Analysis of elite-level soccer players' running performance using GPS technology: the influence of different factors on performance and success in soccer

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ANALIZA TRKAČKIH PERFORMANSI NOGOMETAŠA ELITNOG RANGA NATJECANJA GPS TEHNOLOGIJOM: UTJECAJ RAZLIČITIH VARIJABLI NA IZVEDBU I USPJEH U NOGOMETU

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Analiza trkačkih performansi nogometaša elitnog ranga natjecanja GPS tehnologijom: utjecaj različitih varijabli na izvedbu i uspjeh u nogometu

DOKTORSKA DISERTACIJA

Mentor:
Prof.dr.sc. Damir Sekulić

Split, 2022

UNIVERSITY OF SPLIT
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Analysis of elite-level soccer players' running performance using GPS technology: the influence of different factors on performance and success in soccer

DOCTORAL THESIS

Supervisor:
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SUPERVISOR INFORMATION

Damir Sekulić; Professor at the University of Split, Split, Croatia; born 1970 in Split, Croatia. He earned his PhD title in Kinesiology at the University of Zagreb, Zagreb, Croatia in 2001.

His main scientific interests are sport-specific measuring protocols and tests, performance analysis in sport, and health-related issues of physical exercising and sport. Up to date, he published more than 160 papers in journals indexed in the Web of Science, with more than 2.400 citations (Web of Science Researcher ID: D-4886-2017; https://orcid.org/0000-0001-8022-7886).

He gave invited speeches at 15 international scientific conferences and symposia. He teaches at Universities and Faculties in Croatia and abroad (Reykjavik University, Reykjavik, Iceland; Mid Sweden University, Östersund, Sweden; University of Zagreb, Zagreb, Croatia; University of Ljubljana, Ljubljana, Slovenia; University of Mostar, Mostar, Bosnia and Herzegovina; University of Novi Sad, Novi Sad, Serbia; etc.).

So far, he has mentored eleven doctoral students in the country and abroad. He was awarded by several awards for his scientific work, including National Award for Science of the Republic of Croatia in 2017.

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LIST OF ABBREVIATIONS

MRP – match running performance

RP – running performance

GPI – game performance indicators

CD – central defenders

FB – fullbacks

CM – central midfielders

WM – wide midfielders

FW – forwards

GPS – global positioning system

LPS – local positioning system

VID – video-based system

HDOP – horizontal dilution of precision

AP – aerobic performance

VO2max – maximal oxygen uptake

AnT – anaerobic threshold

AeT – aerobic threshold

TD – total distance covered

LI – low intensity running

R – running

HI – high intensity running (high speed running + sprinting)

ACC – accelerations

DEC – decelerations

HIA – high intensity accelerations

HID – high intensity decelerations

CONTENTS

ABSTRACT

The main aim of this doctoral thesis was to investigate factors that have a strong theoretical basis for their relationship to running performance in soccer but have not been sufficiently investigated among professional elite-level players. Specifically, Study 1 aimed to examine possible associations that may exist between match running performance (MRP) and soccer match performance; Study 2 aimed to examine possible associations that may exist between running performance during matches (e.g., MRP) and training (e.g., the weekly external training load); Study 3 aimed to examine possible associations that may exist between the weekly external training load and match outcomes; and Study 4 aimed to examine possible associations that may exist between MRP and direct measures of aerobic performance (e.g., VO2max, AnT, and AeT).

The studies were carried out on professional soccer players from a single team that competed in the highest national soccer competition in Croatia. All running performance data were collected from training sessions and official matches during the 2018/2019 and 2019/2020 seasons using global positioning system technology (Optim-Eye S5 & X4, Catapult, Melbourne, Australia). Players' performance was classified into five groups according to their playing positions in the game: central defenders (CD), fullbacks (FB), central midfielders (CM), wide midfielders (WM), and forwards (FW). The MRP included the total distance covered; distance covered in the different speed zones of walking, jogging, low-intensity running, running, high-speed running, sprinting, and high-intensity running; total number of accelerations; number of high-intensity accelerations; total number of decelerations; and number of high-intensity decelerations.

The results of Study 1 indicated significant associations between MRP and soccer match performance assessed by the InStat Index for players in specific playing positions. Specifically, the InStat Index was correlated with running ($r = 0.42$, $p = 0.03$) and high-intensity accelerations ($r = 0.49$, $p = 0.01$) for CDs, number of decelerations for FBs ($r = -0.43$, $p = 0.04$), and sprinting for FWs ($r = 0.80$, $p = 0.02$).

The results of study 2 indicated that high-intensity accelerations ($r = 0.42$, $p = 0.01$) and high-intensity decelerations ($r = 0.52$, $p = 0.01$) during training were correlated with the corresponding match running performance for FBs. Running ($r = 0.52$, $p = 0.01$), high speed running ($r = 0.56$, $p = 0.01$), sprinting ($r = 0.64$, $p = 0.01$), high-intensity accelerations ($r = 0.59$, $p = 0.01$), and high-intensity decelerations ($r = 0.52$, $p = 0.01$)

during training were correlated with the corresponding match running performance for CMs. High-intensity accelerations ($r = 0.48$, $p = 0.02$), running ($r = 0.51$, $p = 0.02$), and high-speed running ($r = 0.47$, $p = 0.03$) during training were correlated with the corresponding match running performance for CDs.

The results of Study 3 indicated that match outcome was negatively related to the weekly amount of total distance (OR: 0.98; 95%CI: 0.98-0.99), low-intensity running (OR: 0.99, 95%CI: 0.97-0.99), running (OR: 0.99; 95%CI: 0.98-0.99), high-intensity running (OR: 0.98; 95%CI: 0.97-0.99), total accelerations (OR: 0.99; 95%CI: 0.98-0.99), total decelerations (OR: 0.98; 95%CI: 0.96-0.99), high-intensity accelerations (OR: 0.96; 95%CI: 0.95-0.99), and high-intensity decelerations (OR: 0.98; 95%CI: 0.97-0.99).

The results of Study 4 indicated that the anaerobic threshold was correlated with high-speed running ($r = 0.52$, $p < 0.01$) and sprinting ($r = 0.53$, $p < 0.01$) among side players (e.g., FBs and WMs). For central players (e.g., CDs, CMs, and FWs), the aerobic threshold was correlated with the total distance covered ($r = 0.47$, $p < 0.05$), low-intensity running ($r = 0.49$, $p < 0.05$), and running ($r = 0.39$, $p < 0.05$).

The results of this doctoral thesis show that (i) increased MRP may directly provoke increased soccer match performance, (ii) an increased weekly external training load may provoke increased MRP, (iii) an increased weekly external training load may negatively affect match outcomes in subsequent matches, and (iv) increased aerobic performance may provoke increased MRP. These findings offer new knowledge on factors affecting running performance in elite-level soccer, consequently enabling soccer coaches to design soccer-specific training programs aiming to optimize the whole training process and maximize player performance. In addition, since the MRP of soccer players competing in the Croatian first division was, for the first time, analysed, this doctoral thesis ultimately provides a detailed understanding of the physical demands placed on Croatian elite-level soccer players during matches and training.

Keywords: soccer, running performance, match performance, technical–tactical performance, aerobic performance, weekly external training load, match outcome, elite-level players

SAŽETAK

Glavni cilj ove doktorske disertacije bio je istražiti čimbenike koji imaju snažnu teorijsku pozadinu za povezanost s trkačkim performansama u nogometu, a koji nisu dovoljno istraživani među profesionalnim igračima elitne razine natjecanja. Konkretno, Studija 1 imala je za cilj ispitati moguću povezanost između trkačkih performansi i nogometnih performansi na utakmicama; Studija 2 imala je za cilj ispitati moguće povezanost između trkačkih performansi tijekom utakmica i treninga (tjedno vanjsko trenažno opterećenje); Studija 3 je imala za cilj ispitati moguću povezanost između tjednog vanjskog trenažnog opterećenje i ishoda utakmice; Studija 4 je imala za cilj ispitati moguću povezanost između različitih direktnih mjera aerobnih performansi (maksimalni primitak kisika, anaerobni i aerobni prag) i trkačkih performansi na utakmici.

Istraživanja su provedena na profesionalnim igračima iz jedne momčadi koja se natjecala na najvišem rangu državnog nogometnog natjecanja u Hrvatskoj. Svi podaci o trkačkim performansama prikupljeni su s treninga i službenih utakmica u sezonama 2018/2019 i 2019/2020 koristeći tehnologiju globalnog sustava za pozicioniranje (Optim-Eye S5 & X4, Catapult, Melbourne, Australija). Trkačke performanse igrača su klasificirane u pet skupina prema njihovim pozicijama u igri: središnji braniči, bekovi, središnji vezni, krilni vezni i napadači. Trkačke performanse su uključivale: ukupnu prijeđenu udaljenost, udaljenost prijeđenu u različitim zonama trčanje: hodanje, kaskanje, nisko intenzivno trčanje, trčanje, trčanje velikom brzinom, sprint, visoko intenzivno trčanje, ukupan broj akceleracija, broj visoko intenzivnih akceleracija, ukupan broj deceleracija, broj visoko intenzivnih deceleracija.

Rezultati Studije 1 pokazali da postoji značajna povezanost između trkačkih performansi i nogometnih performansi determiniranih InStat Indeksom za igrače na određenim igračkim pozicijama. Konkretno, InStat Index bio je povezan s trčanjem ($r = 0.42$, $p = 0.03$) i visoko intenzivnim akceleracijama ($r = 0.49$, $p = 0.01$) kod središnji braniča, deceleracijama kod bekova ($r = -0.43$, $p = 0.04$) i sprintom kod napadače ($r = 0.80$, $p = 0.02$).

Rezultati Studije 2 pokazali su da postoji značajna povezanost između visoko intenzivnih akceleracija ($r = 0.42$, $p = 0.01$) i visoko intenzivne deceleracija ($r = 0.52$, $p = 0.01$) na treninzima i na utakmicama kod bekova. Kod središnji veznih postojala je značajna povezanost između trčanja ($r = 0.52$, $p = 0.01$), trčanja velikom brzinom ($r = 0.56$, $p = 0.01$), sprinta ($r = 0.64$, $p = 0,01$), visoko intenzivnih akceleracija ($r = 0.59$, $p = 0.01$) i visoko intenzivnih deceleracija ($r = 0.52$, $p = 0.01$) na treninzima i na utakmicama. Kod središnji braniča postojala je značajna povezanost između visoko intenzivnih akceleracija ($r = 0.48$, $p = 0.02$), trčanja ($r = 0.51$, $p = 0.02$) i trčanja velikom brzinom ($r = 0.47$, $p = 0.03$) na treninzima i na utakmicama.

Rezultati Studije 3 pokazali su da je ishod utakmice bio negativno povezan s tjednom količinom: ukupnog trčanja (OR: 0.98; 95%CI: 0.98-0.99), trčanja niskim intenzitetom (OR: 0.99, 95%CI: 0.97-0.99), trčanja (OR: 0.99; 95%CI: 0.98-0.99), trčanja visokim intenzitetom (OR: 0.98; 95%CI: 0.97-0.99), akceleracija (OR: 0.99; 95%CI: 0.98-0.99), deceleracija (OR: 0.98; 95%CI: 0.96-0.99), visoko intenzivnih akceleracija (OR: 0.96; 95%CI: 0.95-0.99) i visoko intenzivnih deceleracija (OR: 0.98; 95%CI: 0.97-0.99).

Rezultati Studije 4 pokazali su da postoji značajna povezanost između anaerobnog praga i trčanja velikom brzinom ($r = 0.52$, $p < 0.01$) i sprinta ($r = 0.53$, $p < 0.01$) kod igrača koji igraju na vanjskim pozicijama (bekovi i krilni vezni). Kod igrača koji igraju na centralnim pozicijama (središnji braniči, središnji vezni i napadači) postojala je značajna povezanost između aerobnog praga i ukupne prijeđene udaljenosti ($r = 0.47$, $p < 0.05$), trčanja niskim intenzitetom ($r = 0.49$, $p < 0.05$) i trčanja ($r = 0.39$, $p < 0.05$).

Rezultati ove doktorske disertacije pokazuju da (i) veće trkačke performanse na utakmicama mogu potaknuti bolje nogometne performanse, (ii) veće tjedno vanjsko trenažno opterećenje može potaknuti veće trkačke performanse na utakmicama, (iii) veće tjedno vanjsko trenažno opterećenje može negativno utjecati na ishod utakmice, (iv) bolje aerobne performanse mogu potaknuti veće trkačke performanse na utakmicama. Ovi nalazi pružili su nova saznanja o faktorima koji utječu na trkačke performanse u nogometu elitne razine, što posljedično može omogućiti nogometnim trenerima kreiranje trenažnih programa koji mogu optimizirati cjelokupni proces treninga i maksimizirati učinak igrača na utakmicama. Osim toga, s obzirom da su u ovome istraživanju prvi puta analizirane trkačke performanse nogometaša najvišeg ranga natjecanja u Hrvatskoj, ova doktorska disertacija u konačnici omogućuje detaljno razumijevanje fizičkih zahtjeva s kojima se susreću elitni nogometaši tijekom utakmica i treninga u Hrvatskoj.

