should consider ETL as actual values of distance covered within the training sessions adjusted for individual speed being more representative of perceptual responses to training, rather than percentage of total distance.

Acknowledgments

The authors would like to thank Italo Leo, Gianluca Angelicchio and Christian Ferrante for their cooperation. Vincenzo Rago was supported by an individual doctoral grant awarded by *Fundação para a Ciência e Tecnologia* (SFRH/BD/129324/2017).

General discussion and conclusions

3.1. Synthesis of main findings

The present dissertation examined the application of field monitoring systems in professional male football players, with special emphasis on field measurements of TL and fitness testing. Overall, exercise demands are affected by different match opponents and exercise formats. In particular, different training demands can be also observed during the entire week, especially when preparing matches against top-level opponents and after losing a match. Additionally, HR testing during standardised warm-up is a time-saving strategy that showed responsiveness to the amount of training volume and can possibly inform about physical performance during match-play. However, it is important to consider that submaximal tests can be useful to regularly track training status, but do not avoid the implementation (at least once) of maximal tests. Indeed, information from maximal tests (e.g. MAS, MSS, HR_{max}) is of importance to quantify TL and consequently prescribe training based on individual needs. In this sense, arbitrary (player-independent) methods possibly underestimated the actual load imposed on the individual player. The idea of individual capacity (derived from fitness tests) as TL guidance is recommended to coaches and practitioners involved with player' monitoring, to better prescribe training at its high-quality and have an insight about training-induced adaptations.

3.2. The training process: confounding factors and outcomes

Initially, we explored TL in relation to external factors and training adaptations. During training, coaches frequently manage the choice of the opponent for friendly matches, as well as pitch dimension and number of players in SSGs. In general, variations in locomotor demands appear less evident in distance covered within different speed-based intensity zones than in acceleration / deceleration parameters (**Supplementary study 1 and 2**). Greater decreases in work rate (distance per minute) during 8v8 SSGs were observed, compared to 4v4 SSGs (**Supplementary study 1**). Nonetheless, both 4v4 SSGs did not induce substantial fatigue in jump and sprint ability, whereas 4v4 SSGs induced moderate decrements in sprint capacity after exercise. Therefore, it could be speculated that

maintaining the relative pitch-area per player over smaller absolute pitch dimensions could target the development of power-related actions.

Decreases in work rate during SSGs and during matches observed in **Supplementary study 1** and **2** can be attributed to impaired jump capacity and agility after intense periods ($>90\%$ HR_{max}) of the match (**Supplementary study 3**). Consequently, interpreting physical demands during specific periods in addition to the average game / session would add value to the information delivered to the coaching staff.

Higher training volume was observed in the week before and after playing against a top-ranking opponent, and after losing a match (**Study 1**). In particular, the amount of training volume performed was found to be associated to improved cardiorespiratory fitness after a three-month period (**Study 2**). Therefore, it could be speculated that preparing a match against a top-level opponent might positively contribute to cardiorespiratory fitness. The lack of relationship between the amount of high-intensity training and changes in cardiorespiratory fitness could be players could be already well-conditioned at the start of the study period (February). Indeed, meaningful improvements in cardiorespiratory fitness and subsequent associations with TL could have been obtained in the preparatory period, where players were deconditioned following the off-season (Silva et al. 2016). In fact, studies observing significant relationships between the amount of high-intensity training (time $> 90\%$ HR_{max}) and gains in cardiorespiratory fitness have been predominantly conducted during the pre-season period in professional football players (Campos-Vázquez et al. 2017; Castagna et al. 2011, 2013; Manzi et al. 2013). The relevance of the Yo-Yo IR1_{SUB} could be also attributed to the significant relationship observed between cardiorespiratory fitness and the amount of activity performed (total distance covered) during competitive matches (**Study 2**). Therefore, it can be speculated that the latter test is indicative of match performance, assuming that players showing lower ITL (e.g. HR_{mean}) for a same ETL are more prepared to face the demands of the match (Mann et al. 2013).

3.3. Individual capacity as training load guidance

Unlike individual sports, football practitioners may have up to 25 players to monitor. Thus, coaches compel effective strategies to assess how similar TLs might affect individually each player (Borresen and Lambert, 2008). In this sense, we analysed the reliability of an agility test that could incorporate sprint testing simultaneously, based on significant correlations indicating that the quickest players are also the more agile (**Supplementary study 3**). Additionally, individualised intensity zones can improve the interpretation of ETL data, since different physical capacities can be observed between individual players. We found significant associations between ETL expressed as arbitrary speed zones (assuming equal capacity between all players from the same team) and individualised speed zones (based on fitness testing; **Study 3**). However, the amount of high-intensity training determined by these two methods can differ substantially, especially when considering speed zones close to MAS (13 to 17 $\text{km}\cdot\text{h}^{-1}$; **Study 3**). By individualising ETL, we partially removed the confounding effect of individual characteristics on ITL and subsequent training outcome from the conceptual model proposed by Impellizzeri et al. (2005) (**Fig. 3.1**).

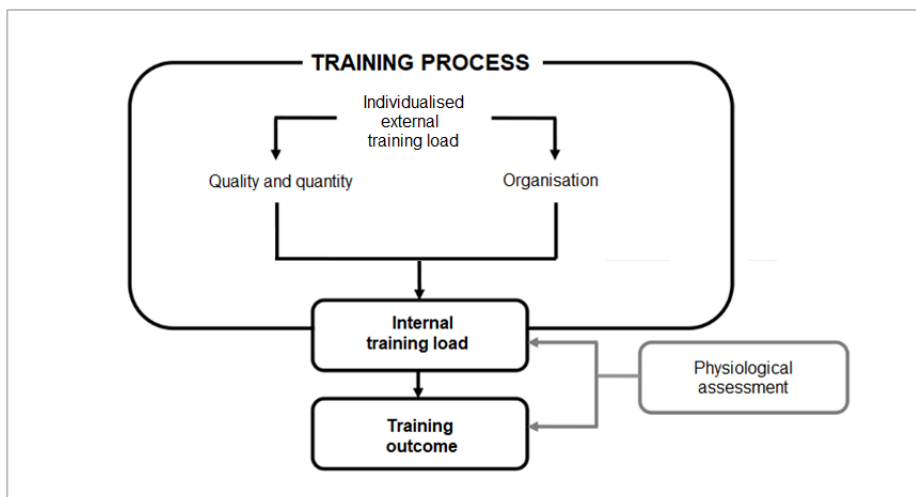


Figure 3. 1. Modified theoretical framework of the training process proposed by Impellizzeri et al. (2005), when external training load quantification is based on individual fitness characteristics (e.g. maximal aerobic speed, maximal sprinting speed, anaerobic speed reserve).

The relevance of individualising ETL is furtherly strengthened by the larger associations found between perceptual responses to training and the amount of

activity performed within individualised speed zones, compared to distance covered within arbitrary speed zones (**Study 4**). This possibly indicates that players rate the intensity of the training session not only based on the ETL delivered by the coach. Rather, individual physical capacity appears to play a meaningful role in moderating the dose-response relationship between prescribed training (e.g. ETL) and player's perception of training intensity.

3.4. Limitations and suggestions for future research

It is important to consider some limitations inherent to this work. Despite the advantages of using individualised speed zones for ETL quantification, arbitrary speed zones were initially adopted (**Study 1** and **2**). This was due to the fact that the dataset was kindly provided by the team, and data had been already exported in agreement with the technical staff requirements. The adoption of an arbitrary threshold (player-independent) of $16 \cdot \text{km}^{-1}$ to quantify the amount high-intensity activity performed could have masked a possible relationship between TL and training adaptations (**Study 3**). Indeed, recent reports in ~17-yrs-old football players revealed that the time spent above individual MAS was better representative of changes in cardiorespiratory fitness than time spent above $17 \text{ km} \cdot \text{h}^{-1}$ (Fitzpatrick et al., 2018). Nonetheless, this limitation was partially solved in the ITL analyses, where HR-based TL was expressed as percentage of individual HR_{max} determined in an incremental test. As far as we know, only one study has investigated the dose-response relationship between amount of activity performed above individual thresholds of MAS and 30% ASR, and changes in cardiorespiratory fitness (Fitzpatrick et al., 2018).

Regarding power-based tests, we measured neuromuscular function using jump height solely, thus neglecting critical information related to spatiotemporal and force parameters during ground contact (**Supplementary study 1** and **3**). For instance, mean power, peak velocity, force at zero velocity and area under the force-velocity trace obtained from a force platform showed greater changes in response to a fatigue protocol than measurement error (Gathercole et al. 2015). Therefore, acute neuromuscular fatigue could have been observed in various

ground-contact parameters, that could better explain the significant decrements observed in 5-m sprint performance after 4v4 SSGs (**Supplementary study 1**).

In **Study 3** and **4**, we only considered intensity zones based on speed thresholds, thus neglecting physiologically demanding tasks such as accelerations and decelerations, even occurring at low speed (Akenhead et al., 2015; Osgnach et al., 2010). Indeed, incorporated the. When applying an individual approach based on maximum accelerative capacity proposed by Sonderegger et al. (2016), significant discrepancies were found between the number of accelerations performed during training using arbitrary and individualised thresholds in U19 players (Abbott et al., 2018). Although these variables are highly dependent upon the starting speed, and the validity and reliability of the wearable device (Sweeting et al. 2017), limited information exists on how to individualise accelerations.

We assumed MSS as the peak speed reached during training, which, in fact, players could not have attained their actual MSS (**Study 3** and **4**). Previous studies quantifying locomotor activity using individual cut-off values based on MSS, measured the best (lower time) 10-m across 40-m straight sprint (Mendez-Villanueva et al., 2013; Djaoui et al., 2017). Nonetheless, recent reports showed higher peak speed reached during matches than during MSS tests (Massard et al., 2018) and moderate correlation between MSS attained during training sessions and the measure of 40-m sprint time ($r = 0.52$), questioning the need of MSS assessment in the latter testing format (Djaoui et al., 2017). Despite, this correlation was moderate, and thus, not necessarily indicative of a valid assessment, which requires an almost perfect correlation coefficient ($r \geq 0.90$; Atkinson and Nevill, 1998). Various studies showed a good agreement between MSS determined using gold-standard measurements (e.g. timing gates or radar gun) and GPS (Scott et al. 2016). Therefore, a suitable time-saving option to test MSS would be via GPS with all players simultaneously sprinting over 40 m, without need of measuring individually using timing gates or radar.

Another meaningful limitation was the estimation of MAS from performance in an intermittent test (**Study 3** and **4**). A seminal study by Bangsbo et al. (2008) revealed a correlation of 0.70 between performance in the Yo-Yo IR1 and laboratory-measured maximal oxygen uptake. Whereas performance in the Yo-Yo

IR1 could be strongly reflective of MAS, covariates associated to shuttle running involve a meaningful neuromuscular component, and therefore, the determination of MAS was not totally isolated. Indeed, performance in this test was moderately correlated to countermovement jump height and peak power ($r = 0.50\text{--}0.57$), indicating the meaningful neuromuscular contribution to achieve performance in this test (Castagna et al. 2006). Based on the lower correlations between the aforementioned neuromuscular parameters and performance in the Yo-Yo Intermittent Endurance – Level 1 ($r = 0.33\text{--}0.49$), the latter test appears to better isolate the cardiorespiratory component (Castagna et al. 2006). In addition, the existent equations to determine MAS from field tests derive from continuous running (Leger and Boucher, 1980) and intermittent bicycle ergometer (Kuipers et al. 1985). At date, the determination of the HR deflection point¹¹ and corresponding MAS is a non-invasive method and could be a suitable alternative to predictive equations (Bodner and Rhodes, 2000).

Recent observations in Australian-rules Football players revealed greater association between injury incidence and ETL, when the latter was quantified using percentage values of individual MSS than arbitrary speed zones (O'Connor et al. 2019). At date, studies examining the relationship between TL and injury in football players have adopted RPE-based methods and ETL expressed using arbitrary speed zones (Fanchini et al. 2018; Jasper et al. 2017; Malone et al. 2017, 2018). Whereas Malone et al. (2018) demonstrated that players with higher intermittent cardiorespiratory fitness better tolerated acute spikes in TL, there is no available information regarding the relationship between TL and injury using individual intensity zones.

Finally, an “overall” measure of perceptual response to TL was adopted (**Study 4**). Future studies investigating the connection between objective and subjective TL indicators might adopt differentiated RPE versions to isolate the neuromuscular and cardiorespiratory effort (Los Arcos et al. 2014). In addition, we adopted a manually-recorded conventional RPE collection after training. Recently,

¹¹ The heart rate deflection point is a downward or upward change from the linear HR-work relationship evinced during progressive incremental exercise testing; it is reported to be coincident with the anaerobic threshold (Conconi et al., 1982)

an application-based monitoring system¹² has been released, which enable the collection of perceptual responses to training / match through answer on the players' mobile phone.

3.5. Conclusions

When prescribing training, coaches should consider the possible variations in physical, physiological and perceptual demands imposed by different external factors (e.g. match opponents, exercise format, surface). In particular, increased physical and physiological demands can be observed throughout the week, when preparing matches against top-level opponents and after losing a match.

Field tests can inform about whether players are responding and adapting to the training programme. In particular, the submaximal version of the Yo-Yo Intermittent recovery test – level 1 can be used to monitor seasonal variations in cardiorespiratory fitness without the need to have players working until exhaustion. However, the usefulness of submaximal tests does not avoid the implementation of a maximal test to obtain a “work parameter” (e.g. HR_{max} , MAS) to individualise TL. Indeed, the demands of training and match-play might differ substantially between and within players, and therefore arbitrary speed-zones might underestimate the actual amount of activity performed above a specific individual capacity. Moreover, expressing ETL using individual thresholds based on fitness test scores (instead of arbitrary thresholds) and using actual values of distance covered (percentage values of distance) appears to better inform about players' perceptual responses to training.

¹² PMSys, <http://forzasys.com/pmsys.html>

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Chapter 1 – Introduction

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Chapter 3 – General discussion and conclusions

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Appendixes

Differences in strength and speed demands between 4v4 and 8v8 small-sided football games

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2016

Journal of Sports Sciences 34 (24): 2246-2254

DOI: 10.1080/02640414.2016.1194527

Keywords: Time-motion; Acceleration demands; Fatigue; Technical skills

This is an accepted Manuscript reprinted by permission of Taylor & Francis in the Journal of Sports Science on 09 June 2016, available online: <https://www.tandfonline.com/doi/full/10.1080/02640414.2016.1194527>

Differences in strength and speed demands between 4v4 and 8v8 small-sided football games

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ABSTRACT

The aims of this study were (i) to characterise the acceleration demands of two different formats of small-sided game (SSG), i.e., 4v4 + goalkeepers (4v4 + GK) and 8v8 + goalkeepers (8v8 + GK); (ii) to analyse the correlation between performance in power-based tests and acceleration-based physical loading during the two different SSG formats and (iii) to analyse the neuromuscular-induced fatigue. Eighteen adult male footballers participated in the study (20.7 ± 1.0 years, 178 ± 5 cm and 71.4 ± 2.1 kg). Baseline measurements were obtained from countermovement jumps, 15 s repeated jumps and 5 and 15 m sprints. A total of 36 min was analysed for each SSG (4v4 + GK: two sets of 3×6 min, and 8v8 + GK: 2×18 min). Heart rate, blood lactate, perceived exertion and movement pattern (GPS) were analysed. Distances covered by very-high-intensity activities and very-high-speed running were lower in 4v4 + GK than in 8v8 + GK (effect sizes (ES) = -0.69 ± 0.67 and -1.04 ± 0.67 , respectively; very likely), while accelerations and decelerations were higher in 4v4 + GK than in 8v8 + GK (ES = 1.13 – 1.52 ; almost certainly). Blood lactate concentrations were higher (ES = 1.40 ± 0.58 ; almost certainly) and players perceived themselves to be more tired (ES = 0.80 – 2.31 ; almost certainly) after 4v4 + GK than after 8v8 + GK. Sprint ability in 5 and 15 m tests decreased (ES = 0.87 ± 0.58 and 0.89 ± 0.58 , respectively; almost certainly) only after 4v4 + GK. This SSG format appeared more demanding in relation to repetitions and fatigue development of muscle power-based actions than 8v8 + GK. It may therefore be logical to use the former type of SSG to target development of power-related football actions.

ARTICLE HISTORY

Accepted 16 May 2016

KEYWORDS

Time-motion; acceleration demands; fatigue; technical skills

Introduction

Small-sided games (SSGs) have been extensively used in training footballers worldwide and have shown very good efficacy in improving player performance (Hill-Haas, Dawson, Impellizzeri, & Coutts, 2011). As an example, it has been shown that the technical performance (Owen, Wong del, McKenna, & Dellal, 2011) and physical performance (Chaouachi et al., 2014; Dellal, Varliette, Owen, Chirico, & Pialoux, 2012) of footballers can be enhanced using SSG-based football training programmes.

In the last two decades, extensive research has been published on physical and physiological response during SSGs in football (for refs, see Halouani, Chtourou, Gabbett, Chaouachi, & Chamari, 2014). It was found that the time-motion characteristics of SSGs could vary greatly depending on certain structural (e.g., pitch size, number of players, type and number of goals) and rule (e.g., number of ball touches) constraints. For example, it was observed that higher maximum speeds are reached during SSGs played on bigger pitches (Casamichana & Castellano, 2010). Furthermore, heart rate (HR) and lactate concentrations were shown to be sensitive to structural and rule changes in SSGs.

With regard to time-motion characteristics, running speed has been the most extensively studied variable. However, recent studies have shown that, in order to better characterise

the physiological loading during SSGs, acceleration analysis is of major importance. In fact, the physiological strain induced by acceleration and deceleration movements has a pronounced impact on both energetic and neuromuscular systems (Gaudino, Alberti, & Iaia, 2014a; Gaudino et al., 2014b). Thus, when seeking to analyse the physical demands of different SSG formats, acceleration characterisation is strongly recommended. Although the value of GPS technology in determining accelerations in the field appears questionable (Buchheit et al., 2012), acceptable values of validity and reliability in the measurement of constant velocity would be expected when higher sample rates are used (Varley, Faiweather, & Aughey, 2013).