Ključne riječi: nogomet, trkače performanse, nogometne performanse, tehničko-taktičke performanse, aerobne performanse, tjedno vanjsko trenažno opterećenje, ishod utakmice, elitni igrači

THESIS OUTLINE

This doctoral thesis consists of four published articles:

1. Modric, T., Versic, S., Sekulic, D., & Liposek, S. (2019). Analysis of the Association between Running Performance and Game Performance Indicators in Professional Soccer Players. *International journal of environmental research and public health*, 16(20), 4032. https://doi.org/10.3390/ijerph16204032.
2. Modric, T., Versic, S., & Sekulic, D. (2020). Playing position specifics of associations between running performance during the training and match in male soccer players. *Acta Gymnica*, 50(2), 51-60. https://doi.org/10.5507/ag.2020.006.
3. Modric, T., Versic, S., & Sekulic, D. (2021). Relations of the Weekly External Training Load Indicators and Running Performances in Professional Soccer Matches. *Sport Mont*, 19(1), 31-37. https://doi.10.26773/smj.210202.
4. Modric, T., Versic, S. & Sekulic, D. (2021): Does aerobic performance define match running performance among professional soccer players? A position-specific analysis. *Research in Sports Medicine*, 29:4, 336-348, https://doi.org/10.1080/15438627.2021.1888107.

1 INTRODUCTION

1.1 Context

Soccer is the most popular sport in the world with approximately 300 million registered players globally (Krustrup & Krustrup, 2018; Silvers-Granelli et al., 2015). The game is played by two teams, each consisting of ten outfield players and one goalkeeper, for two 45-minute periods on an approximately 100x65-meter grass field. Outfield players' classifications are based on their positions on the pitch and typically include five playing positions: central defender (CD), fullback (FB), central midfielder (CM), wide midfielder (WM), and forward (FW) (Bush, Barnes, Archer, Hogg, & Bradley, 2015; V. Di Salvo et al., 2010; Kołodziejczyk et al., 2022; Lorenzo-Martinez et al., 2021; Modric et al., 2022a; Tierney, Young, Clarke, & Duncan, 2016; J. Trewin, Meylan, Varley, Cronin, & Ling, 2018). The individual duties of the players in different playing positions vary according to the teams' formations or playing styles, with cooperative and competitive interactions among them enabling successful match performance (Aquino, Carling, Vieira, et al., 2020; Baptista, Johansen, Figueiredo, Rebelo, & Pettersen, 2019; Modric, Versic, & Sekulic, 2020).

Match performance in soccer is complex, multifactorial, and dependent on technical, tactical, physical, and psychosocial abilities (Sarmento et al., 2014; Turner & Stewart, 2014; Qing Yi et al., 2019). At its core, soccer is a highly demanding intermittent sport characterized by brief bouts of high-intensity activity and longer low-intensity periods (Castagna, Chamari, Stolen, & Wisloff, 2005; Giménez, Leicht, & Gomez, 2019; Rampinini, Coutts, Castagna, Sassi, & Impellizzeri, 2007). Research shows that the intensity level of soccer matches has increased tremendously over the last decades (Barnes, Archer, Bush, Hogg, & Bradley, 2014). To successfully cope with such an increased match load, optimal physical preparation of the players should be ensured during the training process. An effective approach to achieve this preparation is by mimicking the movement patterns of actual competition (Modric, Jelicic, & Sekulic, 2021; Scott et al., 2014). The primary step in this process is a detailed assessment of the physical performance that players are exposed to during matches.

The assessment of physical performance in soccer is commonly undertaken using video-based systems (VID), radar-based local positioning systems (LPS), and global positioning systems (GPS) (Bastida-Castillo, Gómez-Carmona, De La Cruz Sánchez, & Pino-Ortega, 2019; Buchheit et al., 2014; Oliva-Lozano, Martín-Fuentes, Granero-Gil, & Muyor, 2021). Although all these systems allow the objective collection of highly valid data on players' locomotion during match-play (Aughey, 2011; Delves, Aughey, Ball, & Duthie, 2021; Malone, Lovell, Varley, & Coutts, 2017), some differences among them can be observed. Thus, VID technology is fully unobtrusive as it does not require players to wear any sensors. However, VID do not allow the use of microelectromechanical devices (e.g., accelerometers, gyroscopes, and magnetometers). Due to maintenance and installation difficulties, VID cannot be easily moved from stadiums to training facilities and are not commonly used for monitoring training sessions (Pino-Ortega, Oliva-Lozano, Gantois, Nakamura, & Rico-González, 2021). Therefore, GPS and LPS have become standard instruments used to monitor physical performance during training and matches in soccer (Alarifi et al., 2016; Leser, Baca, & Ogris, 2011; Rico-González, Los Arcos, Rojas-Valverde, Clemente, & Pino-Ortega, 2020).

A recent review that aimed to compare data from different monitoring systems indicated that using LPS usually resulted in higher accuracy than using VID or GPS (Pino-Ortega et al., 2021). Although it is also a fixed system, the advantages of this technology in comparison to GPS is that LPS is not affected by environmental conditions and can be used indoors (Hirokawa & Ebinuma, 2009; Serrano et al., 2020). However, the major advantage of GPS technology is its portability, which allows monitoring matches at different stadiums (especially important when playing away), as well as in training sessions at different training facilities (i.e., elite teams typically use a few different fields). Taken together with the fact that GPS provides highly valid and accurate data, it not surprising that this technology is currently the most popular among professional teams and sports scientists in soccer (Malone et al., 2017; Pino-Ortega et al., 2021; Rico-González, Pino-Ortega, et al., 2020). For all these reasons, GPS technology was chosen to monitor the physical performance of players participating in the analyses of this dissertation.

GPS technology consists of three main parts: (i) The GPS unit placed into the vest, which should be wearable by the players, (ii) hardware with a USB port that processes raw data from the GPS unit to the computer, and (iii) software to analyse players' physical performance. To analyse the quality of positional data in GPS devices, the horizontal dilution of precision (HDOP) and average number of connected satellites are typically monitored (Malone et al., 2017; Witte & Wilson, 2004). In particular, HDOP values greater than one or satellite numbers less than 10 may be grounds for data exclusion in the monitoring processes (Delves et al., 2021). Research shows that systems with higher sample frequencies (i.e., 10-20 Hz) provide greater data validity than systems with lower sample frequencies (i.e., 1-5 Hz) due to the higher number of communications with orbiting satellites in one second (Hoppe, Baumgart, Polglaze, & Freiwald, 2018). The most commonly used frequencies in soccer are 10 Hz systems, which were found to be appropriately reliable and valid in sport settings (i.e., with less than 1% measurement error and 80% common variance with running speed measured by timing gates) (Castellano, Casamichana, Calleja-González, San Román, & Ostojic, 2011; Johnston, Watsford, Kelly, Pine, & Spurrs, 2014). This system was used to assess physical performance in this thesis.

In general, GPS technology allows one to monitor various variables such as the distance covered, peak speed, number of accelerations and decelerations, jumps, changes of direction, metabolic power, impacts, etc. However, in soccer matches, players' physical performance is typically assessed by quantifying match running performance (MRP) such as the total distance covered and distance covered in different speed zones. The classification of speed zones generally varies due to the usage of different monitoring systems, but the most common (i.e., that generally used in studies, including this thesis) is as follows: walking (<7.1 km/h), jogging (7.2–14.3 km/h), running (14.4–19.7 km/h), high-speed running (19.8–25.1 km/h), maximal sprinting (>25.2 km/h), and high-intensity running (>19.8 km/h) (Paul S Bradley et al., 2013; Christopher Carling, 2011; Valter Di Salvo, Gregson, Atkinson, Tordoff, & Drust, 2009; Mallo, Mena, Nevado, & Paredes, 2015). In addition, for a more extensive assessment of physical performance in soccer, the number of total and high-intensity accelerations (>3 m/s^2) and decelerations (less than –3 m/s^2) are also often quantified.

In contemporary soccer, players during the match can cover between 9 and 14 km, as well as achieve 0.7–3.9 km of high-speed distance, 0.2–0.6 km of sprint distance, and approximately 600 accelerations (Barrera, Sarmento, Clemente, Field, & Figueiredo, 2021; Modric et al., 2022b; Russell et al., 2016). These MRP metrics vary according to the playing positions of the players due to their different duties during the match (Aquino et al., 2017; Dalen, Lorås, Hjelde, Kjøsnes, & Wisløff, 2019; Konefał et al., 2019a). Thus, as CMs are responsible for the connection between defence and attack, these players generally achieve the greatest total distance. Players that play by the side of the pitch (i.e., FBs and WMs) experience the greatest amount of high-intensity running due to their frequent participation in attacking actions. On the other hand, CDs mostly cover the lowest total and high-intensity distance of all outfield players because their technical roles (i.e., aerial duels, tackles, positioning, and interceptions) are generally more focused on reactions instead of running (Bangsbo & Peitersen, 2000; Jones & Tranter, 1999; Mallo et al., 2015; Vigne, Gaudino, Rogowski, Alloatti, & Hautier, 2010).

Knowledge of players' MRP allows individual physical performance profiles to be determined, which can subsequently be used to design soccer-specific training programs. This personalization will undoubtedly make training programs more optimized, which may consequently maximize players' match performance (Paul S Bradley et al., 2009; Buchheit et al., 2014; V Di Salvo et al., 2007). Indeed, some key match metrics that are critical for the final match result are actually directly affected by the MRP (Andrzejewski, Chmura, Konefał, Kowalczuk, & Chmura, 2017; Chmura et al., 2018; Valter Di Salvo et al., 2009). In particular, creating a spatiotemporal advantage over opposing players may be crucial when FWs attack space behind the opponent's defensive line, when WMs perform counterattacks, when FBs sprint into the last third of the pitch for crossing, when CMs engage in high pressing, or when CDs perform fast defensive transitions. These elements of a match can be executed efficiently only by running at higher speeds. Taking this factor into account, MRP can be linked with match performance (i.e., technical–tactical performance). The translation of knowledge and expertise gleaned from data derived from match analysis (i.e., MRP) into a form that is usable and applicable in training and competition is paramount if it is to have a meaningful impact on match performance (C. J. Carling, 2012).

However, the interpretation and application of findings from match analysis can be hampered by the large natural match-to-match variability (Christopher Carling, Bradley, McCall, & Dupont, 2016; Hopkins, 2000). Indeed, research that investigated match-to-match variation in elite-level soccer demonstrated a very high variability of MRP, especially for high-speed running and sprinting distance (Christopher Carling et al., 2016; Gregson, Drust, Atkinson, & Salvo, 2010; Rampinini et al., 2007; Joshua Trewin, Meylan, Varley, & Cronin, 2018). Considering that without a stable measurement of performance, it may be difficult to evaluate the effectiveness of a training intervention programme, it is not surprising that interest in match analysis, particularly the analysis of factors associated with MRP, has risen exponentially in recent decades (Mackenzie &

Cushion, 2013; Paul, Bradley, & Nassis, 2015). Such growing interest has led to a large body of published research that has helped to determine a myriad of factors potentially affecting MRP (Aquino et al., 2017; Christopher Carling, 2013). The playing position in the game (Konefał et al., 2019b; Zhou, Lorenzo, Gómez, & Palao, 2020), team formation (Arjol-Serrano et al., 2021; Modric et al., 2020), competitive level (Paul S Bradley et al., 2013; Sæterbakken et al., 2019), match outcome (Andrzejewski, Konefał, Chmura, Kowalczuk, & Chmura, 2016; Lago-Peñas, 2012), match location (Barrera et al., 2021; García-Unanue et al., 2018), team quality (Aquino et al., 2021; Valter Di Salvo et al., 2009), quality of opposition (Lago, Casais, Dominguez, & Sampaio, 2010; Teixeira et al., 2021), congested match schedule (Arruda et al., 2015; C. Carling et al., 2015), and even environmental factors (Chmura et al., 2021; Joshua Trewin, Meylan, Varley, & Cronin, 2017) have all been found to be associated with MRP.

Despite the current vast literature, knowledge on factors affecting MRP in soccer is still limited. This is especially evident in elite-level soccer where conducting research experiments may be challenging due to the crowded match schedule. For example, it is currently accepted that well-developed aerobic performance helps soccer players maintain repetitive high-intensity actions in a soccer match, accelerate the recovery process, and maintain their fitness at an optimum level during the entire match and season (Slimani, Znazen, Miarka, & Bragazzi, 2019). Thus, it is logical to expect that players' aerobic performance affects their MRP. However, there is no study examining the association between MRP and direct measures of aerobic performance among elite-level soccer players, such as maximal oxygen uptake and aerobic and anaerobic thresholds, to confirm such considerations.

Further, taking into account that properly planned and performed training is essential for allowing players to meet match requirements (Radzimiński, 2021), it is reasonable to expect that the weekly training load affects MRP. Moreover, considering the previously discussed fact that optimized training programs may maximize players' match performance (Paul S Bradley et al., 2009; Buchheit et al., 2014; V Di Salvo et al., 2007), it is also reasonable to expect that the weekly training load may affect the outcomes of subsequent matches. However, despite the vast research examining MRP, detailed analysis of the customary training loads of elite soccer players is comparatively limited (Anderson et al., 2016; Barnes et al., 2014; Hannon et al., 2021; Malone et al., 2015; Reilly & Thomas, 1979). In addition, no study has analysed the position-specific influence of weekly training loads on MRP and match outcomes to confirm the influence of training load on match loads and match outcomes.

Finally, as the performance of aspects of some soccer matches dominantly includes running at higher speeds, meaning that MRP could be related to match performance, it is plausible that MRP may be an important determinant of match performance. Although MRP and match performance in elite-level soccer are often investigated separately (Aquino, Carling, Maia, et al., 2020; Delves et al., 2021; Lorenzo-Martínez, Padrón-Cabo, Rey, & Memmert, 2020; Palucci Vieira, Carling, Barbieri, Aquino, & Santiago, 2019; Sarmento et al., 2014; Q. Yi et al., 2020; Qing Yi, Jia, Liu, & Gómez, 2018), there is no study that simultaneously observed both of these groups of performance variables during official matches in elite-level soccer. As a result, knowledge on the possible influence of MRP on match performance is still completely unknown.

Therefore, the main rationale for this doctoral thesis comes from the global lack of studies that investigate factors with a strong theoretical relationship to MRP but which have not been sufficiently investigated among professional elite-level players (i.e., physical capacities, training load, and technical–tactical effectiveness). Providing new knowledge on factors affecting running performance in elite-level soccer will enable soccer coaches to design soccer-specific training programs aiming to optimize whole training processes and maximize player performance (C. J. Carling, 2012; Gregson et al., 2010; Iaia, Ermanno, & Bangsbo, 2009) (Paul S Bradley et al., 2009; Buchheit et al., 2014; V Di Salvo et al., 2007). This measure may help players better adapt to the physical demands required in matches, maintain their fitness during the whole season, and even reduce their injuries, ultimately contributing to achieving greater success in elite-level soccer. Furthermore, considering that no studies have investigated MRP in the Croatian first division and that the sample in this study included professional soccer players from a team competing in the highest national soccer competition in Croatia, the findings from this work will, for the first time, provide a detailed understanding of the physical demands placed on Croatian elite-level soccer players during matches and training

1.2 Research aims and hypotheses

The main aims of this research were (i) to examine the possible associations that may exist between MRP and soccer match performance, (ii) to examine the possible associations that may exist between running performance during matches (e.g., MRP) and training (e.g., weekly external training load), (iii) to examine the possible associations that may exist between weekly external training load and match outcome, and (iv) to examine the possible associations that may exist between MRP and direct measures of aerobic performance (e.g., VO2max, AnT, and AeT).

The hypotheses of this research are as follows: (i) MRP and soccer match performance are significantly associated, (ii) weekly external training load are significantly associated with MRP and match outcome, and (iii) MRP and aerobic performance are significantly associated.

2 ORIGINAL STUDIES

2.1 Study 1: Analysis of the Association between Running Performance and Game Performance Indicators in Professional Soccer Players

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Analysis of the Association between Running Performance and Game Performance Indicators in Professional Soccer Players

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Abstract: Running performance (RP) and game performance indicators (GPI) are important determinants of success in soccer (football), but there is an evident lack of knowledge about the possible associations between RP and GPI. This study aimed to identify associations between RP and GPI in professional soccer players and to compare RP and GPI among soccer playing positions. One hundred one match performances were observed over the course of half of a season at the highest level of national competition in Croatia. Players (mean ± SD, age: 23.85 ± 2.88 years; body height: 183.05 ± 8.88 cm; body mass: 78.69 ± 7.17 kg) were classified into five playing positions (central defenders (n = 26), full-backs (n = 24), central midfielders (n = 33), wide midfielders (n = 10), and forwards (n = 8). RP, as measured by global positioning system, included the total distance covered, distance covered in five speed categories (walking, jogging, running, high-speed running, and maximal sprinting), total number of accelerations, number of high-intensity accelerations, total number of decelerations, and number of high-intensity decelerations. The GPI were collected by the position-specific performance statistics index (InStat index). The average total distance was 10,298.4 ± 928.7 m, with central defenders having the shortest and central midfielders having the greatest covered distances. The running (r = 0.419, p = 0.03) and high-intensity accelerations (r = 0.493, p = 0.01) were correlated with the InStat index for central defenders. The number of decelerations of full-backs (r = −0.43, p = 0.04) and the distance covered during sprinting of forwards (r = 0.80, p = 0.02) were associated with their GPI obtained by InStat index. The specific correlations between RP and GPI should be considered during the conditioning process in soccer. The soccer training should follow the specific requirements of the playing positions established herein, which will allow players to meet the game demands and to perform successfully.

Keywords: GPS, football, accelerations, decelerations, efficacy

2.1.1 Introduction

Soccer is a highly complex team sport with changing dynamics and multistructural movements played by two teams. Each team consists of 10 outfield players and a goalkeeper and the final game achievement depends directly on the performance of all 11 players [1,2]. Therefore, performance analysis is crucial in the evaluation of players' achievement [3]. The global popularity of soccer has led to the implementation of scientific and technological knowledge in everyday use, and this is particularly evident within the field of performance analysis. One of the important aspects of performance analysis is termed "running performance", which is nowadays mostly evidenced by global positioning software systems (GPS) [4].

GPS technology is known to be highly applicable in evaluation of mobility and physical activity patterns within the field of public health [5,6,7]. With the improvement of their accuracy/precision, design, usability and safeness (Figure 1), the GPS-based devices are becoming prevalent even in competitive sports, including soccer [8,9].

Figure 1. Global positioning device (GPS) used for the measurement of running performances in soccer.

Specifically, GPS allows collecting data about players' running performance, such as the total distance covered, the distance covered at different intensities (i.e., speeds), and the number of accelerations and decelerations. Studies conducted so far have provided playing-position-specific evidence with regard to running at different intensities, with midfielders covering the largest total distance and wingers performing the most high-intensive sprints [10]. Furthermore, match running performance in Brazilian professional soccer players indicated that winning teams, home playing teams and teams that play against "weaker" opponents had the greatest total distance covered [11]. A study performed with <21- and <18-year old soccer players found that a 3–5–2 formation elicited the highest total distance, with a 4–2–3–1 formation eliciting the highest number of accelerations and decelerations [12]. The results of the previously cited studies that used GPS technology as a measurement tool were generally consistent with those from investigations where authors used different video-based computerized match analysis systems in the evaluation of players' running performances [13,14,15,16,17].

Game performance indicators are another set of variables that are used in performance analysis in soccer. Basically, game performance indicators are defined as a "selection and combination of variables that define some aspect of performance and that help achieve athletic success" [18]. The most frequently used game performance indicators are passes, shots, crosses, dribbles, challenges etc. [19]. Currently, numerous video-based platforms that track performance indicators of soccer players are available (InStat, Optasport, Wyscout). Such platforms quickly and accurately provide a large range of data about game performance indicators, allowing the simultaneous analysis of the physical efforts, movement patterns, and technical actions of players, both with and without the ball [20,21,22].

Previous studies conducted in the field of performance analysis in soccer found that both the physical (i.e., total distance covered, high-intensity running, accelerations and decelerations) and technical–tactical performances (i.e., shots, crosses, challenges, and dribbles) of players were correlated with specific conditions such as match outcome (win/draw/loss), match location (home/away), type of match (league/cup/friendly), and strength of the opponent team [19,23,24,25,26,27,28]. Situational variables, such as ball possession, total shots, shots on target, crosses, dribbles, clearances, challenges, and interceptions, and their influence on technical–tactical parameters were mostly evaluated by the variation of counts of technical match actions, which include shots, passing, tackles, aerial duels, and dribbles [18,27,29,30]. Briefly, situational variables that discriminate among winning, drawing and losing were mostly those related to ball possession and offensive actions (e.g., total shots, shots on goal, and crosses) [29,30], while some studies found that indicators of defensive efficacy (e.g., interceptions, clearance, and aerial challenges) were the variables most related to the match outcome [27].

Although game performance indicators and running performance are often investigated separately, to the best of our knowledge, there is no study that simultaneously observed both groups of performance variables during official soccer matches. Additionally, there is no information about the relationship that may exist between these two groups of variables. Therefore, the aim of this study was to identify possible associations that may exist between running performance and game performance in professional soccer players. Additionally, running performance and standard soccer performance variables were compared among playing positions. Authors were of the opinion that a study of this type would allow a better understanding of the relationships that exist between running performance and game performance indicators and that such understanding would therefore improve the applicability of both sets of variables in soccer training and competition.

2.1.2 Materials and Methods

Participants and Design

The participants in this study were professional soccer players from Croatia (mean ± SD, age: 23.85 ± 2.88 years; body height: 183.05 ± 8.88 cm; body mass: 78.69 ± 7.17 kg), and all were members of one team competing at the highest national. Players were observed over one competitive half season, resulting in 101 match performances which were used as cases for this study. All data were collected during 14 matches of the Croatian Soccer League 2018/2019 season, and for the purpose of this study only the results of those players who participated in the whole game were analyzed. Players were classified in five groups based on playing positions: central defenders (CD; n = 26), full-backs (FB; n = 24), central midfielders (CM; n = 33), wide midfielders (WM; n = 10), and forwards (FW; n = 8), as suggested previously [10]. Sociodemographic and anthropometric data of observed players are presented in Table 1. In the observed half-season, the team played seven home and seven guest matches, with three wins, eight draws and three losses. At the end of the observed half-season, the team ranked 6th of 10 teams which competed in Croatian Soccer League. The investigation was approved by

Ethical Board of the University of Split, Faculty of Kinesiology, Split, Croatia (approval number: 2181-205-02-05-19-0020).

Table 1. Sociodemographic and anthropometric characteristics of the studied players with differences among playing positions.

	Age (years) Mean ± SD	Body height (cm) Mean ± SD	Body mass (kg) Mean ± SD
Total sample (n = 101)	23.85 ± 2.88	183.05 ± 6.88	78.69 ± 7.17
Central Defenders (n = 26)	23.25 ± 2.21	192.25 ± 5.61	87.27 ± 7.38
Full-Backs (n = 24)	23.2 ± 3.56	176.6 ± 3.36	73.4 ± 4.34
Central Midfielders (n = 33)	22.66 ± 2.73	175 ± 6.08	76.51 ± 5.02
Wide Midfielders (n = 10)	26.0 ± 1.0	183 ± 3.46	76.2 ± 4.17
Forwards (n = 8)	27.0 ± 2.82	181.5 ± 0.7	85 ± 4.1
F-test (p)	1.51 (0.24)	5.92 (0.01)	5.04 (0.01)

2.2. Procedures

The variables in this study were two sets of soccer performance variables (running performance and game performance indicators) and the final game outcome (observed as loss, draw, win).

Data on the running performance of the players were collected by GPS technology (Catapult S5 and X4 devices, Melbourne, Australia) with a sampling frequency of 10 Hz. Such device was already investigated for metrics, and was found to be appropriately reliable and valid in sport settings (i.e., less than 1% measurement error, and 80% of common variance with running speed measured by timing gates) [31,32].

The variables included the following: total distance covered (m); distance in five speed categories (walking (<7.1 km/h), jogging (7.2–14.3 km/h), running (14.4–19.7 km/h), high-speed running (19.8–25.1 km/h), and maximal sprinting (>25.2 km/h)); number (frequency) of total accelerations (>0.5 m/s2); number of high-intensity accelerations (>3 m/s2); number of total decelerations (less than –0.5 m/s2) and number of high-intensity decelerations (less than –3 m/s2).