It has already been observed that the physical fitness of football players can be correlated with physical performance during official matches (Manzi, Impellizzeri, & Castagna, 2014; Rebelo, Brito, Seabra, Oliveira, & Krstrup, 2014). However, little (or nothing) is known about the correlation between the physical fitness of players and their physical and technical performance in SSGs. This is important information for coaches as the physical loading of the training session should be individually designed to improve performance and avoid excess of fatigue and overtraining. Intriguingly, there is limited scientific data on the effects of SSGs versus other training

methods (e.g., high-intensity interval training) on fatigue (Faude, Steffen, Kellmann, & Meyer, 2014). Moreover, analysis of fatigue induced by different SSGs is extremely scarce (Katis & Kellis, 2009).

Given the above, the aims of this study were (i) to characterise the acceleration and speed demands of two different SSG formats (4v4 + goalkeepers (GK) and 8v8 + GK); (ii) to analyse the effects of each type of SSG on neuromuscular performance and (iii) to analyse the accumulation of fatigue during the SSGs.

Methods

Participants

Eighteen adult male footballers were invited to participate in the study. Their age, height and weight were 20.7 ± 1.0 years, 178 ± 5 cm and 71.4 ± 2.1 kg. The participants were college students representing different local football clubs. All the players were interviewed to determine how long they had been playing football and how many hours a week they trained. The players had been registered with local football clubs for 6.0 ± 2.5 years, the last 2–3 years at semi-professional level. They had four training sessions and one official match per week, resulting in a total training time of 7.1 ± 0.7 h per week. When questioned about familiarity with SSGs, the participants reported that they had frequently been exposed to SSG formats similar to those used in the study. All the players were informed about the protocol and signed an informed consent form before the investigation. The Scientific Board of the Faculty of Sport at the University of Porto, Portugal, approved the design of the study.

Experimental design

The participants were evaluated during two different SSGs: 4v4 + GK and 8v8 + GK. In order to analyse SSG-induced fatigue, baseline measurements were obtained from physical tests performed 1 week before the SSG assessments. On two separate days, the participants completed tests comprising countermovement jumps (CMJs; Digitime 1000, Digitest, Finland), 5 and 15 m sprints (Speed Trap II; Brower Timing System, Utah, USA) and quadriceps strength tests (Tempo Technologies, Globus Ergometer). HR, blood lactate, time-motion, technical actions and rate of perceived exertion (RPE) were obtained during SSGs.

Following baseline testing, the participants were randomly allocated to four teams of four players. At baseline, teams were balanced in terms of the players' jump and sprint performance (CMJ: 0.43 ± 0.03 , 0.38 ± 0.04 , 0.42 ± 0.05 and 0.42 ± 0.06 m; 5 m sprint: 1.12 ± 0.06 , 1.14 ± 0.06 , 1.14 ± 0.06 and 1.10 ± 0.06 s; 15 m sprint: 6.09 ± 0.20 , 6.13 ± 0.20 , 6.14 ± 0.30 and 6.15 ± 0.28 s; $P > 0.05$). All games were played outdoors between 9 and 11 am in dry conditions. Ambient temperature (16 – 20°C) and humidity (60–75%) were monitored. All SSGs were played on a third-generation artificial pitch developed especially for football consisting of long and widely spread fibres of polypropylene filled with rubber granules. The two SSG

sessions took place in a random order with an interval of 72 h. A total of 36 min was analysed for each SSG (4v4 + GK: two sets of 3×6 min and 8v8 + GK: 2×18 min). The games included a 3 min rest break between repetitions and a 5 min rest break between the two sets of 4v4 + GK. The pitch size was adapted to each SSG format (4v4 + GK: length 47.72 m, width 29.54 m; 8v8 + GK: length 85.90 m, width 53.18 m). The goals were 7×2 m (width \times height). Minor rule modifications were applied, such as no offside, restart of the game after a goal by the goalkeeper and kick-in awarded to the opposing side to that of the player who last touched the ball. Games were played without referees or sideline encouragement. The scores of the games were prospectively recorded by one of the researchers. Six extra footballs were always available near the goals and at the side of the pitch to facilitate a quick restart when the ball left the playing area. The chief investigator was always available to immediately replace the ball when it was kicked out. All players were encouraged to drink water before the start of the game, during the breaks and after the last game prior to the sprint, jump and strength tests.

Post-game measurements were obtained immediately after each SSG session.

Testing

Sprint times were determined by a flat sprint test performed in a straight 20 m line. The times were measured by three pairs of photoelectric cells positioned at the starting point and at 5 and 15 m. The participants were instructed to run as fast as possible from a standing start 30 cm behind the starting line. Baseline and post-game sprint tests were performed outdoors on a tartan track located within 20 m of the pitch.

For the CMJ test, the participant stood upright, bent the knees to the squat position and jumped vertically as high as possible keeping hands on hips and landing with straight knees on the mat. The flight time was used to calculate the change in the height of the body's centre of gravity (Bosco, Luhtanen, & Komi, 1983).

Maximal voluntary isometric torque of the quadriceps with knees positioned at 90° of flexion was measured using an isometric loading cell. After a warm-up set of five submaximal repetitions of knee extension at the stated angle, the participants completed two maximal repetitions separated by 60 s of rest. The participants received verbal encouragement and the best result of the two was used in further analysis.

Heart rate measurements

HR was recorded at 5 s intervals by short-range radio telemetry (Polar Team System, Kempele, Finland). To reduce HR recording errors, the players were asked to check their HR monitors before each game. The monitors were attached to the participants using an adjustable elastic chest strap. Data were transferred to a computer using the Polar Precision Performance 4.03 software program (Polar Team System). Mean HR values during the games were expressed in absolute values (beats per min).

Blood lactate

Blood lactate was collected as a physiological indicator of the contribution of anaerobic glycolysis during exercise. Blood lactate was measured via 5 µl capillary blood samples taken from an earlobe (Lactate Pro, Arkray Inc., Japan). The analyser was calibrated according to precision standards and routinely assessed by external quality controls. The accuracy and reliability of the blood lactate analyser has been assessed elsewhere at different lactate concentrations (coefficient of variation ranged between 2.8% and 5.0%) and between test strips (intraclass correlation coefficient, $r = 0.999$) (Baldari et al., 2009). The participants were asked to temporarily leave the pitch (± 30 s) to sit on a chair positioned 2 m outside the sideline for collection of the blood samples. One researcher carefully cleaned, disinfected and dried the participant's earlobe before blood collection in order to avoid any possible interference as a result of sweat and dirt. The participant's skin was then punctured with a lancet and the first drop of blood placed straight onto the strip. One blood sample was taken from each participant in each SSG repetition in a random order. All samples were collected 1–2 min after game activity and analysed within a few seconds of collection (Taoutaou, Granier, Mercier, Ahmaidi, & Prefaut, 1996). All samples were collected during SSGs and analysed within a few seconds of collection. An outfield substitute replaced the participant from whom the blood sample was being collected.

Time-motion analysis

Movement pattern during the games was measured using unobtrusive portable global positioning system (GPS) units (GPSports SPI Elite, Canberra, Australia). Based on signals from at least three Earth-orbiting satellites, the GPS receiver recorded the players' positional data (x - and y -) with a time resolution of 15 Hz (obtained through interpolation of a 5 Hz signal). The system used the GPS Doppler data and distances were calculated from changes in position and subject to the manufacturer's proprietary algorithm integrated to reduce measurement error. The data from each receiver were treated and extracted using proprietary software (GPSports team AMS v1.2.1.12, Canberra, Australia). The software calculated the total distance covered during a game, the average speed and maximum speed achieved during the game, and the time spent in five locomotor categories defined in advance in accordance with Buchheit, Mendez-Villanueva, Simpson, and Bourdon (2010). For data analysis purposes, the following locomotor categories were chosen: low-intensity running (LIR) ($0\text{--}13 \text{ km} \cdot \text{h}^{-1}$), high-intensity running ($13.1\text{--}16 \text{ km} \cdot \text{h}^{-1}$), very-high-intensity running ($16.1\text{--}19 \text{ km} \cdot \text{h}^{-1}$), very-high-intensity activities (VHIA) ($16.1\text{--}19 \text{ km} \cdot \text{h}^{-1}$) and very-high-speed running (VHSR) ($>19.1 \text{ km} \cdot \text{h}^{-1}$). The time spent in each locomotor category during the games was presented as a percentage of total playing time. The GPS software calculated the frequency and duration of high-intensity running and VHSR in relation to the specific speed categories.

Accelerations and decelerations

Acceleration and deceleration distances were captured using GTX3 accelerometers (100 Hz, ActiGraph, version 4.4.0). The

raw data of the accelerometers and the coordinates of the GPS system in the x - (longitudinal) and y - (lateral) directions were extracted and matched temporally for each game (using satellite time, recorded in both the GPS and the accelerometers). The speed of each player was computed (using GPS coordinates) to assess whether the player was accelerating or decelerating. Acceleration and deceleration data were then calculated in $\text{m} \cdot \text{s}^{-2}$ using the accelerometers' g forces in the longitudinal (gx) and lateral (gy) directions through the following formula – $\sqrt{gx^2 \times gy^2}$. Finally, all acceleration distances were measured according to type (acceleration or deceleration) and category ($2\text{--}3 \text{ m} \cdot \text{s}^{-2}$ and $>3 \text{ m} \cdot \text{s}^{-2}$). All computations were made using MATLAB routines (R2011a, MathWorks, USA).

Rating of perceived exertion

Perceived exertion, physical effort and fatigue state were recorded using a visual analogue scale (VAS) questionnaire (Andersson, Ekblom, & Krustup, 2008). The questionnaire comprised five questions worded to analyse the players' perceptions of playing each of the two SSG formats. The questions were as follows: "How do you feel after today's training session?" (*not tired*–*very tired*; VAS1); "How hard physically was today's SSG?" (*not hard*–*very hard*; VAS2); "In terms of strength, how demanding was today's SSG?" (*not very demanding*–*very demanding*; VAS3); "In terms of endurance, how demanding was today's SSG?" (*not very demanding*–*very demanding*; VAS4); "In terms of sprinting, how demanding was today's SSG?" (*not very demanding*–*very demanding*; VAS5). The VAS was anchored by two items with a 100 mm horizontal line connecting them and scored from 0 (*not tired/not hard/not very demanding*) to 100 (*very tired/very hard/very demanding*), but the participants were unaware of the numbers.

Technical actions

The SSGs were videoed (DCR-HC53E, Sony, Tokyo, Japan), and defensive and offensive technical skills were measured: tackles, ball interceptions, defensive duels, passes, offensive duels, runs with the ball, shots and goals. Games were filmed with cameras positioned on a platform positioned at the stand on the side of the pitch at the halfway line, at a height of 5 m and about 5 m behind the sideline. Two experienced observers analysed all SSG videos. Data quality was ensured by assessing intra- and inter-observer reliability. Specifically, Cohen's kappa index (Cohen, 1960) was calculated from the records of two experienced observers. Results yielded values of 0.88–0.98, well above the value of 0.75 established as being indicative of high data quality.

Statistics

Differences between 4v4 and 8v8 in (i) technical, physical and physiological demands and (ii) post tests and baseline were analysed using magnitude-based inferences (Hopkins, Marshall, Batterham, & Hanin, 2009). Between-treatment effect sizes (ES) with 90% confidence intervals (CIs) were calculated using pooled standard deviations. Threshold values for Cohen's ES were >0.2

(small), <0.6 (moderate) and >1.2 (large) (Cohen, 1992). Probabilities were calculated to assess whether true effects obtained represented substantial changes (Batterham & Hopkins, 2006). The smallest standardised change for each variable was considered to be 0.2 multiplied by the between-subject standard deviation value, based on Cohen's ES principle. Quantitative probabilities of higher or lower differences were evaluated qualitatively as <1% = almost certainly not, 1–5% = very unlikely, 5–25% = unlikely, 25–75% = possibly, 75–95% = likely, 95–99% = very likely, >99% = almost certainly. If the probabilities of the effect being higher or lower than the smallest worthwhile difference were simultaneously >5%, the effect was deemed unclear. Otherwise, the effect was clear and reported as the magnitude of the observed value. The tendency of physical and technical parameters during the different stages of each format (4v4 + GK or 8v8 + GK) were analysed through linear regression slopes (describing tendency).

Pearson correlation coefficients (r , with 90% confidence intervals) were calculated to verify the association between variables. To interpret the magnitude of the correlation coefficients, the following criteria were used: <0.10 trivial, 0.10 < r < 0.30 small, 0.30 < r < 0.50 moderate, 0.50 < r < 0.70 large, 0.70 < r < 0.90 very large and 0.90 < r < 1 almost perfect (Hopkins, Marshall, Batterham, & Hanin, 2009). Practical inferences of the correlation

coefficients were also considered. The default threshold of r was considered 0.1 based on Cohen's assumption of the smallest clinically important correlation. Data analysis was performed in SPSS statistical software (version 23, IBM SPSS Statistics, Chicago, IL, USA) and a modified statistical Excel spread sheet (Hopkins, 2007).

Results

Time-motion analysis, physiological demands and perceived exertion

Between-game differences (i.e., 4v4 + GK vs. 8v8 + GK) in distance covered by VHIA and VHSR were very likely (4/0/96; 0.9/0/99, respectively) moderate (ES = -0.69 ± 0.67 and -1.04 ± 0.67 ; Table 1). Very likely (96/0/4) moderate (ES = 0.67 ± 0.67) differences were observed in accelerations of 2–3 $\text{m}\cdot\text{s}^{-2}$, while decelerations of 2–3 $\text{m}\cdot\text{s}^{-2}$, >3 $\text{m}\cdot\text{s}^{-2}$ and total decelerations were almost certainly (99.9/0/0.1; 99.9/0/0.1; 99.5/0/0.5) moderately to largely (ES = 1.52 ± 0.67 , 1.13 ± 0.67 and 1.44 ± 0.67) different.

Blood lactate differences between games were almost certainly (99.9, 0, 0) large (ES = 1.40 ± 0.58).

Differences in RPE (VAS1, VAS2, VAS3 and VAS4) during games were almost certainly (99.9/0/0; 99.6/0/0.3; 99.7/0/0.3

Table 1. Overall comparison of 4v4 + GK versus 8v8 + GK reported as distance covered per minute.

	4v4 + GK	8v8 + GK	4v4 + GK vs 8v8 + GK	
	Mean \pm SD	Mean \pm SD	SMD (90% CL)	Uncertainty in true differences
<i>Locomotor activities</i>				
LIR (m)	87.11 \pm 4.43	84.18 \pm 12.61	0.29 (–0.37; 0.96)	Unlikely (15.8, 83.4, 0.8)
HIR (m)	11.21 \pm 1.78	11.88 \pm 3.70	–0.22 (–0.89; 0.44)	Unclear (11.8, 34.8, 53.4)
VHIR (m)	4.96 \pm 0.82	5.45 \pm 2.12	–0.29 (–0.96; 0.37)	Unclear (12.9, 16.8, 70.3)
VHIA (m)	8.04 \pm 1.80	9.96 \pm 3.33	–0.69 (–1.36; –0.02)	Very likely (4, 0, 96)
VHSR (m)	2.92 \pm 1.00	4.35 \pm 1.59	–1.04 (–1.71; 0.36)	Very likely (0.9, 0, 99)
TD (m)	107.07 \pm 5.47	107.01 \pm 18.68	0.00 (–0.66; 0.67)	Almost certainly not (0.8, 98.5, 0.7)
Acc 2–3 $\text{m}\cdot\text{s}^{-2}$ (m)	4.81 \pm 0.44	4.17 \pm 1.21	0.67 (0.005; 1.34)	Very likely (96, 0, 4)
Acc >3 $\text{m}\cdot\text{s}^{-2}$ (m)	2.36 \pm 0.37	2.00 \pm 0.84	0.53 (–0.13; 1.20)	Unclear (93.4, 0, 6.6)
Acc tot (m)	28.81 \pm 5.36	29.91 \pm 1.81	–0.26 (–0.93; 0.40)	Possibly (4.8, 37.5, 57.7)
Dec 2–3 $\text{m}\cdot\text{s}^{-2}$ (m)	5.28 \pm 0.61	4.09 \pm 0.87	1.52 (0.85; 2.20)	Almost certainly (99.9, 0, 0.1)
Dec >3 $\text{m}\cdot\text{s}^{-2}$ (m)	2.52 \pm 0.41	1.88 \pm 0.66	1.13 (0.46; 1.80)	Almost certainly (99.9, 0, 0.1)
Dec tot (m)	32.63 \pm 1.93	28.96 \pm 2.88	1.44 (0.77; 2.11)	Almost certainly (99.5, 0, 0.5)
<i>Physiological variables</i>				
BLA ($\text{mmol} \cdot \text{l}^{-1}$)	6.56 \pm 1.23	4.59 \pm 1.48	1.40 (0.82; 1.99)	Almost certainly (99.9, 0, 0)
HR ($\text{beats} \cdot \text{min}^{-1}$)	170.2 \pm 2.0	169.6 \pm 3.5	0.08 (–0.49; 0.66)	Likely (91.7, 0, 8.3)
<i>Subjective ratings</i>				
VAS1 (au)	238.5 \pm 43.5	177.3 \pm 47.2	2.31 (0.73; 1.89)	Almost certainly (99.9, 0, 0)
VAS2 (au)	242.3 \pm 59.9	175.5 \pm 50.6	1.17 (0.59; 1.75)	Almost certainly (99.6, 0, 0.3)
VAS3 (au)	228.4 \pm 54.2	162.0 \pm 60.2	1.12 (0.54; 1.71)	Almost certainly (99.7, 0, 0.3)
VAS4 (au)	245.9 \pm 67.7	194.6 \pm 56.5	0.80 (0.22; 1.38)	Almost certainly (98.6, 0.1, 1.3)
VAS5 (au)	197.3 \pm 61.3	196.9 \pm 53.7	0.00 (–0.57; 0.58)	Almost certainly not (0, 100, 0)
<i>Technical actions</i>				
Tackles (n)	4.2 \pm 2.9	2.9 \pm 2.23	0.77 (0.17; 1.37)	Very likely (98.2, 0, 1.7)
Ball interceptions (n)	6.3 \pm 1.9	3.3 \pm 1.53	1.70 (1.10; 2.30)	Almost certainly (100, 0, 0)
Defensive duels (n)	23.3 \pm 7.7	12.2 \pm 9.21	1.26 (0.66; 1.86)	Almost certainly (100, 0, 0)
Passes (n)	43.2 \pm 12.5	22.4 \pm 6.8	2.00 (1.40; 2.60)	Almost certainly (99.9, 0.1, 0)
Offensive duels (n)	7.7 \pm 5.7	4.2 \pm 4.4	0.67 (0.07; 1.27)	Almost certainly (99.4, 0, 0.5)
Runs with the ball (n)	8.5 \pm 4.4	3.6 \pm 2.1	1.39 (0.79; 1.99)	Almost certainly (100, 0, 0)
Shots (n)	5.1 \pm 3.0	1.5 \pm 1.7	1.45 (0.85; 2.05)	Almost certainly (100, 0, 0)
Goals (n)	1.9 \pm 1.3	0.2 \pm 0.4	1.77 (1.17; 2.37)	Almost certainly (100, 0, 0)

Threshold values for effect sizes were <0.2 (trivial), 0.2–0.6 (small), 0.6–1.2 (moderate), >1.2 (large).

Quantitative probabilities of higher or lower differences were evaluated qualitatively as: <1% = almost certainly not, 1–5% = very unlikely, 5–25% = unlikely, 25–75% = possibly, 75–95% = likely, 95–99% = very likely, >99% = almost certainly.

Acc tot: total distance covered by accelerations; Acc 2–3: distance covered by accelerations of 2–3 $\text{m}\cdot\text{s}^{-2}$; Acc >3: distance covered by accelerations greater than 3 $\text{m}\cdot\text{s}^{-2}$; BLA: blood lactate; Dec tot: total distance covered by decelerations; Dec 2–3: distance covered by decelerations of 2–3 $\text{m}\cdot\text{s}^{-2}$; Dec >3: distance covered by decelerations greater than 3 $\text{m}\cdot\text{s}^{-2}$; HR: heart rate; HIR: high-intensity running; LIR: low-intensity running; TD: total distance covered; VAS: visual analogue scale; VAS1: “How do you feel after today's training session?” (not tired–very tired); VAS2: “How hard physically was today's SSG?” (not hard–very hard); VAS3: “In terms of strength, how demanding was today's SSG?” (not very demanding–very demanding); VAS4: “In terms of endurance, how demanding was today's SSG?” (not very demanding–very demanding); VAS5: “In terms of sprinting, how demanding was today's SSG?” (not very demanding–very demanding); VHIA: very-high-intensity activities; VHSR: very-high-speed running.

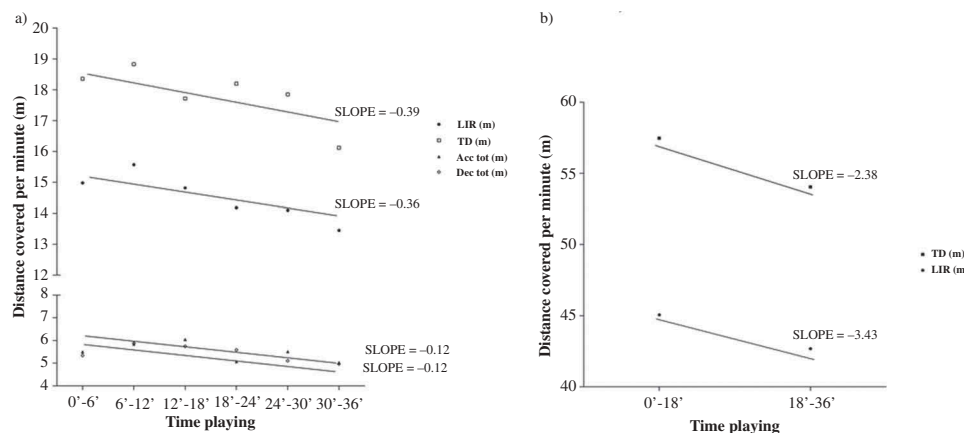


Figure 1. Changes in physical performance throughout 4v4 + GK (a) and 8v8 + GK (b).

Acc tot: total distance covered by accelerations; Dec tot: total distance covered by decelerations; LIR: low-intensity running; TD: total distance covered.

and $98.6/0.1/1.3$) moderate to large ($ES = 2.31 \pm 1.58$; 1.17 ± 0.58 ; 1.12 ± 0.58 and 0.80 ± 0.58).

Technical-action differences between games were very likely or almost certainly moderate to large ($ES = 0.67$ – 2.00).

Changes in physical performance throughout game repetitions

Total distance and distance covered by LIR and by accelerations and decelerations tend to decrease throughout repetitions of 4v4 + GK, as can be depicted from the negative slopes represented in Figure 1. In 8v8 + GK, total distance and distance covered in LIR also showed a tendency to decrease (more markedly than in 4v4 + GK) between the two repetitions.

Differences in physical capacity between baseline and post SSG

Differences in repeated jump ability (15" RJ) and in sprint times (5 and 15 m) between baseline and after 4v4 + GK were almost certainly ($100/0/0$; $99.1/0/0.9$ and $99.8/0/0.1$, respectively; Table 2) small to moderate ($ES = -0.38 \pm 0.58$, 0.87 ± 0.58 and 0.89 ± 0.58 , respectively). Repeated jump ability after 8v8 + GK was almost certainly ($100/0/0$) moderately ($ES = 0.78 \pm 0.58$) different from baseline measurements.

Relationship between neuromuscular testing and performance in 4v4 + GK and 8v8 + GK

Positive moderate correlations between CMJ performance and distance covered in VHIA and VHSR in 4v4 + GK ($r = 0.51 \pm 0.33$ and $r = 0.55 \pm 0.32$, respectively; Table 3) and between repeated jump ability and VHSR ($r = 0.54 \pm 0.32$, CI (90%)) were very likely ($95.2/3.9/0.8$; $96.9/2.6/0.5$ and $96.5/2.9/0.6$). A positive moderate correlation between 15 m sprint performance and distance covered by accelerations $>3 \text{ m}\cdot\text{s}^{-2}$ was very likely ($r = 0.52 \pm 0.33$; CI (90%); $95.7/3.6/0.7$).

Discussion

In this study, we aimed to characterise acceleration and VHSR demands as well as the neuromuscular fatigue induced by two commonly used SSG formats in football training, i.e., 4v4 + GK and 8v8 + GK, and to analyse the link between the neuromuscular performance of players and acceleration- and high-speed-based physical loading during these SSGs. 4v4 + GK appeared more demanding in relation to repetitions and fatigue development of muscle-based actions than 8v8 + GK based on higher anaerobic energy turnover, perceived exertion and number of technical actions. Moreover, jump ability and repeated jump performance in specific physical tests correlated with high-intensity running in 4v4 + GK, while 15 m sprint performance correlated with distance covered by accelerations during 8v8 + GK.

Table 2. Comparison of neuromuscular performance between baseline values and post SSGs.

	Baseline		Post 4v4 + GK		Post 8v8 + GK		
	Mean + SD	Mean + SD	SMD \pm 90% CI	Uncertainty in true differences	Mean \pm SD	SMD \pm 90% CI	Uncertainty in true differences
CMJ (cm)	42.88 \pm 11.9	38.84 \pm 5.2	0.45 (–0.13; 1.03)	Likely (95.9, 0, 4.1)	39.46 \pm 5.69	0.37 (–0.20; 0.95)	Likely (93, 0, 7)
15" RJ (num)	17.37 \pm 2.6	18.31 \pm 2.15	–0.38 (–0.96; 0.19)	Almost certainly (100, 0, 0)	19.28 \pm 2.11	–0.78 (–1.36; –0.20)	Almost certainly (100, 0, 0)
5 m sprint (m-s)	4.8 \pm 0.28	4.08 \pm 1.073	0.87 (0.29; 1.46)	Almost certainly (99.1, 0, 0.9)	4.76 \pm 0.2	0.09 (–0.48; 0.67)	Unclear (62.3, 3.5, 34.2)
15 m sprint (m-s)	6.14 \pm 0.27	5.92 \pm 0.224	0.89 (0.31; 1.47)	Almost certainly (99.8, 0, 0.1)	6.09 \pm 0.201	0.21 (–0.36; 0.79)	Unclear (85.2, 0, 14.7)

Data are presented as means \pm SD.

Threshold values for effect sizes were <0.2 (trivial), 0.2 – 0.6 (small), 0.6 – 1.2 (moderate), >1.2 (large). Quantitative probabilities of higher or lower differences were evaluated qualitatively as $<1\%$ = almost certainly not, 1 – 5% = very unlikely, 5 – 25% = unlikely, 25 – 75% = possibly, 75 – 95% = likely, 95 – 99% = very likely, $>99\%$ = almost certainly.

CMJ: countermovement jump; RJ: repeated jumps.



Table 3. Relationship between physical performance during SSCs and neuromuscular performance post SSCs.

	HIR	VHIR	VHIA	VHSR	TD	Acc 2–3 m·s ⁻²	Acc >3 m·s ⁻²	Acc tot	Dec 2–3 m·s ⁻²	Dec >3 m·s ⁻²	Dec tot
4v4 + GK (N = 16)											
CMJ	0.29 ± 0.40 Unclear	0.43 ± 0.36 Likely moderate	0.51 ± 0.33 Very likely moderate	0.55 ± 0.32 Very likely moderate	0.48 ± 0.34 Likely moderate	-0.063 ± 0.44 Unclear	0.097 ± 0.44 Unclear	-0.30 ± 0.44 Likely moderate	-0.17 ± 0.43 Unclear	0.44 ± 0.37 Likely moderate	-0.60 ± 0.30 Very likely large
15" RJ	-0.22 ± 0.41 Unclear	0.28 ± 0.40 Unclear	0.35 ± 0.41 Likely moderate	0.54 ± 0.32 Very likely moderate	0.38 ± 0.38 Likely moderate	-0.01 ± 0.44 Unclear	0.07 ± 0.44 Unclear	0.23 ± 0.42 Unclear	-0.31 ± 0.41 Unclear	0.21 ± 0.43 Unclear	-0.27 ± 0.42 Unclear
MIVC	-0.48 ± 0.34 Likely moderate	0.01 ± 0.43 Unclear	0.03 ± 0.43 Unclear	0.05 ± 0.43 Unclear	-0.32 ± 0.40 Unclear	-0.36 ± 0.39 Likely moderate	-0.08 ± 0.44 Unclear	0.42 ± 0.38 Unclear	-0.40 ± 0.38 Likely moderate	-0.28 ± 0.41 Unclear	0.19 ± 0.43 Unclear
5 m sprint	0.18 ± 0.42 Unclear	0.15 ± 0.42 Unclear	0.37 ± 0.38 Likely moderate	0.46 ± 0.35 Likely moderate	0.007 ± 0.44 Unclear	-0.58 ± 0.31 Very likely large	0.04 ± 0.44 Unclear	-0.19 ± 0.43 Unclear	-0.57 ± 0.32 Very likely moderate	0.05 ± 0.44 Unclear	-0.45 ± 0.37 Likely moderate
15 m sprint	0.17 ± 0.42 Unclear	0.46 ± 0.35 Likely moderate	0.43 ± 0.36 Likely moderate	0.43 ± 0.36 Likely moderate	0.10 ± 0.44 Unclear	-0.29 ± 0.41 Likely small	-0.03 ± 0.44 Unclear	-0.18 ± 0.43 Unclear	-0.26 ± 0.42 Unclear	0.03 ± 0.44 Unclear	-0.40 ± 0.38 Likely moderate
8v8 + GK (N = 16)											
CMJ	0.08 ± 0.42 Unclear	0.27 ± 0.40 Unclear	0.26 ± 0.40 Unclear	0.18 ± 0.42 Unclear	0.22 ± 0.42 Unclear	-0.43 ± 0.37 Likely moderate	0.13 ± 0.44 Unclear	-0.34 ± 0.40 Unclear	-0.39 ± 0.39 Likely moderate	-0.05 ± 0.44 Unclear	0.11 ± 0.44 Unclear
15" RJ	-0.17 ± 0.42 Unclear	-0.12 ± 0.42 Unclear	-0.06 ± 0.43 Unclear	0.01 ± 0.43 Unclear	-0.21 ± 0.43 Unclear	0.38 ± 0.39 Likely moderate	0.03 ± 0.44 Unclear	0.32 ± 0.40 Unclear	0.39 ± 0.39 Likely moderate	0.23 ± 0.42 Unclear	-0.28 ± 0.41 Unclear
MIVC	-0.44 ± 0.36 Likely moderate	-0.25 ± 0.40 Unclear	-0.28 ± 0.40 Unclear	-0.28 ± 0.40 Unclear	-0.41 ± 0.38 Likely moderate	0.27 ± 0.42 Unclear	0.12 ± 0.44 Unclear	0.51 ± 0.34 Very likely moderate	0.14 ± 0.44 Unclear	0.15 ± 0.43 Unclear	-0.18 ± 0.44 Unclear
5 m sprint	0.13 ± 0.42 Unclear	-0.01 ± 0.43 Unclear	0.16 ± 0.42 Unclear	0.36 ± 0.38 Likely moderate	0.15 ± 0.43 Unclear	-0.30 ± 0.41 Unclear	0.14 ± 0.44 Unclear	-0.23 ± 0.42 Unclear	0.003 ± 0.44 Unclear	0.18 ± 0.43 Unclear	-0.03 ± 0.44 Unclear
15 m sprint	0.21 ± 0.41 Unclear	0.27 ± 0.40 Unclear	0.32 ± 0.39 Unclear	0.30 ± 0.40 Unclear	0.28 ± 0.41 Unclear	-0.01 ± 0.44 Unclear	0.52 ± 0.34 Very likely moderate	0.06 ± 0.44 Unclear	0.043 ± 0.44 Unclear	0.37 ± 0.39 Unclear	0.48 ± 0.36 Likely moderate

Data are presented as magnitude of correlation ± 90% CI.

Acc tot: total accelerations; Acc 2–3: accelerations of 2–3 m·s⁻²; Acc >3: accelerations greater than 3 m·s⁻²; CMJ: countermovement jump; CV: coefficient of variation; Dec tot: total decelerations; Dec 2–3: decelerations of 2–3 m·s⁻²; Dec >3: decelerations greater than 3 m·s⁻²; HIR: high-intensity running; LIR: low-intensity running; MIVC: maximal isometric voluntary contraction; MVIC: maximal isometric voluntary contraction; RJ: repeated jumps; TD: total distance covered; VHIR: very-high-intensity running; VHIA: very-high-intensity activities; VHSR: very-high-speed running.

Demands of 4v4 + GK and 8v8 + GK

In this study, it was observed that distance covered by VHIA and high-speed running was greater in 8v8 + GK than in 4v4 + GK. Similar results were reported in other studies investigating SSGs that found an increase in distance covered in higher speed categories with a number of players. Hill-Haas, Rowsell, Dawson, and Coutts (2009b) examined the effect on physiological responses of three game formats (2v2, 4v4 and 6v6) with a constant ratio of player number to pitch size. The largest game format (6v6) correlated with a greater range of distances covered at speeds $>18 \text{ km} \cdot \text{h}^{-1}$. Castellano, Casamichana, and Dellal (2013) also found significant differences for the high-intensity speed category depending on the number of players involved in different game formats, with greater distances covered in this speed category in 7v7 than in 3v3. In fact, it appears that a concurrent increase in player number and relative pitch area per player in SSGs induces lower exercise intensity (Hill-Haas et al., 2011).

For a more detailed analysis of SSG demands, we need to take into account an essential element of football, namely accelerations and decelerations, as a massive metabolic load is imposed on players not only during high-speed running but every time acceleration is elevated, even when speed is low (Casamichana, Castellano, & Dellal, 2013; Gaudino et al., 2014a; Varley & Aughey, 2013). Moreover, the high-intensity demands of SSGs on elite footballers are underestimated by running speed alone, particularly in “small” SSGs (Gaudino et al., 2014b).

Previous studies showed an increase in acceleration/deceleration demands as the number of players in the SSG decreased. Gaudino et al. (2014a) analysed three SSG formats (5v5, 7v7 and 10v10) and found that both the number of moderate ($2\text{--}3 \text{ m} \cdot \text{s}^{-2}$) accelerations and decelerations, and the total number of changes in velocity, were greater as the pitch dimensions decreased. Predicted energy cost, average metabolic power and distance covered in all metabolic power categories were higher for large pitches than for small pitches. Our study confirmed these results, with a greater distance covered by accelerations and decelerations performed in 4v4 + GK than in 8v8 + GK, which could mean a higher metabolic and mechanical loading of the neuromuscular system in the smaller format. Thus, this information should be taken into consideration when designing weekly training schedules for footballers. As eccentric exercises impose a high mechanical strain (Clarkson & Hubal, 2002), requiring long recovery times, coaches should not schedule SSGs with a low number of players too close to official matches (either before or after) in order to allow adequate recovery. However, since it is the internal response to training (e.g., HR, blood lactate concentration and RPE) and not the external training load that determines each player's adaptation to a training stimulus, it is recommended that each player's internal load should be monitored to assess how they are coping with different SSG training designs (Hill-Haas et al., 2011).