The game performance indicators for each player were determined by the position-specific InStat index (InStat, Moscow, Russia). The InStat index is calculated on the basis of a unique set of key parameters for each playing position (12–14 performance parameters, depending on the position during the game), with a higher numerical value indicating better performance. The exact calculations are trademarked and known only to the manufacturer of the platform. In most general terms, an automatic algorithm considers the player's contribution to the team's success, the significance of their actions, opponent's level and the level of the competition they play in (i.e., the same performance done in European Champions League and some national-level first division will not be rated with same values). The rating is created automatically, and each parameter has a factor which changes depending on the number of actions and events in the match. The weight of the action factors differs depending on the player's position. For example, grave mistakes done by CD and their frequency affect InStat index to a greater extent than those done by FWD. The key factors included in the calculation of the InStat index are position specific and include tackling, aerial duels, set pieces in defense, interceptions (for CD); number of crosses, number of passes to the penalty area, pressing (for FB); playmaking, number of key passes, finishing (for CM); pressing, dribbling, finishing, counterattacking (for WM); shooting, finishing, pressing, dribbling (for FWD). In order to calculate the InStat Index, the player has to spend a certain amount of time on the field and perform a minimum number of actions, but in this study this issue was solved simply by including only those players who played the whole game (as explained in Section 2.1).

2.3. Statistics

The normality of the distributions was checked by the Kolmogorov–Smirnov test, and the data are presented as the means ± standard deviations. The homoscedasticity of all variables was confirmed by Levene's test. The statistical analyses were performed throughout several phases.

In the first phase the data obtained by InStat index were associated with final game outcome by one-way analysis of variance (ANOVA). For this procedure the game outcomes (loss, draw, win) were considered as the grouping (independent) variable, and differences were established for total sample of players, and separately for each playing position. This allowed identification of the validity of the InStat index as an indicator of the final game achievement for the total sample, and for the five observed playing positions.

The second phase of data analysis comprised calculation of differences among playing positions in running performance and InStat index. This was done by ANOVA with a consecutive Scheffe post hoc test. Throughout these analyses the information of running performance specifics for each playing position were obtained. Also, the analysis of differences in InStat allowed identification of the applicability of the InStat index for the analysis of game achievement for each playing position. To evaluate the effect sizes (ES), partial eta-squared values ($\eta 2$) were presented (small ES: >0.02; medium ES: >0.13; large ES: >0.26) [33].

In the third phase, the associations between running performance (obtained by GPS) and game performance indicators (evaluated by InStat) were identified by calculating Pearson's product moment correlation coefficients.

For all analyses, Statistica 13.0 (TIBCO Software Inc., Greenwood Village, CO, USA) was used, and a $p < 0.05$ was applied.

2.1.3 Results

The ANOVA indicated significant ($p < 0.05$) association between the InStat index and match outcome for the total sample (n = 101, F-test: 23.69, $\eta 2 = 0.30$ (large E)), CD (n = 26, F-test: 3.89, $\eta 2 = 0.24$ (medium ES)), FB (n = 24, F-test: 4.98, $\eta 2 = 0.31$ (large ES)) and CM (n = 33, F-test: 15.71, $\eta 2 = 0.50$ (large ES)). The InStat index was not significantly associated with game outcomes for WM (n = 10, F-test: 0.98, $\eta 2 = 0.21$ (medium ES)), and FW (n = 8, F-test: 2.61, $\eta 2 = 0.52$ (large ES)) (Figure 2).

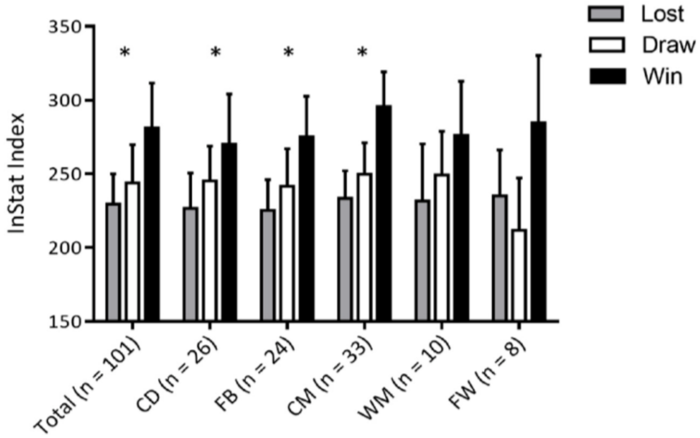

Figure 2. InStat index in relation to the outcome of the match for total sample (Total) and different playing positions (CD, central defenders; FB, full-backs; CM, central midfielders; WM, wide midfielders; FW, forwards); * indicates statistically significant differences at $p < 0.05$ derived by analysis of variance

The descriptive parameters for running performances and InStat index in total sample, and for each playing positions are presented in Table 2. Significant ANOVA differences were found among playing positions ($p < 0.05$) in all running performances, with large ES for differences in: (i) total distance covered ($\eta2 = 0.59$); (ii) distance covered while jogging ($\eta2 = 0.41$); (iii) running ($\eta2 = 0.62$); (iv) high-speed running ($\eta2 = 0.53$); (v) sprinting ($\eta2 = 0.39$); (vi) number of performed accelerations ($\eta2 = 0.27$); (vii) number of decelerations ($\eta2 = 0.45$); (viii) number of high-intensity accelerations ($\eta2 > 0.30$); and (ix) number of high-intensity decelerations ($\eta2 = 0.41$). Small ES was found for differences in distance covered while walking ($\eta2 = 0.11$) (Table 3).

Table 3. Differences among playing positions for running performances and game performance indicator (InStat) determined by analysis of variance (ANOVA), with Scheffe post-hoc test differences.

Variables	ANOVA	Effect Size	Post hoc				
	F (p)	η^2	Central Defenders	Full-Backs	Central Midfielders	Wide Midfielders	Forwards
Total distance (m)	35.02 (0.01)	0.59	FB, CM, WM	CD, CM	CD, FB, WM, FW	CD, CM	CM
Walking (m)	3.18 (0.02)	0.11	-	-	-	-	-
Jogging (m)	16.71 (0.01)	0.41	CM	CM	CD, FB, WM, FW	CM	CM
Running (m)	39.30 (0.01)	0.62	FB, CM, WM	CD, CM	CD, FB	CD, FW	CM
High-speed running (m)	29.30 (0.01)	0.53	FB, CM, WM, FW	CD	CD, WM	CD, CM, FW	CD, WM
Sprinting (m)	15.72 (0.01)	0.39	FB, WM	CD, CM, FW	FB, WM	CD, CM, FW	FB, WM
Accelerations (count)	9.06 (0.01)	0.27	FW	FW	FW		CD, CM, FW
Decelerations (count)	20.11 (0.01)	0.45	FW	FW	FW	FW	CD, FB, CM, WM
High-intensity accelerations (count)	8.53 (0.01)	0.30	WM, FW	WM, FW	WM, FW	CD, FB, CM	CD, FB, WM
High-intensity decelerations (count)	16.70 (0.01)	0.41	FB, CM, WM	CD, WM	CD, WM	CD, FB, CM, FW	WM
InStat (index)	0.64 (0.62)	0.03	-	-	-	-	-

Superscripted letters indicate significant post-hoc differences when compared to specific playing position (CD, central defenders; FB, full-backs; CM, central midfielders; WM – wide midfielders; FW, forwards)

The total running distance and high-intensity accelerations were correlated with the InStat index for CD (r = 0.42 and r = 0.49, respectively). Furthermore, the number of decelerations was significantly correlated with the InStat in FB (r = –0.43), while distance covered during sprinting was correlated with InStat index in FW (r = 0.80). In general, the running performances of players in central and wide midfield positions were not significantly associated with the InStat index (Table 4).

Table 4. Pearson's product moment correlations between running performances and game performance indicator (InStat) for different playing positions.

Variables	Total (*n* = 101)	Central Defenders (*n* = 26)	Full-Backs (*n* = 24)	Central Midfielders (*n* = 33)	Wide Midfielders (*n* = 10)	Forwards (*n* = 8)
Total distance	0.08	0.18	–0.04	–0.02	–0.17	0.01
Walking	–0.02	0.09	0.01	–0.12	0.07	0.04
Jogging	0.05	0.02	–0.10	0.05	–0.41	–0.05
Running	0.16	0.42 *	0.02	0.12	0.01	–0.13
High-speed running	0.02	–0.04	–0.06	–0.10	0.54	0.17
Sprinting	0.01	–0.24	0.17	–0.04	0.22	0.80 *
Accelerations	–0.01	0.12	–0.39	0.07	–0.24	–0.02
Decelerations	–0.09	0.07	–0.43 *	–0.05	–0.26	–0.33
High-intensity accelerations	0.18	0.49 *	0.20	0.29	–0.08	0.26
High-intensity decelerations	0.05	0.29	–0.04	–0.01	0.44	–0.18

* denotes statistical significance of $p < 0.05$.

2.1.4 Discussion

With regard to study aims there are two most important findings. First, the total distance covered and the intensity of running varied according to the different playing positions. Second, running performance parameters (e.g., the number of accelerations or decelerations and the distance covered in different speed zones) affect successful performance in soccer for some playing positions. Prior to discussion of these findings, an overview of the analyses done in order to evaluate the applicability and validity of InStat index as a measure of final match outcome will be provided.

Studies have already investigated the association between different variables explaining situational efficacy (i.e., game performance indicators) and match outcomes. For example, when losing the game, teams had more ball possession [30,34,35] and performed more crosses and dribbles [27]. Additionally, when winning, the teams performed more interceptions, clearances and aerial challenges, fewer passes and dribbles [27], and less high-intensity activities [18,34]. However, previous studies regularly investigated the performance indicators of the whole team, while there has been limited research investigating the position-specific performances in relation to game outcome, even though technical indicators have been considered good predictors of soccer match success [36]. Also, the quality of technical skills in real-game performance, which is actually obtained throughout the InStat index and other similar platforms, has been included as a main component in soccer talent identification and development systems [37,38].

InStat index in soccer is based on wide range of team- and individual-statistics, which are linked to the supporting video episodes. At the final stage, the calculated index should be related to final game outcome, and consequently should be a valid measure of final team achievement (i.e., game outcome). Results of this study indicated significant differences among game outcomes (loss, draw, or win) in InStat index for the total sample and specifically for CD, FB and CM. Although the statistical significance of the F-test did not reach statistical significance for WM and FW, this may be attributed to small number of players in these groups (WM: 10 players, FW: 8 players) and consequent small number of degrees of freedom [39]. Therefore, it might be said that the results presented here confirmed the validity of InStat in evaluation of final game achievement in Croatian professional soccer. It is also important to note that InStat index is specifically calculated for different positions on the basis of position-specific parameters (please see Section 2 for more details). Therefore, the lack of differences among playing positions in InStat (please see Table 2 and Table 3 for more details) indicates that this index might be observed as an applicable measure of position-specific game performance in soccer.

Running Performances and Differences Among Playing Positions

Considering the different tactical roles of different playing positions in soccer games, recent studies confirm that the distance covered during the match appears to be related to playing position [11,14,16,20]. Results of this study evidenced significant differences in running performance among playing positions, and such results are generally in agreement with previous studies that investigated these issues in the English Premier League, the Spanish first division, the Italian Serie A, the French League 1, and the Brazilian first division [13,14,16,20,40]. Specifically, analysis of the Brazilian first division evidenced that the total distance covered by FB, CM and WM was greater than that covered by CD and FW [13]. Supporting this, the lowest total distance was found for CD (9313 m on average). At the same time, CM covered significantly more distance than players in all other positions (11,155 m, on average), which is known to be related to specific playing duties (i.e., CM are responsible for the connection between defense and attack, and such tactical roles require them to achieve greater distances) [14,16].

Previous studies performed indicated 10.7 km as the average total distance covered in Spanish and English top divisions [10,40,41]. Meanwhile players observed herein covered total distance of 10.3 km in average. Therefore, it seems that the total distance covered is not the factor that distinguishes Croatian players from those playing in elite European divisions. On the other hand, there is an evident difference in the intensity of running. More precisely, top-level European soccer players cover 10% of the total distance at a high intensity, which includes high-speed running and maximal sprinting [17,42]. Meanwhile, here presented results indicated that Croatian players perform 6.4% of the total distance covered at a high-intensity running pace.

It is generally accepted that low-intensity activities, such as walking and jogging, are not crucial in elite soccer performance [43]. However, knowledge of these indicators is important to properly understand the position-specific demands. Thus, considering the percentage of the total distance, the most time spent walking and jogging is observed in CD (an average of 85.2% (7935 m) of their total distance covered (9313 m)). On the other hand, the least time spent walking and jogging is observed in WF (76.3%), followed by CM (79.4%), FB (79.8%) and FW (81.8%). Collectively, these findings support previous considerations that Croatian first division players generally play at a lower game pace when compared to elite European national division players, who spend a much lower percentage of time in low-intensity activities (from 74.9% to 79.6% of total distance) [10].