We found higher values of blood lactate in 4v4 + GK than in 8v8 + GK as a result of a higher anaerobic energy turnover.

Other researchers reported similar findings, pointing out that as the number of players in the SSG teams decreased, the overall physiological and perceptual responses increased. In fact, it appears that a concurrent decrease in player number and relative pitch area per player in SSGs elicits higher physiological loading. Little and Williams (2006) investigated the effect on $[\text{La}^-]$ and RPE of six SSG football formats and pitch area. The results showed an increase in $[\text{La}^-]$ ($5.8\text{--}9.6 \text{ mmol} \cdot \text{L}^{-1}$) when the number of players and pitch area decreased. Other studies have also shown that SSG formats with fewer players elicit greater RPE than larger formats (Aroso, Rebelo, & Gomes-Pereira, 2004; Hill-Haas, Coutts, Dawson, & Rowsell, 2010; Hill-Haas, Coutts, Rowsell, & Dawson, 2008; Hill-Haas et al., 2009b; Impellizzeri et al., 2006; Rampinini et al., 2007). Additionally, we found higher perception scores after 4v4 + GK in relation to physical, strength and endurance demands. Altogether, these results suggest that, compared with 8v8, 4x4 calls for more strength-demanding actions requiring muscular eccentric work and relying on anaerobic metabolism. Interestingly, we did not find any difference in HR between 4v4 + GK and 8v8 + GK. It could be hypothesised that both games highly tax the cardiorespiratory system.

As previously reported (Aslan, 2013; Clemente, Wong del, Martins, & Mendes, 2014; Jones & Drust, 2007; Katis & Kellis, 2009), another argument for the use of a low number of players in SSGs is the high frequency of technical actions. We found a higher number of technical actions in 4v4 + GK than in 8v8 + GK (tackles +45%; ball interceptions +91%; defensive duels +91%; passes +93%; offensive duels +83%; runs with the ball +136%; shots +240%; and goals +850%). Reducing the number of players in the game increases the number of repetitions of football skills and the number of decision-making actions, and this provides a logical argument for the use of this strategy both in teaching football and in elite training environments. Thus, this information should be taken into consideration when designing weekly training schedules for footballers.

Fatigue development during and after 4v4 + GK and 8v8 + GK

Total distance and LIR tended to decrease throughout repetitions of 4v4 + GK and 8v8 + GK. Moreover, the distance covered by accelerations and decelerations showed an identical trend throughout 4v4 + GK repetitions. These results indicate that players experienced fatigue throughout repetitions of SSG, particularly during 4v4.

Dellal, Drust, and Lago-Penas (2012) found that the total distance covered by high-intensity activities of elite footballers decreased as a result of the number of exercise periods in 2v2, 3v3 and 4v4, and that the changes associated with the exercise period seem to be related to the number of players. The authors suggested that a reduction in the number of players in an SSG induces a decrease in the number and duration of the recovery periods between efforts. This information should not be neglected when using SSG to improve the physical fitness of footballers; if the aim of the training session is to

maintain the level of physical response during each repetition of the SSG, coaches should pay attention to the number of repetitions prescribed and players should be given enough time between repetitions to completely recover.

We observed a decrease in neuromuscular-based performance after 4v4 + GK and 8v8 + GK. Repeated jump ability decreased after 4v4 + GK and 8v8 + GK, while sprint performance decreased after 4v4 + GK. Results from Katis and Kellis (2009) also showed a deterioration in 30 m sprint test performance after repetitions of 3v3 SSG. This observed reduction in neuromuscular performance after SSG completion could be interpreted as a result of SSG-induced fatigue. However, reductions in sprint ability in 5 and 15 m tests were found only after 4v4 + GK. It should be stressed that, as discussed above, 4v4 + GK induced higher neuromuscular stress and, based on decreased sprint ability, this was only observable in this SSG format.

Altogether, the results suggest that 4v4 + GK provides a greater stimulus for neuromuscular conditioning and technical improvement than 8v8 + GK, and its use in training elite footballers is highly recommended.

Relationship between neuromuscular testing and performance in 4v4 + GK and 8v8 + GK

As far as we know, no previous studies have examined the relationship between sprint and jump testing and SSG performance. In our study, there was a positive correlation between CMJ and distance covered by VHIA and VHSR during 4v4 + GK, while repeated jump ability correlated with VHSR in the same game format. Moreover, 15 m sprint performance positively correlated with distance covered by accelerations at highest intensity ($\text{Acc} > 3 \text{ m} \cdot \text{s}^{-2}$) during 8v8 + GK. These results suggest that neuromuscular performance, as evaluated by jump ability, could influence high-intensity activities and power-based actions in 4v4 + GK and 8v8 + GK.

In recent years, the physiological stress generated in SSG football has been examined with regard to its potential for improving aerobic fitness (Hill-Haas, Coutts, Rowsell, & Dawson, 2009a). However, periodic training interventions involving SSG with a reduced number of players could be capable of improving elite-level football players' neuromuscular characteristics and this should be investigated in future intervention studies.

There were some limitations of this study that should be considered and addressed in future studies. We recommend the analysis of a large sample of professional soccer players in a high number of SSG-based training sessions throughout the season in order to improve the reliability of the preliminary conclusions of the present study. Moreover, it should be emphasised that the metrics of speed calculations with GPS show a great variability and must be interpreted cautiously. A further limitation of this study might be the different duration of bouts of 4v4 and 8v8 SSGs analysed as it was already described that this variable could influence the exercise intensity of SSGs (see Aguiar, Botelho, Lago, Maças, & Sampaio, 2012). However, it should be clarified that in this study we intended to analyse the influence of two examples of soccer training sessions based on two different types of SSG. As the performance of SSGs with different numbers of players

requires an adjustment in exercise duration, we decided to choose a duration for each SSG based on standard soccer practices. In this way, the intention was to improve the validity of the study.

Conclusions

In this study, we compared the physical demands of two SSG formats: 4v4 + GK and 8v8 + GK. It was observed that 4v4 + GK appears more demanding in relation to repetitions and fatigue development of muscle power-based actions based on higher anaerobic energy turnover, perceived exertion and number of technical actions, whereas during 8v8 + GK players run more at high intensity. Furthermore, repeated jump performance evaluated in corresponding tests seems to correlate with distance covered at higher intensities in 4v4 + GK. It may therefore be logical to use 4v4 + GK for targeting the development of power-related football actions, which should be investigated in future intervention studies.

Disclosure statement

No potential conflict of interest was reported by the authors.

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Influence of opponent standard on activity pattern and fatigue development during preseasonal friendly football matches: a team study

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2018

Research in Sports Medicine, 26 (4), 413-424

DOI: 10.1080/15438627.2018.1492400

Keywords: Physiology; Accelerations; Performance; Monitoring; Workload

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Influence of opponent standard on activity profile and fatigue development during preseasonal friendly soccer matches: a team study

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ABSTRACT

We examined the influence of competitive standard of the opponent on activity profile and fatigue during preseason friendly soccer matches. Time motion analysis was performed in a male professional soccer team ($N = 14$) during six friendly games played against professional, semi-professional and amateur-level opponents (PL, SPL and AL). The reference team covered higher acceleration distance, acceleration and deceleration $> 2 \text{ m} \cdot \text{s}^{-2}$ distance against PL than AL ($ES = 0.77$ to 0.91). Acceleration and deceleration distance $> 2 \text{ m} \cdot \text{s}^{-2}$ was also higher ($ES = 0.66$ to 0.84) against SPL than AL. Greater decreases in total distance, distance $> 16 \text{ km} \cdot \text{h}^{-1}$ and $> 22 \text{ km} \cdot \text{h}^{-1}$, total acceleration and deceleration, acceleration and deceleration distance $> 2 \text{ m} \cdot \text{s}^{-2}$ ($ES = 0.84$ to 2.20) were also observed during PL compared to AL opponent. Playing against a stronger opponent seems to be more physically demanding, with special emphasis on events related with change of velocity (accelerations and decelerations). Declines in physical performance appear more evident against a higher opponent.

ARTICLE HISTORY

Received 28 November 2017

Accepted 1 May 2018

KEYWORDS

Physiology; accelerations; performance; monitoring; workload

Introduction

Fatigue has been recently defined as the inability to complete a task that was once achievable within a recent time frame (Halson, 2014). It has been well-documented that high-intensity actions decrease during the course of a soccer match (Fransson, Krstrup, & Mohr, 2016; Mohr, Krstrup, & Bangsbo, 2003; Randers et al., 2010). Fatigue occurs temporarily during a game as well as towards the end of a game, explained by the fact that players' total distance covered, and sprint frequency is

reduced after peak-intensity exercise periods as well as due to accumulated fatigue after 70–75 match minutes (Fransson et al., 2016; Mohr et al., 2003). The onset of fatigue constitutes an important limit affecting players' physical performance, and may influence performance outcomes.

During the soccer preseason, there is an emphasis on the development of physical capacities (Folgado, Duarte, Fernandes, Sampaio, & Haddad, 2014). In addition to specific training modalities (i.e. strength and conditioning training, technical training and tactics) conducted within training sessions, teams use training games to emphasise the multi-dimensional nature of soccer (Bangsbo, 1994; Reilly, 2005). In fact, the use of training games has been suggested for enhancing performance in soccer players due to the relationship between individual time playing and the percentage of improvements in fitness-related parameters (Silva et al., 2011). In this context training games against opponent of various levels also represent a common strategy to enhance match-related performance (Folgado et al., 2014). When examining the competitive standard of the opponent (OS) conflicting results have been presented. For example, elite male soccer players travel either higher total distance or high-intensity speed distance, when playing against higher OS teams during the competitive period (Castellano, Blanco-Villasenor, & Alvarez, 2011; Rampinini, Coutts, Castagna, Sassi, & Impellizzeri, 2007) and during the preseason (Folgado et al., 2014). Similar observations have been made in elite female players (Andersson, Randers, Heiner-Moller, Krstrup, & Mohr, 2010; Mohr, Krstrup, Andersson, Kirkendal, & Bangsbo, 2008). On the other hand, Hewitt, Norton, and Lyons (2014) found a greater distance covered at high-intensity speed against a similar-level opponent, than against a higher – or lower-level opponent in a national female team during official friendly matches. However, Lago-Peñas and Lago-Ballesteros (2011) demonstrated similar physical outcomes at high-intensity speed, observing a shorter distance travelled against high-level teams only at walking and jogging in professional male players. Taken together, these findings have not provided a clear indication of the influence of OS on the running output of players in friendly soccer matches.

In this context, it is also important to detach that profiling match activity based only on distance covered in different velocity zones has been found to underestimate the real workload imposed on the players' energetic system associated to accelerations and decelerations (Akenhead, Hayes, Thompson, & French, 2013; Delaney, Cummins, Thornton, & Duthie, 2017). The acceleration and deceleration movements have a pronounced impact on both energetic and neuromuscular systems (Akenhead, French, Thompson, & Hayes, 2015; Rebelo, Silva, Rago, Barreira, & Krstrup, 2016), possibly affecting the transient of fatigue during a match. Indeed, recent research suggests that match-related fatigue also affects the frequency of changes in velocity, showing a decline in accelerations and decelerations during the course of a soccer match (Akenhead et al., 2013; Russell et al., 2016). As far as we know, no study has investigated the influence of the OS on fatigue development (e.g. drop in high intensity actions throughout the match) during preseason friendly soccer matches. In this context, whereas the influence of OS has been investigated in terms of speed demands and tactical aspects, no research has incorporated either acceleration analysis or fatigue. Thus, it would be of interest to clarify whether these physical variables are affected by the OS.

Information about the potential influence of OS may assist coaches and strength and conditioning professionals dealing with training prescription in men's elite soccer. Moreover, a detailed analysis of the external load imposed by a given opponent, specifically in respect of fatigue development, may inform decision making in pre-season programming (e.g. better understanding into friendly match' physical demands). Given the above, the aim of this study was to analyse the influence of the OS on time-motion demands and fatigue development during a friendly match in a soccer team. Thus, we considered different external load indicators, paying special attention to change-of-velocity efforts. We hypothesise that playing against a higher OS imposes greater physical demands than lower standard, resulting in greater distance covered at high-intensity speed, acceleration and deceleration requirements.

Methods and materials

Participants

Twenty-five players from the same team were monitored throughout the preseason period. In the present research, only players completing at least one half over two matches against each OS were considered for analysis. Finally, the present study involved fourteen male professional soccer players (five defenders, six midfielders and three attackers (mean \pm SD: 27.6 \pm 3.5 years old, body mass 76.8 \pm 7.6 kg, height 179.5 \pm 5.6 cm) from a professional team competing in the second tier (*Serie B ConTe.it*) of the Italian league system. All the subjects had been senior soccer players for 9.6 \pm 3 years. Only injury-free players participating in full training schedules were included. In accordance with the club's policy and medical requirements, all the players underwent medical examinations both at the beginning and during the course of the season. All the subjects were informed of the purpose of the study, and written informed consent was obtained in accordance with the Declaration of Helsinki. The study was approved by the Scientific Committee of the Faculty of Sports, University of Porto.

Experimental design

A mixed-longitudinal design was used to compare (across three sections of one half, 1'-15', 16'-30' and 31'-45') physical variables over 15-min intervals of match play, according to the OS. Data collection took place between July and August 2016 and lasted six weeks. The temporal order of the friendly matches was: "1st week, AL; 2nd week, SPL; 3rd week, AL; 4th week PL; 5th week SPL; and 6th week PL". At least 5-days elapsed between each match. The participants followed their habitual nutrition (Mediterranean diet) according to the team's policies.

Time motion analysis was performed over six different training matches played against opponents at three different competitive levels. The professional level (PL) consisted of two matches played against two different teams competing at national level (*Lega Pro*, the third tier of the Italian league system). The semi-professional level (SPL) consisted of two matches played against two teams competing at inter-regional level (*Serie D*, the fourth tier of the Italian league system). The amateur level consisted of two matches played against two teams competing at district level (*Prima categoria*, the

seventh level of the Italian league system). The system of play used by the reference team was always 1–3–5–1–1, comprising one goalkeeper, three defenders, three central midfielders, two wide midfielders, one attacking midfielder and one striker. Given the fact that substitutions occur during training matches, we took into consideration only players who completed 45 min (Folgado et al., 2014). The second half was considered only if a player had not been employed during the first half, ensuring freshness, and removing the effect of previous fatigue, induced during the first half. In other words, if only the second half was played, the player was included for analysis. On the other hand, if a player was employed in the first half plus various minutes of the second half, then only the first half was considered. During the half in which data were collected, no player was substituted. At least five days elapsed between training matches, and they were played at the same time of day (17.00) with a temperature ranging between 20 and 25°C and relative humidity ranging between 70 and 80%. The same official balls (EvoPower 2.1 Match, Puma Herzogenaurach, Germany) were used in all matches. During rest periods, players were allowed to drink fluids.

Time-motion analysis

The players' movement pattern during each game was obtained using unobtrusive portable global positioning system (GPS) units (GPSports SPI Pro-X, Canberra, Australia; 6 g tri-axial accelerometer sampling at 100 Hz integrated; size = 48 x 20 x 87 mm; mass = 76 g). Based on signals from at least three Earth-orbiting satellites, the GPS receiver recorded the players' positional data (x-and y-) with a time resolution of 15 Hz (obtained through linear interpolation of a 5-Hz signal). A particular vest was tightly fitted to each player to place the receiver between the scapulae. This type of system has previously been shown to provide valid and reliable estimates of instantaneous velocity during soccer-specific activities (standard error of estimates ranging from 1 to 7%) (Coutts & Duffield, 2010; Gaudino et al., 2014). According to the drill duration, total distance covered and high-intensity running were processed using Manufacturer software (Team AMS, GPSports SPI Pro X, Canberra, Australia) and then exported to a custom Excel spreadsheet from split data of time, speed and distance available from the SPI Pro-X Software Team AMS (GPSports SPI Pro-X, Canberra, Australia).

Speed categories were defined as: intermediate-speed running (IS; from 16 to 19 km·h⁻¹); high-speed running (HS; from 19 to 22 km·h⁻¹); very-high speed running (VHS; > 22 km·h⁻¹); intense acceleration distance (> 2 m·s⁻²); and intense deceleration distance (> 2 m·s⁻²). In addition, total distance covered (TD), total high-intensity running (HIR, given by the sum of IS, HS and VHS), total acceleration running (Acc_{tot}) and total deceleration running (Dec_{tot}) were considered.

Statistical analyses

All data were reported as Mean ± SD for each variable. Mean slopes were calculated to describe tendency of physical parameters across three stages of the game (1'–15', 16'–30', 31'–45') and then enable to quantify the degree of fatigue. Subsequently, differences in overall match physical demands and declines in physical performance among OS were analysed using magnitude-based inferences (Hopkins, Marshall, Batterham, & Hanin, 2009).

Between-treatment effect sizes with 90% confidence intervals were calculated using pooled standard deviations. Threshold values for effect sizes were < 0.2 (trivial), 0.2–0.6 (small), 0.6–1.2 (moderate), and 1.2 – 2 (large) and > 2 (very large). Probabilities were calculated to assess whether true effects obtained represented substantial differences (Batterham & Hopkins, 2006). The smallest standardized difference for each variable was considered to be 0.2 multiplied by the between-subject standard deviation value, based on Cohen's effect size principle. Quantitative probabilities of higher or lower differences were evaluated qualitatively as: < 1% = almost certainly not, 1–5% = very unlikely, 5–25% = unlikely, 25–75% = possible, 75–95% = likely, 95–99% = very likely, > 99% almost certain (Hopkins, 2002). If the probabilities of the effect being higher or lower than the smallest worthwhile difference were simultaneously > 5%, the effect was deemed unclear. Otherwise, the effect was clear and reported as the magnitude of the observed value. Data analysis was performed using a customized Excel spreadsheet (Hopkins, 2007).

Results

Descriptive statistics of the total 45-min, including the magnitude of fatigue according to various opponent' standard is reported in Table 1. In addition, descriptive statistics of physical data across the three stages across the match is provided in Table 2. The magnitude of the differences in match activity and fatigue between OS strength is provided in Figure 1.

The reference time covered higher TD and IS when playing against PL or SPL, compared to AL (ES ranging from 0.79 to 1.88). Distance covered by Acc_{tot}, intense accelerations and intense decelerations were possibly to likely higher during PL matches

Table 1. Descriptive values of total 45' according to various opponent' standard. Data are reported as Mean ± SD.

	Professional level	Semi-professional level	Amateur level
<i>Total match (m)</i>			
TD	5359 ± 396	5298 ± 535	4980 ± 194
IS	463 ± 64	435 ± 70	336 ± 93
HS	218 ± 84	219 ± 84	202 ± 54
VHS	159 ± 53	157 ± 43	154 ± 36
HIR	822 ± 234	809 ± 260	719 ± 212
Acc> 2 m·s ⁻²	357 ± 48	331 ± 52	316 ± 67
Dec<-2 m·s ⁻²	340 ± 58	327 ± 54	305 ± 66
Acc _{tot}	2669 ± 207	2619 ± 313	2463 ± 110
Dec _{tot}	2662 ± 185	2620 ± 274	2448 ± 91
<i>Fatigue (%)</i>			
Δ TD	-76.7 ± 33.1	-82.3 ± 40.4	-49.9 ± 21.3
Δ IS	-25.9 ± 9.1	-24.6 ± 6.4	-21.1 ± 11.5
Δ HS	-21.5 ± 4.5	-12.0 ± 8.8	-6.0 ± 3.6
Δ VHS	-12.3 ± 3.7	-3.6 ± 1.7	-4.7 ± 2.2
Δ HIR	-47.5 ± 8.4	-30.2 ± 21.5	-25.5 ± 5.4
Δ Acc> 2 m·s ⁻²	-27.4 ± 7.7	-20.5 ± 6.4	-17.6 ± 6.3
Δ Dec<-2 m·s ⁻²	-21.9 ± 7.9	-18.9 ± 8.0	-15.2 ± 5.4
Δ Acc _{tot}	-38.4 ± 23.7	-39.2 ± 8.0	-19.2 ± 15.5
Δ Dec _{tot}	-32.5 ± 24.4	-38.0 ± 18.9	-17.1 ± 9.3

TD = total distance covered, IS = intermediate speed distance (16 – 19 km·h⁻¹), HS = High speed distance (19 – 22 km·h⁻¹), VHS = very-high speed distance (> 22 km·h⁻¹), HIR = total high-intensity distance, Acc> 2 m·s⁻² = distance above 2 m·s⁻², Dec<-2 m·s⁻² = distance below -2 m·s⁻², Acc_{tot} = total acceleration distance, Dec_{tot} = total deceleration distance, Δ = Mean slope.

Table 2. Descriptive values of the three stages across the match. Data are reported as Mean \pm SD.

	Professional level				Semi-professional level				Amateur level			
	1' – 15'	16' – 30'	31' – 45'	1' – 15'	16' – 30'	31' – 45'	1' – 15'	16' – 30'	1' – 15'	16' – 30'	31' – 45'	1' – 15'
TD (m)	1838 \pm 155	1798 \pm 146	1722 \pm 150	1879 \pm 152	1744 \pm 216	1675 \pm 219	1650 \pm 80	1762 \pm 78	1650 \pm 80	1762 \pm 78	1567 \pm 97	1650 \pm 80
IS (m)	142.6 \pm 46.4	121.5 \pm 33.7	94.1 \pm 22.6	163.3 \pm 46.2	120.8 \pm 32.5	106.2 \pm 19.8	159.2 \pm 36.5	136.6 \pm 32.0	159.2 \pm 36.5	136.6 \pm 32.0	120.4 \pm 28.0	159.2 \pm 36.5
HS (m)	91.8 \pm 37.3	60.5 \pm 13.7	50.4 \pm 14.8	85.9 \pm 22.0	66.3 \pm 31.8	63.6 \pm 20.6	73.9 \pm 22.7	65.3 \pm 24.0	73.9 \pm 22.7	65.3 \pm 24.0	67.0 \pm 29.4	73.9 \pm 22.7
VHS (m)	61.3 \pm 13.5	52.7 \pm 24.9	35.9 \pm 21.1	53.1 \pm 18.6	49.4 \pm 21.1	46.7 \pm 21.3	56.7 \pm 15.8	45.1 \pm 15.1	56.7 \pm 15.8	45.1 \pm 15.1	47.0 \pm 20.7	56.7 \pm 15.8
HIR (m)	333.8 \pm 111.3	251.2 \pm 81.0	237.9 \pm 69.8	305.9 \pm 102.1	255.7 \pm 83.2	247.6 \pm 105.8	267.0 \pm 94.2	232.4 \pm 60.0	267.0 \pm 94.2	232.4 \pm 60.0	220.4 \pm 70.6	267.0 \pm 94.2
Acc > 2 m·s ⁻²	142.7 \pm 18.0	127.9 \pm 22.4	87.9 \pm 14.5	125.2 \pm 27.4	115.0 \pm 19.6	94.2 \pm 16.5	121.7 \pm 26.0	106.8 \pm 21.6	121.7 \pm 26.0	106.8 \pm 21.6	86.5 \pm 24.6	121.7 \pm 26.0
Dec < -2 m·s ⁻²	130.1 \pm 23.1	125.3 \pm 26.0	89.7 \pm 18.1	121.9 \pm 28.3	115.2 \pm 23.7	93.4 \pm 20.7	116.5 \pm 22.8	101.3 \pm 22.5	116.5 \pm 22.8	101.3 \pm 22.5	86.0 \pm 24.6	116.5 \pm 22.8
Acc _{tot}	902.3 \pm 78.5	897.4 \pm 79.4	869.6 \pm 87.8	918.9 \pm 84.4	863.4 \pm 132.9	837.1 \pm 132.2	799.1 \pm 51.7	883.7 \pm 52.1	799.1 \pm 51.7	883.7 \pm 52.1	781.0 \pm 56.0	799.1 \pm 51.7
Dec _{tot}	904.9 \pm 80.4	890.5 \pm 68.9	867.5 \pm 85.0	927.7 \pm 85.8	851.1 \pm 112.9	841.2 \pm 127.4	804.6 \pm 45.7	866.2 \pm 36.7	804.6 \pm 45.7	866.2 \pm 36.7	777.6 \pm 48.0	804.6 \pm 45.7

TD = total distance covered, ISR = intermediate speed distance (16 – 19 km·h⁻¹), HS = High speed distance (19 – 22 km·h⁻¹), VHS = very-high speed distance (> 22 km·h⁻¹), HIR = total high-intensity distance, Acc > 2 = distance above 2 m·s⁻², Dec < -2 = distance below -2 m·s⁻², Acc_{tot} = total acceleration distance, Dec_{tot} = total deceleration distance.

Legend.

TD = total distance covered, IS = intermediate speed distance (16 – 19 km·h⁻¹), HS = High speed distance (19 – 22 km·h⁻¹), VHS = very-high speed distance (> 22 km·h⁻¹), HIR = total high-intensity distance, Acc > 2 = distance above 2 m·s⁻², Dec < -2 = distance below -2 m·s⁻², Acc_{tot} = total acceleration distance, Dec_{tot} = total deceleration distance.

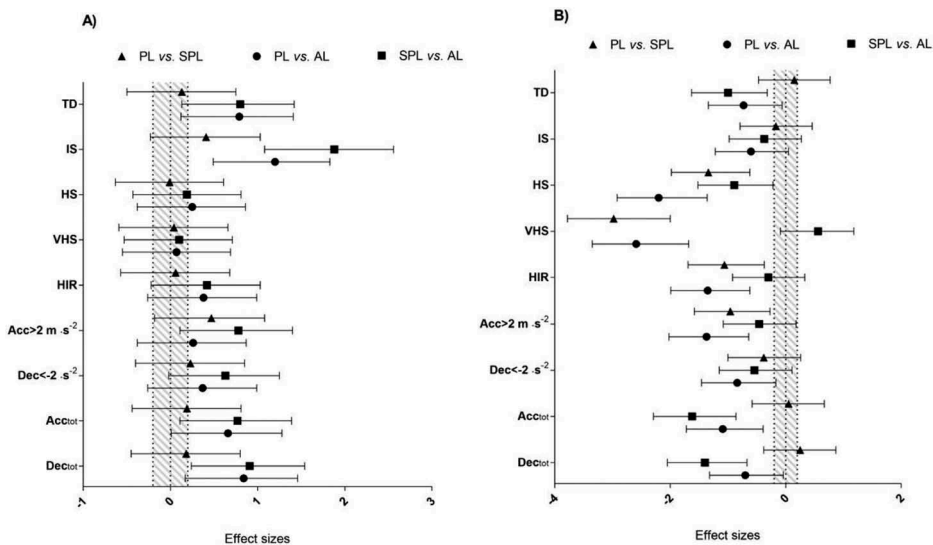


Figure 1. Differences in physical demands (A, overall match activities and B, decreases in physical performance) among opponent' standard.

TD = total distance covered, IS = intermediate speed distance ($16 - 19 \text{ km} \cdot \text{h}^{-1}$), HS = High speed distance ($19 - 22 \text{ km} \cdot \text{h}^{-1}$), VHS = very-high speed distance ($> 22 \text{ km} \cdot \text{h}^{-1}$), HIR = total high-intensity distance, $\text{Acc} > 2 =$ distance above $2 \text{ m} \cdot \text{s}^{-2}$, $\text{Dec} < -2 =$ distance below $-2 \text{ m} \cdot \text{s}^{-2}$. Acc_{tot} = total acceleration distance, Dec_{tot} = total deceleration distance.

compared to AL matches (ES ranging from 0.77 to 0.91). Distance covered by intense acceleration and intense deceleration was also higher (ES ranging from 0.66 to 0.84) during SPL matches compared to AL matches.

The reference team showed greater declines in physical performance during PL matches compared to AL matches, with moderate to very large differences in the decrease of TD, distance covered by HS, VHS, HIR, intense acceleration, intense deceleration, total acceleration and total deceleration (ES ranging from 0.84 to 2.20). When comparing SPL to AL, moderate to large differences were observed only in TD, HS, total acceleration and total deceleration distance (ES ranging from 0.89 to 1.62).

Discussion

In this pilot analysis, match activities and fatigue development according to the opponents' competitive standard across the preseason friendly matches have been analyzed. Playing against a PL or SPL opponent seems require greater accelerations and decelerations efforts and consequently muscular work, rather than maintaining high speed, compared to AL. In addition, declines in physical performance over time appear more devious when playing against a PL or SPL opponent, indicating greater declines in physical performance.

When examining isolated high-intensity running volume ($> 16 \text{ km} \cdot \text{h}^{-1}$), our findings appear to contradict previous research in which speed demands increased with competitive level (Aquino, Martins, Vieira, & Menezes, 2016; Castellano et al., 2011; Folgado et al., 2014; Rampinini et al., 2007). However, when considering speed thresholds, we

found IS distance greater during PL and SPL matches compared to AL matches. Nonetheless, no substantial differences were found in distance covered at HS and VHS. With reference to our contradictory findings in speed analysis, it might be speculated that speed demands obtained playing lower-level opponents, although similar, do not reflect the real physical demands of the game, which is characterized by frequent changes in speeds (Akenhead et al., 2013; Varley & Aughey, 2013).

To the best of our knowledge, no previous research had analysed acceleration and deceleration demands according to opponent level. Our study revealed higher acceleration ($> 2 \text{ m} \cdot \text{s}^{-2}$) and deceleration ($< -2 \text{ m} \cdot \text{s}^{-2}$) is demanded when competing with PL or SPL compared to AL. Specifically, distance covered by total acceleration and deceleration running as well as maximum acceleration and deceleration was greater when the reference team played PL than AL. It might be speculated that competing with a PL or SPL opponent would result in higher running intensities, in particular a greater demand on changes in speed events. However, further research should incorporate internal load measures such (e.g. heart rate and perceived exertion) to better clarify these findings.

Additional factors such as playing position or opponent's team tactics may also influence the movement patterns of the reference team (Lago-Peñas, Casais, Dominguez, & Sampaio, 2010; Lago-Peñas & Lago-Ballesteros, 2011). In fact, when player density is increased, the space available for running is decreased (Hewitt et al., 2014). Notwithstanding, increasing player density may solicit higher accelerations/decelerations movements since players are confronted with less time to decide and perform actions (less free space available). Some caution is needed in generalizing these findings, given our reduced sample size and number of events (6 matches). This is particularly relevant given the high match-to-match variability in physical performance (Gregson, Drust, Atkinson, & Salvo, 2010; Hewitt et al., 2014) and the caution needed when interpreting GPS-derived acceleration data (Buchheit et al., 2014). In addition, our small effect sizes obtained by the influence of opponent level on the transient of fatigue necessitate further studies to reinforce our findings.

The reference team showed moderate differences in HIR and VHS over time against PL teams. This is supported by Mohr et al. (2003), showing that fatigue affects the frequency of high-intensity bursts towards the end of a match in professional soccer players. The physiological mechanism of fatigue linked to a decline in physical performance has been well documented. Slumps in physical performance are due to the accumulation of extracellular potassium and electrical disorders within the muscular cells, followed by a glycogen depletion of type I and IIa muscle fibres as well as hyperthermia occurring during the game (Mohr, Krstrup, & Bangsbo, 2005). It is a matter of fact that glycogen depletion plays one of the most important roles in the onset of fatigue (Krstrup et al., 2006). In addition, the development of fatigue during a game appears to be related to low phosphocreatine concentrations (Bangsbo, Mohr, & Krstrup, 2006). Our observed interaction between differences over time and opponent level provided further evidence regarding variables affecting the transient of fatigue during the course of a match. Indeed, playing PL opponents resulted in a greater decline in high-intensity running.

We are aware that decreases in acceleration and deceleration over time have been analysed in official matches irrespective of opponent level. Indeed, our study accords with previous studies that observed a significant decline in accelerations and decelerations over match duration (Akenhead et al., 2013; Russell et al., 2016). From a

physiological perspective, a reduction in players' ability to perform maximum accelerations may be explained by an impaired hamstrings and quadriceps peak torques production during and/or after the match (Rahnama, Reilly, Lees, & Graham-Smith, 2003; Silva et al., 2017; Small, McNaughton, Greig, & Lovell, 2010). It has also been suggested that a reduction in players' ability to accelerate may consequently increase the distance they have to cover before a specific speed is reached (Akenhead et al., 2013). Whereas no significant time per opponent level interaction was found in decrements in accelerations, the transient of fatigue related to maximum deceleration was found to be affected by the opponent. The greater acceleration and deceleration intensity observed during matches against PL or SPL resulted in a larger decrease in running output.

Although our findings show differences in transient of fatigue between opponent levels, the mechanisms of match-related fatigue are multidimensional. Match-play results in acute systemic alterations in metabolic, biochemical, physical performance, technical and perceptual markers (Silva et al., 2017). Particularly, compromised fiber-specific muscle glycogen level (Krustrup et al., 2006), dehydration, reduced blood glucose level (Bangsbo et al., 2006), reduced force development (Rahnama et al., 2003), postural balance (Brito et al., 2012) and increased perceptual responses (Nédélec et al., 2013) have been documented previously. Possibilities therefore exist to develop interventions to avoid decrements in acceleration and deceleration capacity throughout the full duration of a match (Russell et al., 2016). For instance, improving sprinting technique and concentric or eccentric strength, as well as developing small-sided games focusing on acceleration/deceleration demands to may improve the player's ability to perform these specific actions.

The main limitation of the present study is the reduced sample size and number of events, and therefore, it is not possible to generalize our findings. Consequently, it was not possible to categorize by playing position. Furthermore, changes in physical performance throughout the preseason were not accounted for. Recent reports by Folgado, Gonçalves, and Sampaio (2018) revealed improved players synchronization toward the end of the preseason during 8v8 small-sided games, possibly indicating reduced distance covered. Another concern is the fact that playing against a higher OS would induce higher motivation and thus various psychological factors may have affected our outcomes. In this context, future research may investigate match activities and fatigue by different OS and over a wide range of confounding variables potentially influencing declines in physical performance, such as playing position and various contextual factors.

These pilot findings support and supplement previously published data describing the transient changes in acceleration and deceleration observed (Russell et al., 2016; Akenhead, Harley, & Tweddle, 2016). Future studies should integrate analysis of the physiological strain (i.e. heart rate and blood lactate) associated with changes of speed. Moreover, further research examining the OS-induced intensity on injury risk is warranted, to carefully programming pre-seasonal friendly matches.

Practical applications

Playing against a professional-level opponent seems to require greater capacity to frequently change velocity rather than to maintain high velocities, compared to amateur. Whereas these differences were not evident (small effect sizes) between playing against

professional level opponent and semi-professional level opponent, they were amplified between professional and amateur level' opponent. In addition, signs of fatigue appear to be more remarkable on the frequency of high-intensity bursts when the reference team played against a higher-level opponent, observing greater declines in physical performance. Such data may be considered to inform training programme design and to provide further insight into the physical response of soccer players. Although soccer players should keep training during the transition period in order to better cope with the physical demands of the preseason (Silva, Brito, Akenhead, & Nassis, 2015), choice of opponent should be given special attention in order to obtain sufficient training stimulus during training matches. We would suggest choosing a PL or SPL opponent if the aim of the training matches is to highly stress the neuromuscular system, given the greater acceleration and deceleration demands compared to playing against a AL. Moreover, playing a higher-level opponent may be preferable for improving ability to manage acceleration- or deceleration-induced fatigue. Yet, incorporating training sessions that emphasise acceleration and deceleration would be suggested as this appears to differentiate the running intensity required when playing against opponents of different levels.