The distance covered while jogging among CM is significantly higher than for any other position. As mentioned before, CM had the greatest total distance, which is directly influenced by the distance covered while jogging. Furthermore, CM have the greatest distances in the "running zones" (e.g., 14.4–19.7 km/h). Therefore, results support the findings from previous studies in which authors reported similar figures and concluded that the physical performance of CM is characterized by covering a high overall distance, especially at moderate to high speeds such as jogging and running [10].

High-intensity activities are usually defined as all activities with running speeds of 19.8 km/h and above, and the distance covered at high intensities has been traditionally identified as a key performance indicator of physical match performance [44] and one of the crucial elements of success in soccer [43]. The results showed that the greatest amount of high-intensity running (high-speed running + sprint running) is covered by WM, while the CD have the lowest values for these indicators. This is consistent with previous investigations in which authors reported similar results for the English Premier League and the Spanish first division [10,14,20,40].

It is known that outside players (e.g., WM and FB) perform significantly more sprints than players in central playing positions [14]. Supporting this, our results showed that the greatest sprint distance was covered by WM and FB. However, despite similar differences among playing positions between our study and previous studies, values of high-intensity running in Croatian players were evidently lower than those from the best European national competitions [10,40]. More specifically, the mean high-intensity distance covered among all playing positions in the English Premier League was 936 m, in the Spanish first division an average of 821 m was reported, while the average value for high-intensity running in Croatian players was 652 m.

The highest number of accelerations and decelerations was found for CD and the lowest for FW, which is consistent with some similar studies on friendly matches in the Spanish first division [10]. Specifically, one of the most important tactical roles of FW is to keep the ball in possession in the central position, so it is expected that FWs do not cover a large distance. On the other hand, CD must be constantly prepared for defensive reactions. While trying to find appropriate positioning, they frequently change running directions, but also the type of running (i.e., frontal running to make a defensive line to catch opposing players in offsides and lateral shuffles to obtain better positions versus FW). This certainly results in a high number of accelerations and decelerations for CD. However, the kind of accelerometer unit and the way that the data are mathematically treated could have a significant effect on the calculation of accelerations and decelerations, which actually limits the comparability between different studies [10]. Specifically, while the capacity to accelerate and decelerate plays a critical role in elite soccer, as it represents high energy demanding activities, the determination of accelerations might still have unresolved methodological issues [10].

Associations between Game Performance Indicators and Running Performances—Playing Position Approach

The results suggest that CD covered the shortest distance while running out of all playing positions, and this is in agreement with previous reports where authors found that CD exert the fewest high-intensity efforts compared to all other playing positions [10,14,20,40]. This is understandable knowing that their technical roles (i.e., aerial duels, tackles, positioning, and interceptions of the balls passed to the attackers) are generally more focused on the reactions or accelerations and then on high-speed running. As a result, most of their high-intensity efforts are performed in the zone of running (14.4–19.7 km/h) simply because they do not have many opportunities to develop running speeds above the high-intensity zone threshold (>19.8 km/h). However, because of the positive correlation between the InStat index and the distance covered while running (14.4–19.7 km/h) for CD, running should be considered an important determinant that affects success for this position. Furthermore, a positive correlation between the numbers of high-intensity accelerations and the InStat index among CD shows that a greater number of high-intensity accelerations directly affects real game performance for this playing position. Specifically, stepping out to the duels and putting pressure on opponent players are two of the most important tactical roles of CD. If performed rapidly and aggressively (in other words, with a high acceleration), the chances of winning a duel increase, which consequently has positive repercussions on final match achievement as well.

The total number of decelerations was inversely associated with the InStat index among FB, meaning that a higher number of decelerations negatively affected real game efficacy for that playing position. Although FB are basically defensive players and their starting tactical line-up is in the first third of the pitch, the main technical requirements for FB are the number of entries to the third part of the pitch (i.e., pressing) and the number of crosses [38,45]. These duties are actually performed on the opponent's half. Therefore, some of the most important tactical roles of the FB are actually in attacking. To create more of these activities, FB frequently have to move away from the starting tactical line-up, which actually enables them to make crosses and press. Consequently, if FB have a higher number of stoppings (i.e., decelerations), it probably negatively affects their ability to participate in attacking actions and to perform crosses and entries to the third part of the pitch. Collectively, it seems that soccer success of FB is more affected by their attacking activities, regardless of the fact that they are defensive players.

Previously, it was highlighted that FW had evidently shorter sprinting distances than players in the same position during games from other European competitions (please see previous discussion for details). However, results indicated a strong correlation between the InStat index and the sprint distance for this playing position, which led to conclusion that the sprint distance covered during the game was a highly important determinant of overall game performance for FW. Indeed, FW are positioned close to the opponent's goal, and almost every sprint presents the opportunity to perform attacking actions. In addition, FW have the lowest number of tackles, interceptions and clearances compared with other playing positions [38], which suggests that most of their activities are focused on attacking. With the higher number of attacking actions, there is a growing chance to enter the penalty area, shoot, and score. As a result, the number of attacking situations increases the likelihood for positive game outcomes [28,29,30].

The main role of CM is to organize the offense by proper ball control and passes, rather than by invasion into the opponent's area [38]. Considering the lack of significant association between running parameter and the InStat index for this playing position, it seems that CM soccer success is more influenced by some variables, other than those obtained by GPS, such as ball possession, number of key passes, dribbles, and shots. Also, the running indicators obtained by GPS measurements were not correlated to InStat variables in WM, which may be observed as surprising since WM experience the greatest physical requirements during the game, both in terms of total distance covered and high-intensity running [10]. The possible explanation may be the previously discussed finding of the small amount of overall distance covered in the studied Croatian players, which actually resulted in truncated variance and consequently statistically/mathematically decreased the possibility of achieving significant correlations.

Limitations and Strengths

The main limitation comes from the fact that this study observed only one team which was observed during one half season. Therefore, some specific covariates (limited number of observed players, strength of the opponent, specific tactical requirements) may influence reported results. Next, in this study no data were collected about psycho-physiological responses of the players (e.g., heart rate and RPE), which are known to be important determinants of overall performance. Further, this study actually studied relatively simple “game-related outcomes” (i.e., running performances obtained by GPS and game performance indicators obtained by InStat index), while sport-performances, especially those in team sports, are far more complex (i.e., include interaction, cooperation, and opposition) [46]. Also, in this study relatively simple methodology was applied, while complex systems like sport games may ask for more detailed experimental approaches and the use of mixed methods as an observational methodology [47].

On the other hand, this study has several strengths. First, this is one of the first studies which simultaneously evaluated two sets of performance variables (i.e., running performances and game performance indicators) and probably the first one where associations between these two groups of performances were analyzed. Also, the data were collected during official games, among professional players, and at the highest national competitive level. Therefore, results are generalizable to similar samples of participants and levels of competition. Furthermore, the position-specific approach in identification of the relationships between running performances and game performance indicators is important strength of the investigation. Therefore, despite the evident limitations, the authors believe that this study may contribute to the knowledge on this field and initiate further research.

2.1.5 Conclusions

The total distance covered during the match did not distinguish Croatian first division players from players who compete in elite European divisions (i.e., Spain and Germany). However, the players studied here achieved total distances at lower running speeds than their peers involved in top-level European competitions, which clearly indicates the lower game pace in Croatian soccer competition. These findings can be useful for determining the physical requirements and profiles of the players in the Croatian first division, especially with regard to international competitions (i.e., the European League, Champions League).

This study confirmed the association between the running performance of players involved in certain playing positions and overall game performance. Specifically, it seems that CD distance in the running zone and number of high-intensity accelerations, FB number of decelerations, and FW sprinting distance are crucial physical requirements of team success.

Training prescriptions in soccer should be based on established requirements specific to the playing positions, thereby ensuring that players are more able to fulfill their game duties and tactical responsibilities over the soccer match. In further studies it would be important to identify possible associations that might exist between different parameters of players' conditioning status and indicators of real game performance.

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2.2 Study 2: Playing position specifics of associations between running performance during the training and match in male soccer players

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Playing position specifics of associations between running performance during the training and match in male soccer players

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Abstract

Background: The relationship between the training load and game load considering soccer playing positions has not been sufficiently examined. Objective: The aim of this study was to examine the position-specific associations between running performance (RP) during the training and match in professional-level male soccer. Methods: The RPs of 15 players (age 23.57 ± 2.84 years, body height 181.9 ± 5.17 cm, body mass 78.36 ± 4.18 kg) were measured by the Global Positioning System over one half-season of the highest-level Croatian soccer competition and assessed according to their playing positions: central defenders (n = 22), fullbacks (n = 23), wide midfielders (n = 29), wingers (n = 6), and forwards (n = 12). Variables included the total distance covered; the distance covered by low intensity running, running, high-speed running, sprinting, and high intensity running; and the number of accelerations, high-intensity accelerations (HIA), decelerations, and high-intensity decelerations (HID). Results: Analysis of variance revealed significant differences in high-speed running, HID, and HIA (p = .01, all highest in forwards), and sprinting (p = .01, highest in the wide midfielders). The HIA and HID at training were significantly (p = .04 and .01, respectively) correlated (r = .42 and .52) with the corresponding match RP in fullbacks. The high-intensity running (high-speed running + sprinting), running, HIA and HID performance values were significantly correlated (r = .64, .52, .59, and .52, respectively; all p = .01) with the corresponding running performances from matches in central midfielders. Conclusions: Structure-specific training is highly recommended for some playing positions. The information obtained can be used to improve soccer training programs.

Keywords: football, training load, game load, relationships, conditioning, performance analysis

2.2.1 Introduction

Soccer is a highly complex team sport; it involves two teams, changing dynamics and multistructural movements (Modric, Versic, Sekulic, & Liposek, 2019). The actions during a game involve running at different intensity levels, many changes in direction, tackles and jumps with short recovery periods (Sládečková, Botek, Krejčí, & Lehnert, 2019). Professional soccer training programs are designed to enable players to achieve an appropriate conditioning status, prevent injuries and compete at the highest possible level during the season (Jaspers, Brink, Probst, Frencken, & Helsen, 2017). For such purposes, training programs need to be able to be modified so that they are optimally individualized and that, consequently, players' match performance is maximized (Castagna, Chamari, Stolen, & Wisloff, 2005). Thus, proper and continuous monitoring of the training load is important to determine the applied training load and implement interventions in subsequent sessions (i.e., increases or decreases in the training load; Jaspers et al., 2017; Rebelo et al., 2012).

Training loads can comprise external and internal loads (Impellizzeri, Rampinini, Coutts, Sassi, & Marcora, 2004). External training loads are measured by the work done by players and are currently commonly monitored by Global Positioning System (GPS) technology (Buchheit et al., 2013). Internal training loads are measured by the metabolic demands required to complete the external work (Bingham, 2015) and are commonly monitored using physiological and/or perceptual measures such as the player's heart rate and rating of perceived exertion (Coutts & Cormack, 2014). However, the external load (i.e., total distance covered, distances covered in different speed zones, number of accelerations and decelerations) is most often quantified for a comprehensive understanding of the soccer training program implemented, and there is a growing interest in the monitoring of the external training loads during soccer training (Akenhead & Nassis, 2016; Carling & Orhant, 2010; Jaspers et al., 2017; Owen et al., 2015; Stevens, de Ruiter, Twisk, Savelsbergh, & Beek, 2017).

In a very recent study, the authors assessed the in-season external training load of the UEFA Champions League team and indicated that the total distance tended to decrease during the in-season (from 5,589 m to 4,545 m; Oliveira et al., 2019). These results are consistent with those in reports on training programs for elite English Premier League soccer players (Malone et al., 2015). Akenhead, Harley, and Tweddle (2016) assessed the position-specific external training loads of an English Premier League soccer team during training, especially in terms of acceleration, and found that some acceleration variables successfully differentiated playing positions, with midfield players accounting for a large portion of the total distance covered and central defenders being differentiated by low and moderate acceleration thresholds. Anderson et al. (2016) quantified training loads in English Premier League soccer players during a one-, two- and three-game week schedule and indicated that the total distance covered in daily training sessions was lower in the three-game week than in the one- and two-game weeks.

The match performance in official soccer matches (i.e., external match loads) was more frequently evaluated than were training loads; additionally, the results obtained by highly sophisticated global positioning systems (Aquino et al., 2020; Modric et al., 2019) and those obtained by various video-based platforms are generally consistent (Barros et al., 2007; Bradley et al., 2009; Di Salvo et al., 2007; Liu, Yi, Giménez, Gómez, & Lago-Peñas, 2015; Vigne, Gaudino, Rogowski, Alloatti, & Hautier, 2010). Accordingly, it is evident that both (i) external training load and (ii) match performance during soccer matches are often investigated separately (Jaspers et al., 2017; Sarmento et al., 2014), while the relationship between the external match load in official matches and weekly external training load has not been sufficiently explored. To the best of our knowledge, only two studies have examined players' match performance in official matches in relation to the in-season training periodization of elite soccer teams.