Acknowledgments

The authors would like to thank all the players for their participation in this study and the technical staff for their valuable assistance

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the Fundação para a Ciência e a Tecnologia [SFRH/BD/129324/2017];

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The *Arrowhead* agility test: reliability, minimum detectable change and practical applications in soccer players

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2019

Journal of Strength and Conditioning Research, ahead of print

DOI: 10.1519/JSC.0000000000002987

Keywords: Fitness; Performance; Testing; Fatigue; Assessment

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THE ARROWHEAD AGILITY TEST: RELIABILITY, MINIMUM DETECTABLE CHANGE, AND PRACTICAL APPLICATIONS IN SOCCER PLAYERS

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ABSTRACT

Rago, V, Brito, J, Figueiredo, P, Ermidis, G, Barreira, D, and Rebelo, A. The arrowhead agility test: Reliability, minimum detectable change, and practical applications in soccer players. *J Strength Cond Res* XX(X): 000–000, 2019—Four independent studies were conducted to examine the utility of the arrowhead agility test (AAT) to measure change of direction (COD) capacity in soccer players, specifically, (a) intersession reliability and minimum detectable change ($n = 24$); (b) power-dependent abilities associated with AAT performance ($n = 56$); and (c) fatigue sensitivity ($n = 20$); differences between competitive levels and age groups ($n = 264$). Irrespective of the AAT outcome measure (skillful side, less-skillful side, sum of both), intersession reliability and the ability to detect changes in performance were good (ICC = 0.80–0.83; CV = 1.25–2.21%; smallest worthwhile change, 0.06–0.12 > SEM, 0.01–0.03) except for the asymmetry index. A 15-m sprint explained a significant amount of variance in COD ($p < 0.01$; $R^2 = 0.42$). Arrowhead agility test performance did not change from the prematch toward half time ($p = 0.21$). However, reduced COD performance was observed after an intense period in the second half and after the game, compared with prematch and half-time performance ($p < 0.05$; effect size [ES] = –0.85 to 0.42). Irrespective of age group, national players were more agile than regional players ($p < 0.05$; ES = –1.97 to –0.36). Moreover, independently of their competitive level, senior and U18 players had a better performance than U16 ($p < 0.05$; ES = –2.33 to –0.84), whereas no significant differences were observed between senior and U18. Percentiles

were also reported in the results. The AAT is reliable to measure COD in soccer players. The test may simultaneously encompass 15-m sprint testing but should be implemented independently to countermovement jump. Furthermore, the test is sensitive to match-induced fatigue during the second half and discriminates players from different competitive levels.

KEY WORDS fitness, performance, testing, fatigue, assessment

INTRODUCTION

Agility has been commonly designated as the ability of changing direction (COD), and, in soccer, it is considered an essential functional capacity (12,37). Indeed, a soccer player changes direction every 2–4 seconds during a game, completing ~700 changes of direction, turns, and swerves at different angles (2). Therefore, the players need to be capable of changing direction, often in confined spaces, to perform proficiently. The assessment of COD involves preplanned movements (lack of external stimulus), and therefore, in this research, agility was defined as the capacity to quickly (lowest time indicates higher performance) and effectively (within confined spaces) change direction in a closed-skill condition.

Over the last years, various COD tests have been used to assess soccer players, such as the Illinois agility test (16), the original or modified T-test (36,39), the 505 test (9), the Zigzag test (10), and the Slalom test (41). However, the ecological validity of these tests might be questioned in relation to the specific physical demands of soccer. Most of them consist of one path with given motor tasks sequence and associated turning direction order. Consequently, COD performance could be affected by specific test layout, rather than the actual player capacity. Recent studies on young soccer players have included the

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Journal of Strength and Conditioning Research
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arrowhead agility test (AAT (40)) as part of physical fitness evaluations (6,7,29). Although this test uses a closed-skill preplanned movements, its layout has been specifically designed for soccer players (40). The AAT is divided into 2 trials (1 repetition to the right and 1 to the left directions), possibly reducing either the effect of any individual strength asymmetry, or unilateral muscular fatigue induced by the motor tasks order within the test itself. In this context, it would be also of interest to evaluate the players' functional asymmetries, through existent approaches that have been previously adopted to detect asymmetries in vertical jump tests (22).

Given the well-established importance of fitness testing in soccer (25), and the inexistence of a single gold standard agility test for use in the assessment of soccer players, it is difficult to compare results between tests because different tests may examine different factors associated with this capacity (42). Thus, it is not surprising that a strong interest exists toward the development and validation of field-based agility tests to allow researchers and practitioners to accurately profile their players (in relation to the physical demands of the specific sport modality). Standardized tests such as sprint or jump tests conducted in isolation may not encompass various physical soccer-specific skills. Thus, a COD test should be integrated into power-based evaluations if a comprehensive evaluation of an individual functional capacity is required (42). Indeed, an important aspect of fitness testing is to understand whether a given capacity is dependent on other capacities. Given the implicit demands of the AAT, emphasizing the ability to change direction, to accelerate, and to sprint, it could be hypothesized that power-based capacities such as sprint and countermovement jump (CMJ) are suspected to be linked to COD capacity. For instance, recent observations on young players revealed that COD, sprint, and CMJ height are interdependent, potentially measuring some overlapping attributes (28). Therefore, understanding the potential association between COD, sprint, and vertical jump would be useful for clarifying which physical attributes each of these tests measures. It would be also of interest to examine whether, and to what extent, COD capacity is impaired after an intense exercise period during a game, as well as whether COD differs by competitive standards and age groups.

The primary aim of this research was to investigate the utility of the AAT by examining its (a) reliability and minimal detectable change (MDC), (b) association with power-dependent abilities, (c) fatigue sensitivity, and (d) capacity to discriminate competitive standards and age groups of the AAT, as well as to provide an insight into its descriptive values. It was hypothesized that the AAT (a) would be reliable, (b) would be associated with other power-dependent abilities, (c) would detect changes in performance after the game, and (d) would discriminate age groups and competitive levels.

METHODS

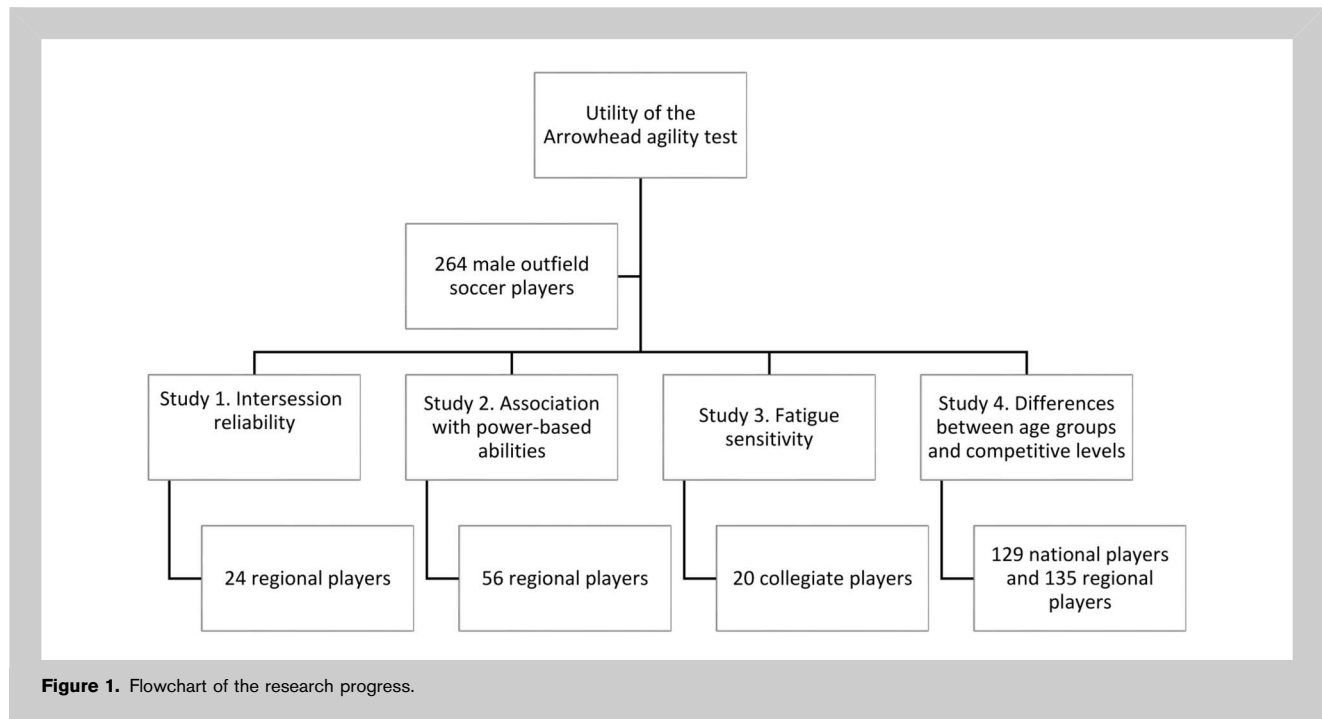
Experimental Approach to the Problem

Four independent analyses were conducted, as reported in the flowchart (Figure 1). In study 1, the degree to which individuals maintained their performance with repeated measurements was determined. In study 2, the degree to which COD (assessed through the AAT) could be associated with other power-dependent capacities was analyzed by the correlations with CMJ height and CMJ peak power, and 5- and 15-m sprint time. In study 3, AAT, CMJ, and 5-m sprint testing were performed before, throughout, and after a 90-minute friendly game to determine whether match-induced fatigue affected AAT, jump, and sprint performance. In study 4, all participants were categorized according to their age group and competitive level. The participants were instructed to maintain their normal dietary habits in the 2 days before testing. Tests were always completed at least 48 hours after the match and after 1 to 2 days of tapering. In all studies, assessments were conducted on third-generation artificial turf surface, wearing soccer boots, and after a standardized warm-up that included jogging, dynamic stretching, 2 submaximal sprints, and 2 submaximal test trials. Physical tests were completed within 10 minutes after the warm-up. Data collections were preceded by a 72-hour tapering period and occurred during the first month of the competitive period of 2017–18 season.

Subjects

Three subgroups from a sample of 264 adult and youth male soccer players were evaluated. Height, weight, measurements, and age of subjects are provided in Table 3. Players were categorized by their competitive level as national and regional, and by their age group as adults ≥ 18 years, U18 (16.1–17.9 years) and U16 (14.1–15.9 years). National-level players participated in the Portuguese third championship and in the Greek second league. Regional-level players played in the Italian fourth league, Portuguese fourth league, and Greek third league. Adult players and parents/legal guardians of youth players were fully informed about the experimental procedures and possible discomforts associated with the study before giving their written informed consent to participate. The ethical board of the Faculty of Sports, University of Porto, approved the study (CEFADE.08.2018).

Study 1: Reliability. Intersession reliability of the AAT was determined in a group of 24 male outfield soccer players (age, height, body mass, and weekly training volume [training sessions and independent weight training]: 24.5 ± 4.8 years, 1.79 ± 0.06 m, 73.5 ± 7.2 kg, and 10.2 ± 2.2 hours, respectively) competing in the Portuguese fourth league. Sample size was determined using GPower for Windows (University of Dusseldorf, Germany) based on previous research (16). Twelve subjects were needed to yield a statistical power of 0.80. After a 1-week familiarization with the testing procedures, all subjects were tested within a 1-week



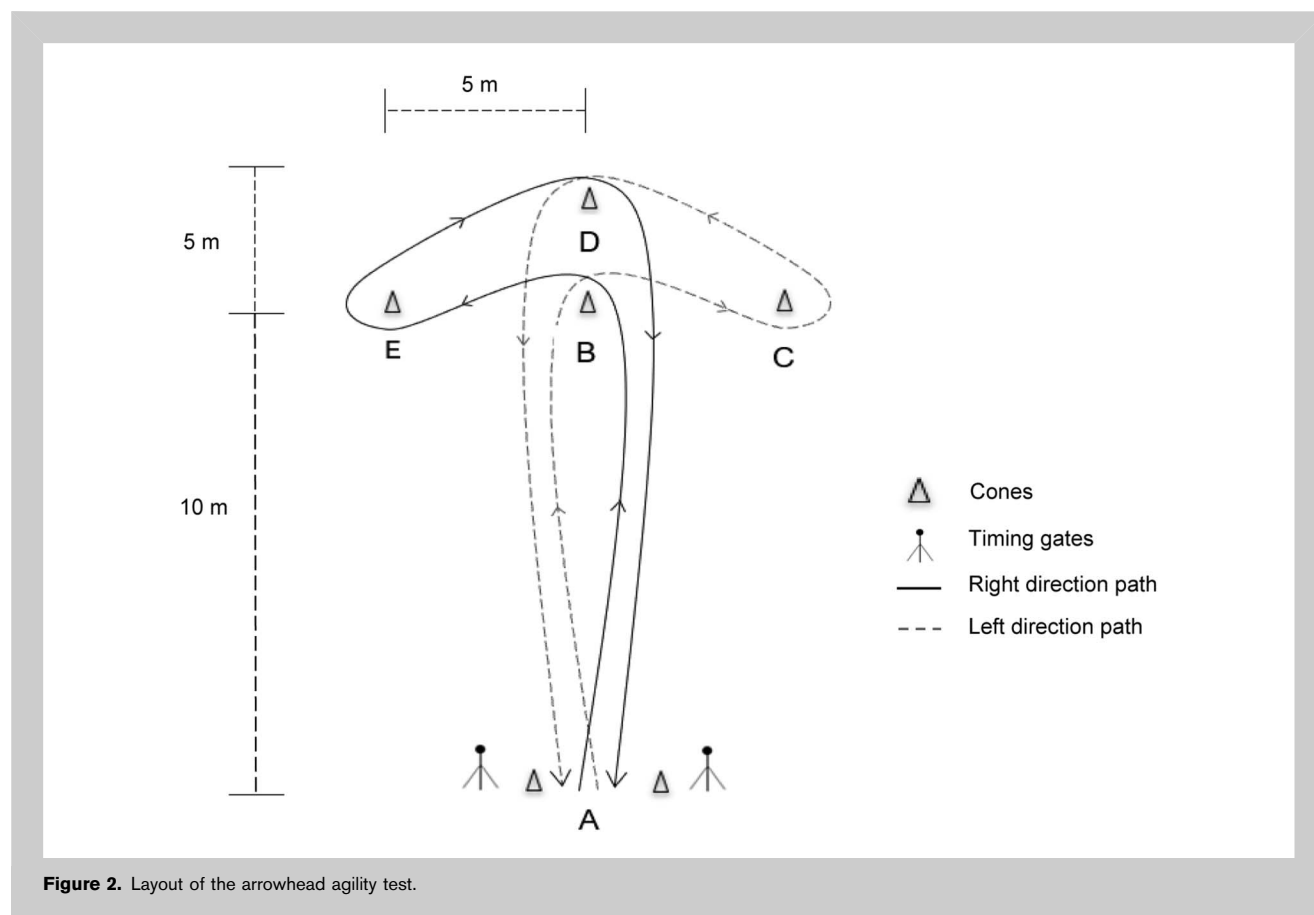
period. The AAT retest was conducted within 3 days (at least 48 hrs separating the trials), to examine the intersession reliability. In this analysis, AAT outcomes included the time for the skillful (lowest time between sides) and the less-skillful side (highest time between sides), and the sum of both sides' times (overall COD performance). In addition, asymmetry index (ASI, percentage of difference between sides) was quantified as the percentage of difference between the skillful side and the less-skillful side as suggested by Impellizzeri et al. (22) for a single-leg CMJ as $[(\text{skillful side}/\text{less-skillful side})/(\text{skillful side})] \times 100$.

Study 2: Associations With Other Power-Dependent Capacities. A group of 56 male outfield soccer players (age, height, body mass, and weekly training volume: 21.9 ± 4.8 years, 1.77 ± 0.07 m and 71.2 ± 7.4 kg, 9.1 ± 3.7 years, respectively) competing at regional level were tested on 2 separate occasions within a week. Testing included CMJ, 5- and 15-m sprint, and AAT (sum of both sides). Countermovement jump, and 5- and 15-m sprint times were modeled as predictors of AAT performance, attempting to explain whether jump performance, accelerations, and sprint ability predict AAT performance.

Study 3: Fatigue Sensitivity. The sensitivity of the AAT test to match-induced fatigue was examined in 20 outfield male collegiate soccer players (age, height, and body mass: 21.2 ± 3.3 years, 1.77 ± 0.06 m, 72.1 ± 7.6 kg, respectively). Players had 3.2 ± 2.5 training hours per week. Measurements were performed at baseline (previous week), throughout the game after ordinary intense exercise periods ($>90\%$ of maximum

heart rate [HR]) within each half ($n = 13$ during the first half; $n = 13$ during the second half), at half time ($n = 10$), and immediately after the game ($n = 21$). As these players were also tested in study 1, the best trial between test and retest was considered as baseline value. A 5-m sprint was obtained within the AAT itself by placing timing gates at 5 m from the start of the AAT. All outfield players had HR measured throughout the game. Maximum HR (HRmax) was estimated using revised age-predicted HRmax equation (43) to determine high-intensity periods ($\text{HR} > 90\%$ individual HRmax) through real-time HR recordings. When a player maintained a high-intensity period during a window of a minimum of 1 second, he was substituted to undergo fitness tests and replaced. The rating of perceived exertion (RPE) was collected approximately 20 minutes after the end of the game and noted as arbitrary units (AUs). Each team had one substitute, ready to replace the player removed from the game to be tested. Players were asked to momentarily leave the field (approximately 3 minutes) to perform the assessments after high-intensity periods, then returned to the field of play immediately after completing the assessments. Given the reduced number of observations throughout the match for each player (e.g., most players could only be tested on one side), AAT was analyzed irrespectively of the side, and this was considered as the criterion COD measure.

Study 4: Discrimination Between Competitive Standard and Age Groups. In this study, 264 male outfield soccer players were categorized according to their competitive level as national



($n = 129$) and regional ($n = 135$), and according to their age group (adult Mean \pm SD: age, height, and body mass of 24.2 ± 4.8 years, 1.76 ± 0.05 m, and 73.5 ± 7.4 kg, respectively; $n = 149$), U18 (16.8 ± 0.4 years, 1.76 ± 0.05 m, and 68.3 ± 6.7 kg, respectively; $n = 57$) and U16 (15.8 ± 0.4 years, 1.70 ± 0.06 m, and 61.6 ± 9.6 kg, respectively; $n = 58$). The AAT, given by the sum both running directions, was considered as the COD measure to discriminate players between age groups and competitive levels, and to report ranges and percentiles.

Procedures

The Arrowhead Agility Test. The AAT time was measured using timing gates (Microgate Witty, Bolzano, Italy) positioned at the start line, as described elsewhere (6,7,29,40). The timing gate was mounted on tripods set at 1 m above the floor and positioned 3 m apart facing each other on either side of the starting/finishing line. To avoid undue switch-on of the timing gates, the participants positioned the front foot 0.20 m from the gate. When ready, the participants sprinted from the start marker (A) to the middle marker (B), turned to the left (E) or right (C) (depending on the trial) to sprint around the side marker, sprinted around the top marker (D), before sprinting back through the timing gate to finish the test (Figure 2). The participants sprinted

and changed direction maximally throughout the test, stepping around and not over the markers; otherwise, the trial was stopped and reattempted after full recovery (~ 4 minutes). Four trials in total were completed; 2 with movement initiation to the left side, and 2 with movement initiation to the right side. The order was randomized among the participants to avoid any effect of fatigue on the other side. The participants started when ready, thus eliminating reaction time and completed 2 trials separated by at least 3 minutes of rest. The best of 2 trials for each side was retained for all analysis.

Countermovement Jump. Vertical jump performance assessed using an accelerometric device (Myotest SA, Sion, Switzerland). The device (dimensions: $5.4 \times 10.2 \times 11.1$ cm; mass: 58 g) contains a 3D inertial accelerometer (68 g) that allows for vertical acceleration to be recorded at a sampling frequency of 500 Hz. The accelerometry data were stored during the assessments and subsequently downloaded using the proprietary software (Myotest PRO Software version 1.0; Myotest, Sion, Switzerland). The equipment is reliable (coefficient of variation, CV = 3.6%) for measuring CMJ height using the flight-time calculation method (4). Countermovement jump peak power was estimated using Sayers' equation (test-retest correlation = 0.95–0.97) (5,35). The device was

TABLE 1. Reliability and capacity to detect changes of the arrowhead agility test.*

	Mean \pm SD		Reliability		Capacity to detect changes (s)		
	Test	Retest	ICC (95% CIs)	CV (%; 95% CIs)	SEM	SWC	MDC
Agility performance (s)							
Skillful side	8.33 \pm 0.31	8.31 \pm 0.35	0.82 (0.69 to 0.92)	1.75 (1.28 to 2.23)	0.02	0.06	0.30
Less-skillful side	8.43 \pm 0.32	8.46 \pm 0.30	0.80 (0.53 to 0.91)	1.25 (1.25 to 2.20)	0.02	0.06	0.28
Sum of sides	16.76 \pm 0.62	16.80 \pm 0.64	0.83 (0.61 to 0.92)	2.21 (2.21 to 2.78)	0.03	0.12	0.01
Functional asymmetries (%)							
ASI index	1.34 \pm 1.34	1.56 \pm 1.42	-0.43 (-2.37 to 0.39)	67.88 (52.96 to 82.81)	2.49	0.28	6.92

*ICC = intraclass correlation coefficient; CI = confidence intervals; CV = coefficient of variation; SWC = smallest worthwhile change; MDC = minimal detectable change; ASI = asymmetries.

perpendicularly attached to a large (8.5 cm) Velcro elastic belt. The device was positioned at the hip level on the left side of the body, as indicated by the manufacturer. As suggested by Domire and Challis (11), the participants executed the jump bending the knees to a position they experimented to be comfortable (e.g., preferred starting push-off position). To limit possible variations in posture during the jump that may affect the final assessment, the no-arm swing was allowed (24). The best of 3 trials (showing the highest CMJ height and associated peak power) was retained for analysis.

Sprint Testing. Sprint performance was determined by a 15-m sprint test. Three timing gates (Microgate Witty) were positioned at the starting point, at 5 and 15 m. The participants were instructed to run as fast as possible from a standing start 0.3 m behind the start line, and to start when

ready, thus eliminating reaction time. The best of 2 trials, separated by at least 3 minutes of rest, was retained for analyses, and times over 5 and 15 m were recorded.

Match Load. Heart rate was continuously monitored using direct telemetry (Firstbeat Technologies, Jyväskylä, Finland). Heart rate data were analyzed directly in the Firstbeat Uploader software (Firstbeat Technologies). Mean HR values during the game were expressed in absolute values (beats per min). In addition, RPE was collected using a visual analogue scale (VAS) questionnaire (32). The questionnaire comprised 3 items worded to analyze the players' perceptions. The questions were as follows: "Please indicate your global physical effort" (RPE); "Please indicate your cardio-respiratory effort" (RPE_{res}); and "Please indicate your musculoskeletal effort" (RPE_{mus}). The VAS was anchored by 2

TABLE 2. Changes in physical capacities (agility, countermovement jump, and 5-m sprint time) throughout the game.*†

Variables	Baseline	After an intense period in the 1 st half	Half time	After an intense period in the 2 nd half	Postmatch
Agility (s)	8.50 \pm 0.027	8.67 \pm 0.20	8.39 \pm 0.13	8.63 \pm 0.25§	8.67 \pm 0.30‡§
CMJ height (m)	0.37 \pm 0.09	0.43 \pm 0.03‡	0.39 \pm 0.05	0.42 \pm 0.05§	0.39 \pm 0.04
CMJ peak power (W·kg ⁻¹)	49.8 \pm 3.3	53.1 \pm 1.7‡	49.9 \pm 2.7	52.5 \pm 3.8§	50.1 \pm 3.7
5-m sprint (s)	1.12 \pm 0.07	1.09 \pm 0.06	1.09 \pm 0.07	1.10 \pm 0.08	1.13 \pm 0.04§

*CMJ = countermovement jump.

†Data are reported as mean \pm SD.

‡Denotes significant differences to baseline, ($p < 0.05$).

§Denotes significant differences to half time, $p < 0.05$.

TABLE 3. Descriptive values of arrowhead agility test performance.

	National-level players (<i>N</i> = 97)			Regional-level players (<i>N</i> = 167)		
	Adults (<i>N</i> = 47)	U18 (<i>N</i> = 30)	U16 (<i>N</i> = 20)	Adults (<i>N</i> = 102)	U18 (<i>N</i> = 27)	U16 (<i>N</i> = 38)
75th (s)	16.82	17.06 s	17.51 s	16.98 s	18.08 s	19.40 s
50th (s)	16.41	16.70 s	17.23 s	16.56 s	17.62 s	18.70 s
25th (s)	15.98	16.05 s	16.70 s	16.17 s	17.05 s	17.98 s
Mean \pm <i>SD</i> (s)	16.42 \pm 0.54	16.48 \pm 0.84	17.21 \pm 0.46	16.62 \pm 0.56	17.46 \pm 1.06	18.52 \pm 0.75
Range (s)	15.46–17.69	14.45–17.85	16.14–17.84	15.53–18.07	14.99–19.18	15.23–20.25

items with a 0.10-m horizontal line connecting them and scored from 0 (not very demanding) to 100 (very demanding) (32). Players had been previously familiarized with RPE procedures.

Statistical Analyses

Descriptive data were reported as mean \pm *SD* for each variable. Shapiro-Wilk test revealed that variables did not follow a normal distribution. Therefore, nonparametric analyses were adopted. Significance was set as $p \leq 0.05$.

Reliability was assessed using ICC (absolute reliability, ICC [2,1], a 2-way random effects model with single measure based on subject's mean), using the criteria suggested by Portney and Watkins (30) for the evaluation of reliability as follows: ≥ 0.75 good, 0.50–0.74 moderate, 0.26–0.50 fair, and $0 \leq 0.25$ poor. In addition, the coefficients of variation (CV) was calculated dividing the within-subject *SD* by the mean and then multiplied by 100. An ICC ≥ 0.75 and a CV $\leq 10\%$ were conventionally suggested sufficient for test-retest reliability. Once CV was calculated, it was qualitatively rated as good ($< 5\%$), moderate (5–10%), and poor ($> 10\%$) (23). Differences between test and retest were quantified using the Wilcoxon nonparametric test. To complement the ICC and CV, Bland-Altman plots were created to provide a representation of the agreement between test and retest (3).

The *SEM* was calculated by dividing the *SD* of the difference score between test and retest by $\sqrt{1 - \text{ICC}}$ (45). The smallest worthwhile change (SWC) was determined to establish the usefulness of the test by multiplying the between-subject *SD* by the standardized effect size (ES) of 0.2 (18,19). If the *SEM* was smaller than the SWC, the ability to detect a change was considered good; if the *SEM* equaled SWC, the test was satisfactory, but if the *SEM* was greater than the SWC, then the test was rated as marginal. The MDC was also calculated as $\text{MDC} = \text{SEM} \times \sqrt{2} \times 1.96$ (17).

The associations between AAT performance and other power-dependent capacities were first assessed using Pearson product moment correlation using the following criteria: ≤ 0.1 (trivial), 0.1–0.3 (small), 0.3–0.5 (moderate), 0.5–0.7 (large),

0.7–0.9 (very large), and ≥ 0.9 (almost perfect). Subsequently, a backward multiple regression model was used to identify the predictors of performance in the AAT. All 5- and 15-m sprint and CMJ were examined as independent variables. The robustness of physical capacities was not compromised by multicollinearity. Tolerance (0.55–0.96) and variance inflation factors (1.03–1.81) were within the normal ranges (> 0.10 and < 10 , respectively) (31). The criteria for selecting variables in the model were $p \leq 0.05$ and $F > 4.16$. Coefficients of determination (R^2) were used to determine the amount of explained variance between physical capacities.

Changes in physical capacities across the 90-minute soccer match were analyzed using Friedman nonparametric test. When a significant effect was found, differences between baseline or half time, and various periods across the game, were quantified using ES according to Hopkins et al. (20): trivial ($\text{ES} < 0.2$), small ($0.2 < \text{ES} < 0.6$), moderate ($0.6 < \text{ES} < 1.2$), large ($1.2 < \text{ES} < 2.0$), very large ($2.0 < \text{ES} < 4.0$), and extremely large ($\text{ES} > 4.0$).

Differences in AAT performance according to different competitive levels were analyzed using Mann-Whitney nonparametric test. When a significant difference was observed for paired comparisons, ES were computed in accordance to the fatigue sensitivity analysis. In addition, ranges 25th, 50th, and 75th percentiles were determined using exploratory data analysis. Data analyses were performed using Statistical package of social science 25 for Windows (IBM, Chicago, USA) and a customized Excel spreadsheet (18).

RESULTS

Reliability

Irrespective of the outcome variable, intersession reliability was good (ICC ranging from 0.80 to 0.83; CV ranging from 1.25 to 2.21%) except for AAT-ASI (ICC [95% CI] = -0.43 [-2.37 to 0.39]; CV [95% CI] = 67.88% [52.96 to 82.81]) (Table 1). Accordingly, irrespective of the outcome type (skillful side, less-skillful side, and sum of sides), the ability of the AAT to detect changes in performance was good (SWC = 0.06–0.12 seconds $>$ *SEM* = 0.02–0.03 seconds) except for asymmetry (SWC = 0.285% $<$ *SEM* = 2.49%).

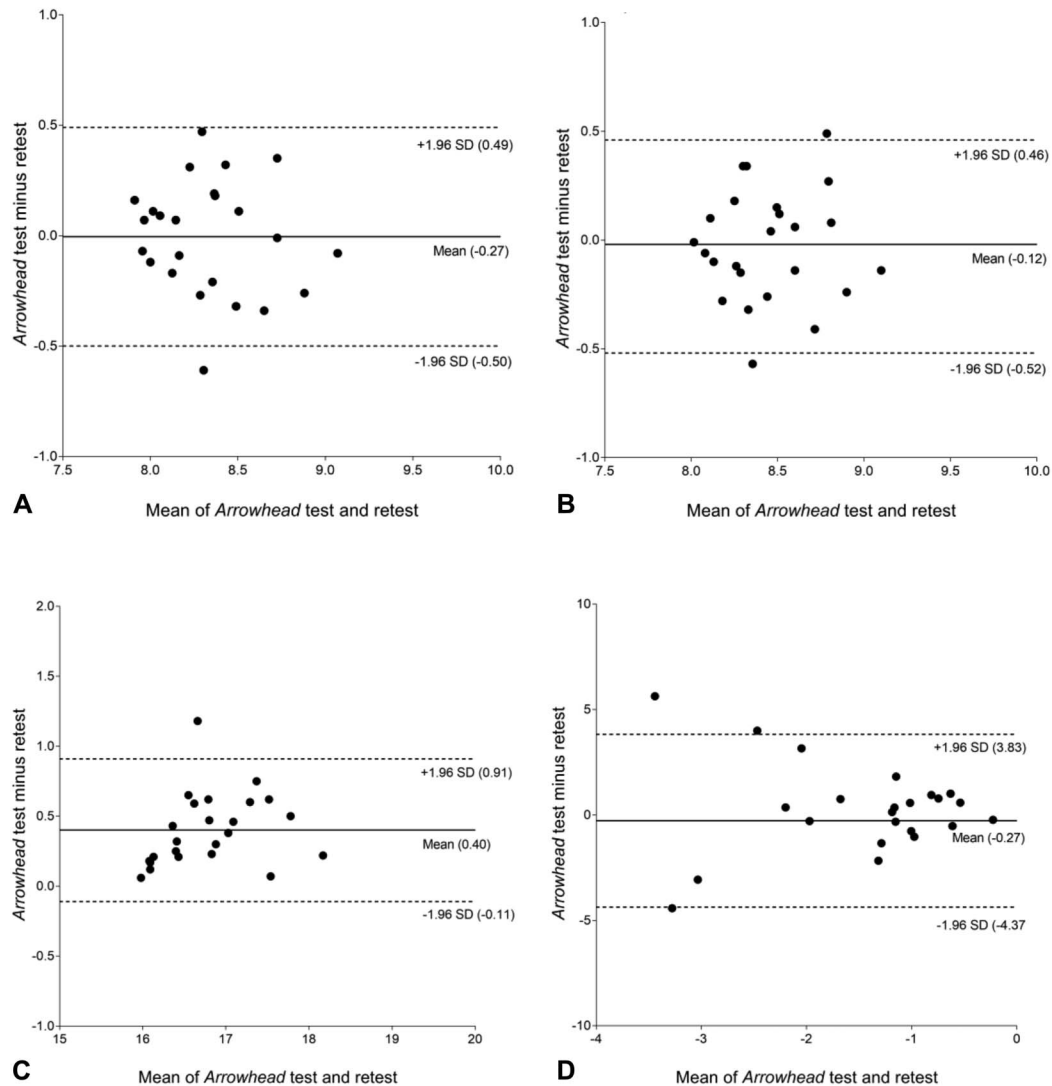


Figure 3. Bland-Altman plot of the arrowhead agility test and retest: (A) skillful side; (B) less-skillful side; (C) sum of both sides; and (D), asymmetry. Traces are limits of agreement.

Average biases of -0.27 , -0.12 , 0.40 , and -0.27 seconds were observed for the AAT skillful side, AAT less-skillful side, sum of both AAT sides, and ASI, respectively. However, no significant differences were found between test and retest for any of the AAT variables ($p > 0.05$). In addition, none of the AAT outcomes showed proportional bias (no associations between test-retest differences and mean differences) (Figure 1). Bland-Altman plots (Figure 1) revealed a good agreement between test and retest with almost all data points within the limits of agreements for all variables analyzed (88–96% of the total observations).

Associations With Other Power-Dependent Capacities

Countermovement jump height, relative CMJ peak power, 5-, and 15-m sprint times were 0.39 ± 0.05 m, 48.14 ± 8.71 W·kg⁻¹, 1.14 ± 0.08 , and 2.55 ± 0.12 seconds, respectively. A detailed analysis of the relationship between AAT performance and other physical capacities was reported in Figure 2. The AAT was correlated with sprint capacity either over 5 and 15 m (r ranging from 0.33 to 0.65), but not CMJ. Multiple regression analysis revealed that 15-m sprint performance explained 42% of variance in the AAT ($p < 0.01$; $F > 4.16$; $R^2 = 0.42$). Regression coefficients are also reported in Figure 4.