Stevens et al. (2017) compared the in-season external training load and match load in professional Dutch Eredivisie soccer players and reported that there was a lower load when training approached the match day Additionally, regarding the relative match values, the weekly acceleration training load was higher (3.1–3.9 times) than the running zone training load and high-speed running training load (2.5 and 2.1 times, respectively). In a very recent study, Clemente et al. (2019) investigated the general relationship between total weekly training loads and the weekly match demands in the Primeira Liga and reported trivial-to small correlations between the total weekly loads and match demands.

Although some previous studies evidenced the correlations between external match load and training load (Clemente et al., 2019; Stevens et al., 2017), to the best of our knowledge, taking into account soccer playing positions, there is no information about the relationship between the training load and game load. We were of the opinion that this topic is important to study since each playing position is associated with specific duties during a game (Kim, 2000), and these specific duties are naturally influenced by position-specific indicators of the game load (Dellal, Wong, Moalla, & Chamari, 2010). Therefore, the main aim of this study was to examine the position-specific associations that may exist between the external training load in one week and match performance in subsequent soccer matches. Additionally, the differences in running performance among (i) playing positions for the total training load in the observed period (e.g., half-season – 15 weeks) and (ii) in each mesocycle (the first three mesocycles lasted 4 weeks, while the last one lasted 3 weeks) were analyzed as suggested previously (Oliveira et al., 2019).

2.2.2 Methods

Participants and design

For the purpose of this research, all participants signed an informed consent form agreeing to participate in the study. Fifteen players were analyzed through 92 match performances and running performance events that occurred during training sessions in the week preceding each match. Averagely, 6 match and running performances were analyzed per each player (ranged from 1 to 12). All the data were collected from the 15 matches of Croatian top-division competitive soccer and from 75 training sessions during one half-season in which matches were played. The half season phase was analyzed through 4 mesocycles, as suggested previously by Oliveira et al. (2019). First three mesocycles lasted 4 weeks, while the last one lasted 3 weeks. The players (M ± SD, age 23.57 ± 2.84 years, body height 181.9 ± 5.17 cm, body mass 78.36 ± 4.18 kg) were members of one team. In this study players' performances were observed according to their playing positions, and resulted in performances at the position of (i) central defender (CD, n = 22), (ii) fullbacks (FB, n = 23), (iii) central midfielders (CM, n = 29), (iv) winger-midfielders (WM, n = 6), and forwards (FW, n = 12).

At the end of the observed period, the team was ranked 2nd of 10 teams. Only the performance of the players who played the whole game and participated in all training sessions in the week before each match were included in this study.

The study protocol was approved by the Ethical Board of University of Split, Faculty of Kinesiology.

Procedures

The variables in this study included players' age, body height, weight and playing position and two sets of running performance variables, namely, running performance variables for the official matches (RMs) and running performance variables measured during training in the preceding week (RTs). Specifically, the RMs were measured during official matches, as previously suggested and reported in detail (Oliveira et al., 2019). The RTs were measured during all the training sessions that the team participated in during the week and preceded official matches. The RTs and RMs included the total distance covered during the match/training week (m); distance covered in five speed categories: low intensity running (< 14.3 km/h), running (14.4–19.7 km/h), high-speed running (19.8–25.1 km/h), sprinting (≥ 25.2 km/h), and high-intensity running (> 19.8 km/h); total accelerations (> 0.5 m/s2); high-intensity accelerations (> 3 m/s2); total decelerations (< [–]0.5 m/s2); and high-intensity decelerations (< [–]3 m/s2).

All data were collected by GPS technology (OptimEye S5 & X4, Catapult, Melbourne, Australia) with a sampling frequency of 10 Hz. The average number of satellite signals was 12.03 ± 0.5, while the horizontal dilution of precision was 0.83 ± 0.1. The reliability and validity of the equipment has previously been presented in detail (Castellano, Casamichana, Calleja-González, San Román, & Ostojic, 2011; Johnston, Watsford, Kelly, Pine, & Spurrs, 2014).

Statistics

The normality of the distributions was confirmed by the Kolmogorov-Smirnov test, and the data are presented as the means ± standard deviations. Homogeneity was checked by Levene's test. Differences among the playing positions in terms of running performance were analyzed by one-way analysis of variance, while the consecutive Scheffe post hoc test was used to analyze the specific differences across playing positions. To evaluate the effect sizes (ES), partial eta-squared values were presented (> .02, small; > .13, medium; > .26, large; Cohen, 1988; Ferguson, 2009).

To identify the associations in the running parameters between training sessions and games, Pearson's correlation coefficient was calculated for the observed half-season period.

For all analyses, Statistica (Version 13; TIBCO Software, Palo Alto, CA, USA) was used, and a significance level $\alpha = .05$ was applied.

2.2.3 Results

Table 1 presents the descriptive parameters for the running performance in weekly training sessions and the corresponding differences among playing positions. The highest amount of high-intensity running (highspeed running + sprinting) was performed by FBs (732 m; significant post hoc difference between FBs and CMs; all $p < .01$), with medium ES. The number of high-intensity decelerations was significantly lower in the CMs (37 repetitions) than in the CDs (63 repetitions) and FWs (71 repetitions), all $p < .01$, large ES. The number of high-intensity accelerations was significantly higher in the FWs, CDs and FBs (37, 32 and 26 repetitions, respectively) than in the CMs (16 repetitions), $p < .05$, large ES.

Table 1. Comparison of running performance in weekly training sessions across playing positions (data are given as M ± SD)

	Central defenders	Fullbacks	Central midfielders	Wide midfielders	Forwards	F (p)	η_p^2
Total distance (m)	18130.5 ± 3802.7	17862.0 ± 5727.5	19397.5 ± 5658.7	20048.0 ± 6827.8	20330.8 ± 6604.7	0.64 (.64)	.03
Low intensity running (m)	16098.4 ± 3432.7	15606.7 ± 5220.8	17260.8 ± 4892.1	17652.0 ± 6101.8	17764.2 ± 5811.0	0.67 (.62)	.03
Running (m)	1486 ± 315.5	1525.6 ± 441.6	1716.0 ± 831.7	1676.0 ± 572.06	1881.0 ± 662.7	1.14 (.34)	.05
High speed running (m)	454.4 ± 149.1	594.7 ± 172.9^{CM}	399.6 ± 249.9^{FB}	584.2 ± 245.1	596.3 ± 217.9	4.11 (.01)	.16
Sprint (m)	91.1 ± 78.3	134.7 ± 90.6^{CM}	33.5 ± 35.1^{FB,WM}	135.5 ± 75.9^{CM}	89.1 ± 45.0	8.27 (.01)	.27
High intensity running (m)	549.5 ± 191.2	729.4 ± 244.8^{CM}	433.0 ± 274.1^{FB}	719.7 ± 320.4	685.5 ± 243.5	5.74 (.01)	.21
Accelerations (count)	809.4 ± 195.4	729.2 ± 255.6	820.5 ± 328.7	815.7 ± 364.4	932.3 ± 334.9	1.01 (.41)	.04
Decelerations (count)	807.4 ± 190.1	718.4 ± 255.6	828.1 ± 297.1	857.3 ± 295.1	920.8 ± 332.1	1.25 (.30)	.05
High intensity accelerations (count)	32.6 ± 12.3^{CM}	26.1 ± 10.1^{CM}	16.1 ± 7.1^{CD,FB,FW}	24.3 ± 12.7	37.2 ± 17.3^{CM}	10.63 (.01)	.32
High intensity decelerations (count)	63.3 ± 23.3^{CM}	42.9 ± 14.1^{FW}	37.1 ± 23.6^{CD,FW}	38.2 ± 15.6	71.4 ± 28.3^{FB,CM}	8.48 (.01)	.28

Table 2 presents descriptive parameters for the match performance and the corresponding differences among playing positions. The greatest total distance was covered by CMs (10,951 m; significantly higher than that of FBs, CDs and FWs; all $p < .01$, large ES). Compared to all other playing positions, CDs had the lowest high-intensity distance covered (432 m, large ES) and distance covered in the zone of running (958 m, large ES). CMs carried out the highest number of total accelerations (478 repetitions, large ES) and decelerations (473 repetitions, large ES), which was both significantly higher than that of FBs, CDs and FWs (all $p < .01$). The number of high-intensity accelerations (31 repetitions, large ES) and decelerations (52 repetitions, large ES) was significantly higher for FWs than for all other playing positions (all $p < .01$).

Table 2. Comparison of match performance in weekly training sessions across playing positions (data are given as M ± SD)

	Central defenders	Fullbacks	Central midfielders	Wide midfielders	Forwards	F (p)	η_p^2
Total distance (m)	8957.0 ± 500.0^{CM,WM,FB}	9719.5 ± 597.6^{CM,CD}	10951.0 ± 595.3^{FB,CD,FW}	10515.5 ± 768^{CD,FW}	9598.1 ± 449.7^{CM,WM}	42.7 (< .001)	.66
Low intensity running (m)	7566.8 ± 393.0^{CM,WM}	7805.7 ± 462.8^{CM}	8706.2 ± 531.3^{FB,CD,FW}	8409.5 ± 463.3^{CD,FW}	7478.3 ± 312.0^{CM,WM}	28.6 (< .001)	.57
Running (m)	958.1 ± 138.9^{CM,WM,FB,FW}	1171.3 ± 134.4^{CM,CD}	1593.2 ± 271.6^{FB,CD,FW}	1359.8 ± 197.2^{CD}	1227.6 ± 95.6^{CM,CD}	37.6 (< .001)	.63
High speed running (m)	335.8 ± 88.5^{CM,WM,FB,FW}	517.6 ± 106.9^{CD}	557.8 ± 151.7^{CD}	527.8 ± 198.8^{CD}	596.4 ± 120.8^{CD}	12.5 (< .001)	.36
Sprint (m)	96.2 ± 40.5^{WM,FB,FW}	215.5 ± 62.2^{CM,CD,FW}	97.0 ± 53.9^{WM,FB,FW}	218.0 ± 72.2^{CM,CD}	295.0 ± 96.0^{CM,FB,CD}	34.1 (< .001)	.61
High intensity running (m)	432.0 ± 110.4^{CM,WM,FB,FW}	733.1 ± 148.5^{CD}	654.8 ± 183.0^{CD,FW}	745.8 ± 268.8^{CD}	891.4 ± 188.8^{CM,CD}	17.5 (< .001)	.44
Accelerations (count)	395.9 ± 54.7^{CM}	392.0 ± 84.4^{CM}	477.9 ± 50.6^{FB,CD,FW}	446.2 ± 49.8	396.4 ± 35.0^{CM}	9.4 (< .001)	.30
Decelerations (count)	399.2 ± 61.2^{CM}	404.1 ± 38.7^{CM}	472.6 ± 45.8^{FB,CD,FW}	447.5 ± 62.1	404.1 ± 33.0^{CM}	1.6 (< .001)	.33
High intensity accelerations (count)	12.6 ± 3.4^{FW}	12.5 ± 4.6^{FW}	10.7 ± 4.6^{FW}	10.3 ± 2.7^{FW}	30.6 ± 7.5^{CM,WM,FB,CD}	41.9 (< .001)	.66
High intensity decelerations (count)	27.5 ± 6.2^{FW}	32.2 ± 9.7^{FW}	35.0 ± 10.3^{FW}	34.5 ± 11.7^{FW}	51.8 ± 5.7^{CM,WM,FB,CD}	15.0 (< .001)	.41

Figure 1 presents training loads across playing positions in four mesocycles. In the first mesocycle (Figure 1A), significant differences among the playing positions were found for high-intensity running (sprinting + high-speed running) and the number of high-intensity accelerations/decelerations (all were highest in the FWs). In the second mesocycle (Figure 1B), significant differences were found in high-intensity accelerations and decelerations (which were the highest in the CDs and FWs). In the fourth mesocycle (Figure 1D), the playing positions differed by the sprint distance covered (which was the highest in the WMs and FWs).