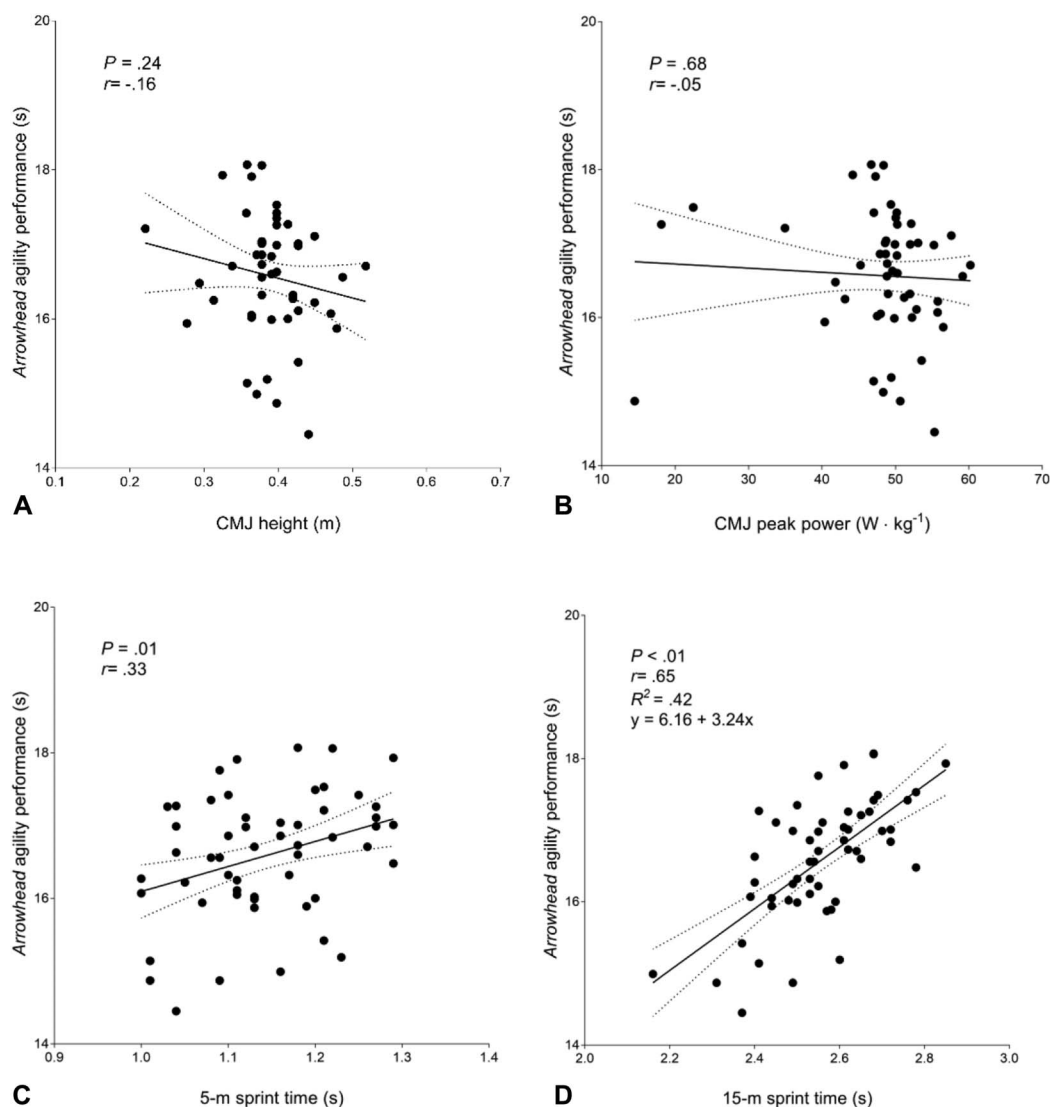
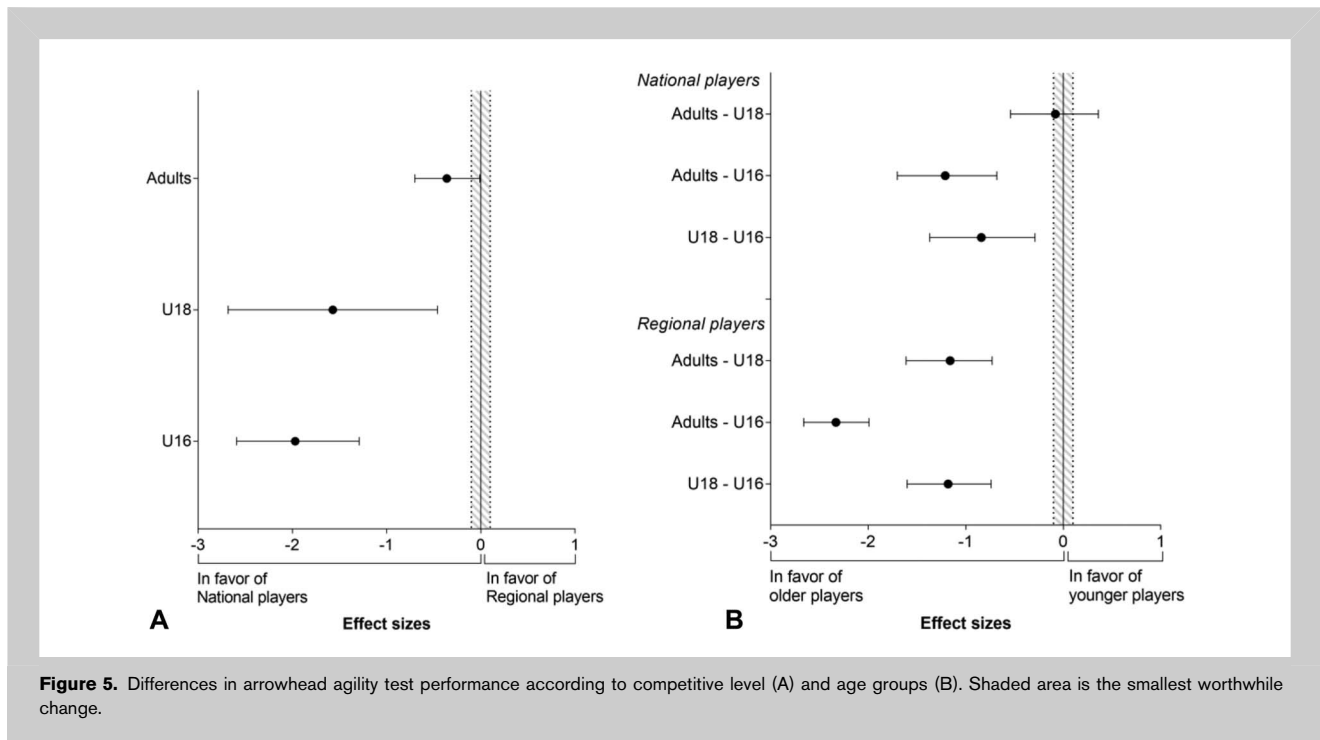


Figure 4. Relationships between arrowhead agility test performance and other neuromuscular capacities (A, CMJ height; B, CMJ peak power; C, 5-m sprint; D, 15-m sprint). Traces are 95% confidence intervals. CMJ = countermovement jump.

Fatigue Sensitivity

Effective individual match-playing time during the match was 86 ± 15 minutes. Mean HR was 164 ± 15 bpm ($83 \pm 15\%$ HRmax) during the first half, and 159 ± 15 ($77 \pm 8\%$ HRmax) during the second half. Time spent above 90% HRmax during the whole game was 24.8 ± 16.3 minutes, of which 16.5 ± 9.8 minutes during the first half, and 8.38 ± 7.1 minutes during the second half. Rating of perceived exertion was 8.1 ± 1.3 AU, RPE_{res} was 6.7 ± 2.0 AU, and RPE_{mus} was 7.7 ± 2.0 AU. Descriptive values of changes on physical capacities throughout the game are reported in Table 2. Change of direction capacity remained stable from the start of the match toward half time, but significant re-

ductions were observed after intense periods in the second half and after the game, compared with half-time performance ($ES = -0.83$ and -0.85 , respectively). Moreover, COD capacity performance was reduced after match compared with baseline ($ES = -0.42$). Sprint time over 5 m increased from half time to postmatch ($ES = -0.61$). Either CMJ height or CMJ peak power were improved after an intense period in the first and second halves ($ES = -0.55$ and -0.91 , respectively) and remained similar to baseline values during half time and postmatch. No significant relationships were observed between percent changes in COD capacity and percent changes in 5-m sprint time with CMJ throughout the game.



Discrimination Between Competitive Levels and Age Groups

Irrespective of age group, significant differences were observed in AAT performance between competitive level, with national-level players being more capable to change direction than regional-level players ($p < 0.05$; ES ranging from -1.97 to -0.36). Moreover, independently of competitive level, adult and U18 players were moderately to very largely better COD performers than U16 ($p < 0.05$; ES ranging from -2.33 to -0.84), whereas no significant differences were observed between adult and U18. Ranges and percentiles of AAT are reported in Table 3. A detailed representation of differences between competitive levels and age groups are shown in Figure 5.

DISCUSSION

To the best of our knowledge, this is the first study attempting to investigate the reliability, the association with other physical attributes, fatigue sensitivity, and ability to discriminate players by competitive levels and age groups using the AAT. The present research showed that the AAT (a) is a reliable field-based COD test for soccer players; (b) is positively associated with sprint capacity but not to vertical jump; (c) is sensitive to match-induced fatigue after an ~ 45 -minute game; and (d) discriminates players from different competitive levels and age groups (except for adults vs. U18).

The AAT has been used in previous soccer studies (6,7,29,40). However, as far as we know, this is the first study to analyze its reliability and capacity to detect changes in performance. Independent of the outcome measure (e.g., skillful side, less-skillful side, and sum of sides), the reliability

analysis showed that the ICC across the 2 occasions within 72 hours exceeded 0.75 (0.80–0.83) and the CV was below 10% (1.25–2.21%), indicating that repeated measurements did not vary significantly for individuals, and players relatively maintained their values on a second occasion. These findings indicate that the AAT can be used by coaches and practitioners to test players' COD. This study investigated intersession (short-term) reliability, and therefore, future studies may attempt to investigate the capacity of the AAT to detect changes over a long period (e.g., seasonal changes). As far as we know, only one study explored seasonal changes in AAT, reporting small impairments in COD as the season progressed (increased time) in ~ 17 -year elite soccer players (29). It can be speculated that oscillations in COD over the season can be related with changes in lower-limb strength or sprint capacity. Silva et al. (38) showed that seasonal changes in COD (modified version of the T-test) were correlated with changes in knee flexion isokinetic strength of dominant limb, and hamstring/quadriceps strength ratio ($r = 0.52$ and 0.76 , respectively) in professional male soccer players. Furthermore, COD capacity and sprint improved to a similar extent after an 8-week resistance training program in ~ 16 -year soccer players (15). However, recent reports in well-trained soccer players showed that 1 week of training cessation did not affect AAT performance (7), indicating that COD capacity can be maintained over short periods. The good reliability obtained in AAT performance was not observed in the ASI, which showed poor reliability (ICC < 0.25 and CV $> 10\%$; ICC = -0.43 and CV = 68%). This could be attributed to the

nonstandardized nature of the AAT, including a sequence of motor skills (sprint, COD, and sprint again). Indeed, previous research using standardized tests (e.g., single-leg CMJ) showed good reliability for ASI ($ICC = 0.91$, $CV = 2.4\%$) (22).

A minimum change of 0.12 seconds in AAT would indicate a change in performance rather than a change because of the test variation (error) in semiprofessional soccer players. Therefore, a decrease of 0.12 seconds in the AAT would indicate improved COD performance in this sample population. Notwithstanding, caution should be taken when applying this MDC to another cohort of different biological and physical characteristics. Different methods to calculate ASI can be applied (e.g., injured vs. noninjured leg, dominant vs. nondominant side, skillful or stronger vs. weaker or less skillful). However, reports on young soccer players (~16 years) showed that the use of the dominant limb allows for better COD (5-m straight sprint, a turn of 45, 90, 135, or 180°) performance than the nondominant limb during sidestepping maneuvers (34). Further research should investigate players' functional asymmetries in the AAT, using different ASI approaches and over a wide range of relationships with validated ASI tests, such as single-leg CMJ (22) or isokinetic strength tests (39).

The results of study 2 revealed that quickest players over 5 and 15 m also performed better in the AAT. Indeed, 15-m sprint performance explained 42% of performance in the AAT. This indicates that COD assessment, through the AAT test, seems to share physical attributes with 15-m sprint. Accordingly, recent findings revealed a positive relationship (R^2 ranging from 0.28 and 0.44) between COD (Illinois test and T-test), and sprint performance of young soccer players (~12 years) over 10 and 20 m (28). On the other hand, the present research showed that better COD performers were neither the most powerful nor the best jump performers, indicating a dissociation between COD capacity and lower-extremity power. This finding is supported by research from Vescovi and McGuigan (44) with high school and college female athletes showed that COD capacity and CMJ were independent physical capacities. Taken together, the results of our study suggest a considerable AAT performance may be likely observed if a player has a good sprint capacity (e.g., over 15 m), rather than vertical jump performance. Therefore, strength and conditioning coaches are advised to interpret vertical jump and COD independently. It seems strength and power measures have an influence on COD (28), but this relationship might only be observable when comparing tasks involving changes of direction over short distances (37). However, our results contrast with the results of a previous study with young players that found that CMJ performance explained 37% of the total variance of COD performance (28). This could be potentially attributed to the use of fixed arm on the hip CMJ. As such, athletes rarely jump without using their upper extremities, possibly explaining our lack of relationship with COD per-

formance. It would be of interest to place an additional timing gate before the last portion of the test (15-m sprint), isolating the COD portion of the AAT, and subsequently analyze its relationship with strength and power measurements (e.g., isokinetic strength and CMJ, respectively).

Fatigue sensitivity analysis showed players maintained their COD and acceleration capacity (5-m sprint) throughout the first half of the game, displaying meaningful decrements in performance during the second half. This is in line with our hypothesis and with Hughes et al. (21) that reported a reduced postmatch COD (*L-run*) performance compared with baseline (Cohen's $ES = 0.36$) in semiprofessional soccer players. Taken together, these findings indicate that COD is sensitive to match-induced fatigue in the second half. However, because the participants analyzed in this specific study were collegiate players, caution should be made regarding the extension of conclusions to elite or youth soccer. Nonetheless, further factors have been suggested to possibly influence the reliability of power-based test such as individual training status or intertrial time (20). Both elite and nonelite players have been suggested to exhibit signs of temporary fatigue during the game (including the first half), translated by the decreases in total distance covered and sprint frequency after periods with a large amount of high-intensity efforts (14,27). In fact, in the 5-minute period after the most intense periods of a match, the number of intense accelerations and decelerations is reduced to levels below game average (1). Thus, similar is expected to occur in COD performance in the same periods. With this evidence in mind, future research using GPS- or acceleration-derived parameters should investigate if high-intensity periods during the match affect COD of highly trained soccer players. Another interesting finding from the analysis of fatigue sensitivity of AAT is the lack of significant associations between changes in physical capacities throughout the game and performance in the test. Indeed, COD performance remained stable throughout the first half of the game while jump ability increased. This can be partially justified by the results of study 2 that showed a dissociation between these 2 physical capacities, potentially having practical implications for testing soccer players. Indeed, it seems that COD and CMJ are quite independent abilities, expressing also distinct fatigue kinetics (stable COD and increased CMJ across the first half, see Table 2). The reduced number of observations throughout the match for each player (e.g., most players could only be tested on one side) is an important limitation inherent to this analysis.

The AAT seems to successfully discriminate players of different competitive levels and age groups. Our findings are in accordance with previous research that observed elite players were more agile than nonelite. For instance, Rebelo et al. (33) found that U19 elite players performed better in the modified T-test than nonelite counterparts. In addition, Coelho-e-Silva et al. (8) showed that regional U14 players

from the lowest competitive levels did not differ in COD performance obtained in the 10 × 5-m shuttle run test.

Senior and U18 players did not show differences in AAT performance but both age groups were reasonably more agile than U16 players. On one hand, probably 18-year players were sufficiently matured and accumulated enough training to reveal similar COD performance to adult players. Another possible explanation to the inexistence of difference in performance between national-level adults, and U18 could be attributed to the fact that our sample did not represent top-level players; rather, they were competing in the second tier of their respective national league system. On the other hand, because players were yet in maturation (13), 16-year players showed a lower performance ability than the U18 and adult players. This is corroborated by previous findings (6) showing that AAT performance of adult soccer players was greater than performance of young players (~15-year). Despite these differences, it seems that the magnitude of improvements across growth is greater in regional-level players, possibly indicating that national-level players develop this capacity from early stages of growth (before 16 years). Considering the link with sprint capacity, it has been suggested that the development of sprint capacity (and possibly agility) is influenced by growth and maturation (26). Thus, another possible explanation to the lack of significant differences between adults and U18 could be the fact that we did not control age-related differences in AAT performance for maturity status.

In summary, our findings provide insights on a novice soccer-specific COD test that could be used by soccer practitioners. However, practitioners should be aware of extending our findings to top-level players or other populations. The application of our MDCs in top-level players could be argued, considering that, in study 1 (reliability), regional-level players were tested. It should also be pointed out that knowledge about the link between training and COD measured in the AAT is missing. Research about the seasonal changes of AAT performance and the possible relationship with training- and match-load is warranted. In addition, the effect of detraining on COD performance (e.g., off-season period) would be also of interest.

PRACTICAL APPLICATIONS

Coaches and practitioners can use the AAT to assess soccer players' COD in a reliable manner, considering that a decreased time of 0.12 second would indicate a meaningful change in performance, within our sample population (semi-professional players). An interesting indication provided by AAT is the possible identification of quick players over middle distances (~15 m) given its significant amount of shared variance with 15-m sprint test. Thus, from a practical point of view, the AAT could constitute a time-saving strategy to evaluate COD and sprint ability over 15 m with the same test. However, further individual characteristics (e.g., anthropometrics) could be better to explain our results. Moreover,

AAT seems to be sensitive to fatigue during the second half and toward the end of soccer matches and has the capacity to discriminate players from different competitive levels and age groups. Descriptive values of ranges and percentiles presented in this article can be also of interest for players' selection and fitness evaluation purposes.

ACKNOWLEDGMENTS

The authors would acknowledge all the people who cooperated in the data collection (Erik Nughes, Rafael Bagatin, Maickel Padilha, João Ribeiro, Tiago Fernandes, Paulo Santos, Tomas Schieber, Gilberto Tozo and Lucas Monteiro) and all coaches. In particular, we would acknowledge Júlio Costa for the heart rate analysis, and Estefania for drawing Figure 2.

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