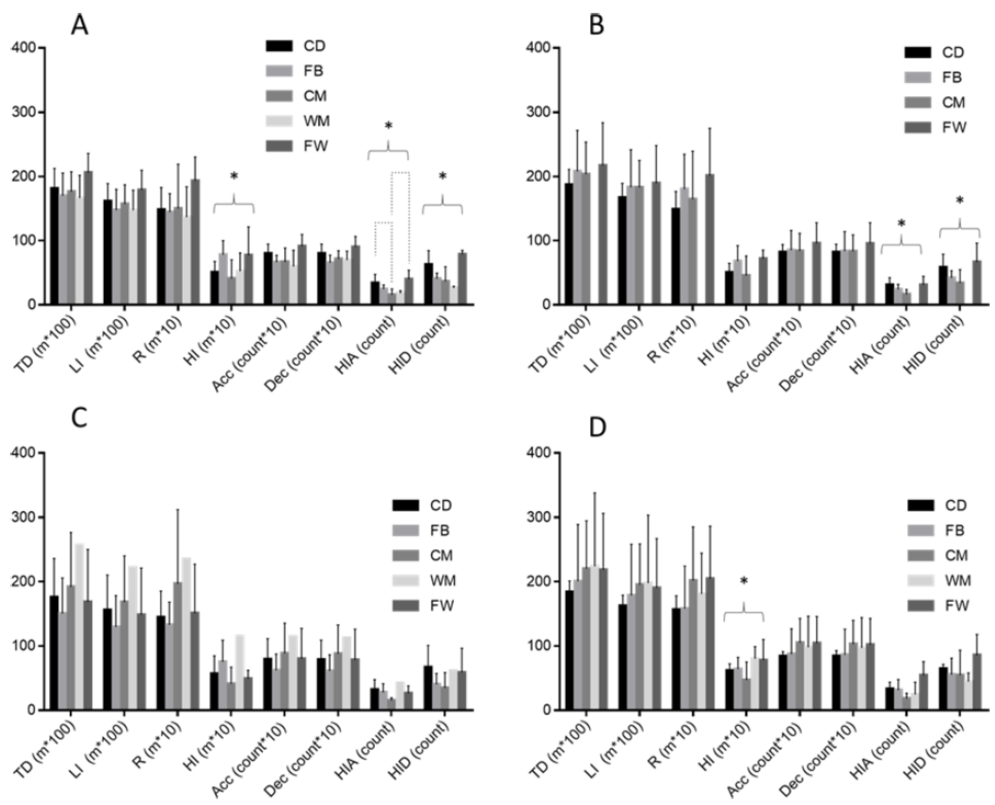

Figure 1. Differences among the playing positions (CD = central defenders, FB = fullbacks, CM = central midfielders, WM = wide midfielders, FW = forwards) in the running performance during training in each mesocycle (A = first mesocycle, B = second mesocycle, C = third mesocycle, D = fourth mesocycle). TD = total distance covered, LI = low intensity running, R = running, HI = high intensity running (high speed + sprint), Acc = accelerations, Dec = decelerations, HIA = high intensity accelerations, HID = high intensity decelerations. *denotes significant differences among playing positions obtained by analysis of variance. Dashed lines present significant post-hoc differences.

Table 3 presents the correlations between match performance and weekly values of the same variables (e.g., corresponding variables/performance). The FBs' high-intensity accelerations and decelerations in matches were significantly correlated ($p = .04$ and .01, respectively) with corresponding variables obtained in the previous week during training ($r = .42$ and .52 for accelerations and decelerations, respectively). For the CDs, the distance covered in the zone of running and high-intensity accelerations in the matches were found to be correlated with the corresponding training variables ($r = .51$ and .48, respectively). The CMs' distance covered during high-intensity running (high speed running + sprinting; $r = .64$), distance covered during running ($r = .52$), and number of high-intensity accelerations/ decelerations ($r = .59$ and .63, respectively) were found to be significantly correlated with the corresponding performance in the training sessions (all $p = .01$).

Table 3. Pearson's correlation coefficients between match performance and weekly training performance of the corresponding variables for the observed half-season (data are given as r (p)) 4. Discussion

	Central defenders (*n* = 22)	Fullbacks (*n* = 23)	Central midfield-ers (*n* = 29)	Wide midfielders (*n* = 6)	Forwards (*n* = 12)
Total distance	.01 (.95)	.06 (.78)	.34 (.06)	-.14 (.78)	.10 (.74)
Low intensity running	–.13 (.55)	–.08 (.72)	.20 (.28)	–.10 (.84)	.25 (.42)
Running	.51 (.02)	.08 (.72)	.52 (.01)	.17 (.74)	.02 (.94)
High speed running	.47 (.03)	.20 (.35)	.56 (.01)	.41 (.42)	–.25 (.44)
Sprint	.16 (.49)	.01 (.99)	.64 (.01)	.30 (.56)	.17 (.59)
High intensity running	.54 (.01)	.17 (.41)	.64 (.01)	.37 (.46)	–.21 (.50)
Total accelerations	.14 (.52)	.01 (.99)	.23 (.21)	.28 (.58)	.23 (.47)
Total decelerations	.20 (.36)	.23 (.28)	.17 (.35)	.44 (.38)	.33 (.29)
High intensity accelerations	.48 (.02)	.42 (.04)	.59 (.01)	.08 (.87)	.42 (.17)
High intensity decelerations	.33 (.13)	.52 (.01)	.63 (.01)	.47 (.35)	.29 (.35)

2.2.4 Discussion

Differences among playing positions in running performance

The present study demonstrated that the FWs tended to cover the longest total distance (20,330 m on average per week), and the FBs covered the shortest total distance (17,862 m on average), but there was no significant difference across the playing positions in terms of the weekly total distance covered. These findings are in line with those in the previously cited Portuguese study in which the authors demonstrated limited relevant variation among the playing positions (Oliveira et al., 2019). This result may suggest that immediately after the preseason, coaches still emphasize physical conditioning for certain players and consequently implement position-specific training loads only at the very beginning of the competitive season**.**

The external players (FBs and WMs) and front players (FWs) observed herein covered the greatest distance during high-intensity running in training sessions (FB = 729 m, WM = 719 m, FW = 685 m, followed by CD = 545 m and CM = 433 m), which is logical considering that similar patterns are observed in soccer games (Bradley et al., 2009; Di Salvo et al., 2007; Mallo, Mena, Nevado, & Paredes, 2015). Additionally, we found significant differences between FBs and CMs in the high-intensity running distance covered during training, which indicates that different coaching approaches and position-specific training were implemented. This result supports the recent considerations of different physical requirements and training demands for each playing position (Oliveira et al., 2019). For instance, the main tactical requirements for FBs include the number of entries to the third part of the pitch (i.e., presses) and the number of crosses (van Lingen, 1997; Yi, Jia, Liu, & Gómez, 2018). Therefore, specific training for this playing position should involve more high-intensity running than CM training, as the main role of CMs is to organize the offense by facilitating ball control and passes rather than by invading the opponent’s area (Yi et al., 2018).

Analysis of the weekly total number of accelerations and decelerations in training did not indicate differences across playing positions. On the other hand, the CMs’ weekly number of high-intensity accelerations in training was found to be statistically significantly lower than those for nearly all other playing positions. Additionally, the number of high-intensity decelerations in training was found to be statistically significantly lower in CMs than in CDs and FWs. These findings, together with the previously reported results of the high-intensity distance covered each week, imply that CMs train at a relatively low intensity throughout the week. These players are probably more focused on ball possession and the number of key passes, dribbles and shots, considering that these performance variables are key for their success in soccer games (Modric et al., 2019).

When the total training load was assessed through mesocycles, there were significant differences across playing positions for training running performance in almost all mesocycles. These results are not in accordance with those in the very recent study performed by Oliveira et al. (2019), in which the authors demonstrated that there are significant differences among playing positions only in the first mesocycle after the preseason. Presumably, this inconsistency may be a result of the different training approaches and philosophies implemented in different countries (e.g., Portugal and Croatia). Regardless of the differences in the results between studies, it is clear that in the mesocycles where significant differences among positions were found, the training sessions involved position-specific training drills. In contrast, through the weeks in which there were no significant differences, the coaches actually used a similar training methodology for all players, independent of their playing positions in the matches.

Correlations between training load and game performance

Our results indicated that the distance covered while running (speed of 14.4–19.7 km/h) and number of high-intensity accelerations in matches are correlated with the weekly values of the same variables for CDs. In other words, training demands that involve (i) more effort in the running zone and (ii) high-intensity accelerations correspond to changes in the same performance variables during games for this playing position. As previously mentioned, these variables were identified as important determinants of game success for this position (Modric et al., 2019). Therefore, the correlation between training sessions and matches in these variables implies that (i) structurally position-specific training has been applied in training programs for CDs and that (ii) such an approach directly corresponded to their performance during games. As a result, along with specific soccer requirements, it is highly recommended that position-specific training for CDs involve training in the running zone and high-intensity accelerations, which can consequently improve the success of CDs in soccer games.

Of all the positions, central midfielders covered the shortest distance during high-intensity running (high-speed running [19.8–25.1 km/h] + sprinting [≥ 25.2 km/h]) and had the fewest high-intensity accelerations and decelerations during training. Accordingly, this result may suggest that CMs are more focused on developing soccer skills than performing high-intensity tasks. This result is consistent with those in previous studies on match performance (Modric et al., 2019). Additionally, it must be noted that the Croatian First Football (Soccer) League is less competitive than the top-level European leagues (Modric et al., 2019), so it seems that high-intensity efforts in CM training and the style of the games are probably sufficient for position-specific success in the competitive soccer league observed in this study (Croatian National League). However, the presence of a positive correlation between high-intensity efforts (i.e., correlation between distance covered during high-intensity running and number of high-intensity accelerations and decelerations) achieved during training sessions and games indicates that training focused on high-intensity efforts may lead to improvement in CMs' high-intensity match performance in the same week. This relation is important for creating position-specific training programs for the central midfielders that are planning to play in top-level European soccer leagues.

The sprint distance covered during games is an important determinant of FWs' overall game performance (Modric et al., 2019). In other words, the greater the distance covered while sprinting, the higher the position-specific performance of these players will be during games. Our results indicated that FWs cover the greatest distance during high-intensity running (i.e., both high speed and sprinting distances) during the weekly training sessions (please see previous discussion for details), but surprisingly, no correlations between any of the external load variables observed in training and during matches for this position were observed. Although correlations for FWs possibly did not reach statistical significance because of the relatively small number of running performances (n = 12), this result is particularly interesting and important to highlight, as sprinting is an important determinant of their success. Because the authors of this study have been deeply involved in the training and conditioning of the players included in this study, we suggest that the reason for this finding is specific (i.e., a lack of correlation between sprinting in training sessions and sprinting in games). In brief, the main objective of FWs is to score goals, which is also the main objective in soccer matches (Kim, 2000). To improve their scoring skills, FW players are usually more involved than other players in position-specific work, which mostly consists of different finishing drills (i.e., shooting, scoring goals). In fact, at the end of most team training sessions, FWs stay for extra practice. However, their training drills are based on short-intensity efforts (high-intensity accelerations and decelerations + shooting) rather than sprinting + shooting. The differences among playing positions directly support this explanation (FWs had the most high-intensity accelerations/ decelerations of all playing positions; see Results for details). Accordingly, it seems that sprinting, although it is an important determinant of FW success, is actually undertrained in weekly training sessions.

Previously, it was discussed that performing more stops (i.e., decelerations) negatively affects FBs' success in soccer games (Modric et al., 2019). Specifically, it was suggested that more decelerations alter FBs' ability to perform attacks, crosses and moves to the third part of the pitch (i.e., presses), which are all important determinants of successful performance for players in this position (Modric et al., 2019). In general, soccer players with higher maximum acceleration rates can jump higher, sprint faster (over short distances), and achieve changes in direction at higher velocities (Loturco et al., 2019). Thus, to achieve more presses (i.e., number of entries to the third part of the pitch), higher maximum acceleration and deceleration rates may enable FBs to have an advantage over the opponent defenders and make more crosses. Taking this concept into account, the positive correlation between the number of high-intensity accelerations and decelerations during the matches and weekly training sessions may suggest that the training for FBs was specifically structured. Evidently, performing more high-intensity accelerations and decelerations in a week will positively affect the number of high-intensity accelerations and decelerations that FBs achieve during matches. Such training may decrease the total number of decelerations performed in matches and consequently improve the performance of FBs in particular; however, this topic should be explored in more detail in future studies.

The present study did not show a correlation between running performance variables observed in matches and weekly training sessions for WMs. Further, a small sample for this position (n = 6) contributed to statistical significance not being reached. However, this result is not surprising considering that previous position-specific analyses have indicated that there is no correlation between WMs' match performance and general performance in matches (Modric et al., 2019). Collectively, these results suggest that the performance of WMs is based on soccer skills, both during training and matches. Specifically, although WMs generally experience the highest physical requirements during matches and training (Mallo et al., 2015; Oliveira et al., 2019), it seems that it is more important for them to be focused on soccer-related skills (i.e., passing, dribbling, shooting) rather than running performance; running performance is actually a necessary prerequisite (i.e., basis) and not a factor that directly influences their performance.

Limitations and strengths of the study

This study has several limitations that must be mentioned before drawing the conclusion. First, the study evaluated a team competing in the Croatian National Championship, which is certainly not the top-level European competition. Therefore, the results are generalizable to similar competitive levels. Next, we observed only one half-season, and for more extensive analysis, evaluation of the whole competitive season is necessary. Additionally, in this study, we included only players who participated in all training sessions and played the whole game in each week, which reduced the number of observations. However, this approach was done intentionally since otherwise, the running performance results would be logically influenced by numerous other factors apart from those related to training load and game performance. Last, due to the limited number of entities, the associations were not analyzed for different mesocycles (i.e., we observed only those players who participated in all training sessions and played the whole game during each week over the observed half-season).

This is probably the first study where the running performance at training and during games was studied separately for playing positions. Therefore, we believe that the findings can be used to improve the training process and consequently increase the possibility of achieving positive competitive results in soccer. Additionally, the present study is the first to utilize position-specific external training load measures to assess changes in the match performance of elite soccer players while at the same time reinforcing the importance of a load monitoring system in elite sporting environments. Ultimately, the results of this study can be used to change the current monitoring approaches and lead to a better understanding of position-specific demands.

2.2.5 Conclusions

This study suggests that training sessions based on high-intensity accelerations and efforts during running likely positively affect related performance variables measured during m atches for CDs, which consequently increase their success in soccer. Additionally, FW players should perform more sprinting-related training during the week, as it has previously been indicated to be an important determinant of their success in soccer.

Training for CMs and WMs should be based more on soccer skills rather than running performance. However, although CMs' success in soccer is not dependent on their match performance, it should be emphasized that increasing the training intensity can probably positively affect their performance in matches.

The results suggest that structure-specific training is highly recommended for CD and FW players, while the relationship between weekly external loads and running match performance in FB players should be explored in further detail in future studies. Furthermore, the results of this study can be used to improve the training process and consequently increase the performance of the whole team.

Finally, this study did not show significant differences between playing positions during the weekly training sessions in variables that determine training volume (e.g., the total distance covered, distance covered during low-intensity and moderate-intensity running, total number of accelerations/decelerations), while the intensity variables (e.g., distance covered during high-speed running and sprinting, number of high-intensity accelerations/decelerations) could be used to differentiate the players by playing positions.

Conflict of interest

There were no conflicts of interest.

2.2.6 References

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2.3 Study 3: Relations of the Weekly External Training Load Indicators and Running Performances in Professional Soccer Matches

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Relations of the Weekly External Training Load Indicators and Running Performances in Professional Soccer Matches

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Abstract

The aim of this study was (i) to examine associations between training load during the week and match outcomes; (ii) to evidence position-specific differences between playing positions of training load and match running performances in top-level soccer/football. Training load and match running performances were evaluated through external load parameters: total-distance-covered, distance covered by walking, jogging, running, high- intensity-running (high-speed-running + sprinting); the number of accelerations, high-intensity-accelerations, decelerations, and high-intensity- decelerations. All data were obtained via the Global Positioning System from twelve matches of the highest-level Croatian soccer competition and from training sessions in the preceding weeks. The players (age: 23.57±2.84 years) were divided into five playing positions: central defenders (n=18), full- backs (n=20), central midfielders (n=26), wing midfielders (n=5) and forwards (n=9). Significant ANOVA differences ($p<0.05$) were found in all external match load variables, while in weekly training sessions only in high-intensity- running, high-intensity-accelerations, and high-intensity-decelerations distinguished players across their playing positions. Inverse correlation for most of the external load parameters and positive correlation for the number of training sessions with match outcome was evidenced. Chances of positive match outcome were greater in weeks when the team participated in fewer training sessions and consequently had lower values of external training load.

Keywords: football, training load, game load, relationships, conditioning, performance analysis

2.3.1 Introduction

Soccer (football) is characterized by numerous dynamic activities' cyclic and acyclic movements (Gardasevic & Bjelica, 2019). The physical demands of elite soccer matches have increased substantially over the previous decade (Bradley et al., 2016). With regards to the different tactical roles, these demands vary according to the different playing positions (Di Salvo, Gregson, Atkinson, Tordoff, & Drust, 2009; Mallo, Mena, Nevado, & Paredes, 2015; Modric, Versic, Sekulic, & Liposek, 2019; Mouloud, 2019). Previous studies have provided detailed information about the position-specific running performances (Sarmento et al., 2014). In brief, it was highlighted that midfielders cover the highest total distance and players that play by the sides of the field (e.g., full-backs and wing midfielders) cover the greatest distances in high-intensity running (Di Salvo et al., 2007; Modric et al., 2019).

With the increased physical demands of soccer matches, optimal physical preparation of players became an indispensable part of professional soccer (Andrzejewski, Konefał, Chmura, Kowalczuk, & Chmura, 2016), while the monitoring of the training load turned out to be a key factor for accurate control of the training process (Rebelo et al., 2012). Specifically, an accurate evaluation of training load is paramount for the planning and periodization of training, especially with regard to the prevention of undertraining or overtraining, and ensuring that athletes are in an optimal condition for competition (Rebelo et al., 2012).

Training load can be differentiated into external and internal loads. The external load can be derived from measurements of a player's movement on the pitch, and the internal load is related to the physiological and psychological stresses imposed on the player's body (Jaspers, Brink, Probst, Frencken, & Helsen, 2017). Typically, measures of internal training load are heart rate-based training impulse (TRIMP) and the session rate of perceived exertion (s-RPE) (Wallace, Slattery, & Coutts, 2014), while external training load is mostly evaluated with measures obtained from GPS or video-based technologies (i.e., total distance covered, different speed zone distance covered, accelerations and decelerations) (Scott, Lockie, Knight, Clark, & de Jonge, 2013).

Previous studies have described the in-season training periodization practices of elite soccer teams in detail. Briefly, Malone et al. (2015) and Stevens, de Ruiter, Twisk, Savelsbergh, and Beek (2017) reported lower training loads when training sessions approached match day. In a recent study, Oliveira et al. (2019) evidenced in-season external training load of UEFA Champions League team and indicated that total distance tended to decrease during the in-season (from 5589 m to 4545 m) (Oliveira et al., 2019). Akenhead, Harley, and Tweddle (2016) observed position-specific external training load of an English Premier League soccer team during training and found that some acceleration variables successfully differentiated playing positions with midfield players covering more distance within the total, low, and moderate acceleration thresholds than central defenders (Akenhead, Harley, & Tweddle, 2016). Clemente et al. (2019) reported that weeks with five training sessions had statistically more significant values for all external load ratios than weeks with three or four sessions.

The final achievement of the soccer game is assessed by match outcome (winning, losing or drawing). Therefore, it is not surprising that authors often search for the parameters that affect match outcome (Oberstone, 2009; Tenga & Sigmundstad, 2011). Several attempts have been made to determine performance indicators that may distinguish winning from losing teams (Oberstone, 2009; Tenga & Sigmundstad, 2011). Consequently, the essential aspects of final performance and achievement were technical indicators (Rampinini, Impellizzeri, Castagna, Coutts, & Wisløff, 2009), tactical- (Taylor, Mellalieu, & James, 2005), physical indicators (Gregson, Drust, Atkinson, & Salvo, 2010), and situation variables (Taylor, Mellalieu, James, & Barter, 2010). Although these studies provided a great deal of valuable information, there is an evident lack of studies that examined the training load parameters as factors of possible influence on match outcomes. While there is a growing interest for the analysis of how running match performances (i.e., external match load) affect match outcome, to the best of our knowledge, there is no study that has explored the association between external training load from weekly sessions and match outcomes in soccer. Interestingly, authors from other sports (e.g., ice hockey and Australian soccer) have focused on this issue and reported valuable results for their sports (Douglas et al., 2019; Sullivan et al., 2014). Therefore, the main objective of this study was to examine possible associations between external training load during the week and the match outcomes. Additionally, we examined position-specific training loads, game loads, and training/match ratio for studied soccer players. Altogether, these findings will provide better insight and understanding of the weekly external training sessions' load effects on success in soccer. Consequently, it could positively affect a team's possibility of winning the matches.

2.3.2 Methods

Participants and design

In this research, 77 training running performances were analysed as well as match performances of the same players at the end of the following week. All data were collected during 12 matches of the 2019/2020 season and during training sessions. In the observed period, the team played 7 home and 5 guest matches, with 8 wins, 2 draws, and 2 losses. Players (age: 23.57±2.84 years; body height: 181.9±5.17 cm; body mass: 78.36±4.18 kg) were divided into five different groups depending on playing positions: central defenders (n=18), full-backs (n=20), central midfielders (n=26), wide midfielders (n=5), and forwards (n=9); only players that played the whole game and participated on all training sessions in the week before each match were included in the study. This study was approved by the Ethics Board.

Procedures

The variables observed in this study were running parameters obtained during (i) game and (ii) training over the preceding week, playing position (central defenders, full-backs, central midfielders, wide midfielders, forwards), number of training session performed each week, home/guest match, and final match outcome (win, draw, lost) Running performances observed in the study were: total distance covered (m); distance in five speed categories (walking (<7.1 km/h), jogging (7.2-14.3 km/h), running (14.4–19.7 km/h), high speed running (19.8–25.1 km/h), and sprinting (>25.2 km/h)); total accelerations (>0.5 m/s²); high-intensity accelerations (>3 m/s²); total decelerations (< (-) 0.5 m/ s²) and high-intensity decelerations (< (-) 3 m/s²). For collecting data, GPS technology (Catapult S5 and X4 devices, Melbourne, Australia) with a sampling frequency of 10 Hz was used. The reliability and validity of the equipment had previously been confirmed in studies (Castellano, Blanco-Villaseñor, & Alvarez, 2011; Johnston, Watsford, Pine, & Spurrs, 2014).

Statistics

The normality of the distributions was checked with a Kolmogorov-Smirnov test, and data are presented as the means ± standard deviations. Differences between playing positions in running variables were analysed using a one-way analysis of variance (ANOVA) with Scheffe posthoc test. The ANOVA calculations were done separately for game-load and training-load variables. Associations between running parameters obtained at training and games were identified with Pearson's coefficient of correlation. Logistic regression for binary outcome was calculated in order to identify the association between running performances achieved at training during the preceding week and match outcome. The match outcome was binarized, and a won match was considered to be a "positive outcome" (coded as "2"), while the remaining two outcomes (loss and draw) were considered to be "negative outcomes" (coded as "1"). The logistic regression was controlled for covariate "home/guest match", since it was expected that there is a strong influence of this variable on match outcome, with a lower likelihood for a positive outcome for guest matches. In addition to running performances, the correlation was calculated between the number of training sessions in a week and match outcome (criterion). The Odds Ratio (OR), and 95% Confidence Interval (95%CI) were reported for each predictor (running performance). For all analyses, Statistica 13.0 (TIBCO Software Inc, USA) was used, and a p-level of 95% was applied.

2.3.3 Results

Significant ANOVA differences across playing positions ($p<0.05$) were found in all external match load variables. The greatest total distance (10,944 m) covered by central midfielders was significantly higher compared to almost all playing positions (e.g., when compared to central defenders, full-backs and forwards). The forwards covered the greatest distance in high intensity running (894 m), while central defenders high-intensity distance covered (411 m) was significantly lower compared to all playing positions. The central midfielders carried out the highest number of accelerations and decelerations, while forwards carried out the highest number of high-intensity accelerations and decelerations (Table 1).

Table 1. Comparison of game running performance across playing positions

	Central defenders M±SD	Full backs M±SD	Central midfielders M±SD	Wide midfielders M±SD	Forwards M±SD	F-test (p)
Total distance (m)	8880.2±512.3	9712.9±578.2	10944.6±615.9	10451.8±860.4	9625.9±471.4	36.59 (0.01)*
Low-intensity (walking + jogging) (m)	7539.0±417.5	7842.7±452.8	8727.7±535.4	8300.3±490.3	7495.6±348.3	23.50 (0.01)*
Running (m)	929.7±135.5	1150.1±128.5	1576.2±279.9	1328.3±230.7	1235.0±98.2	30.81 (0.01)*
High-intensity (high speed running + sprinting) (m)	411.3±111.8	709.4±123.5	644.2±184.2	823.3±284.3	894.0±195.4	16.60 (0.01)*
Accelerations (count)	395.2±58.8	387.7±89.9	477.3±53.5	434.5±59.7	393.0±39	7.30 (0.01)*
Decelerations (count)	396.0±64.7	401.8±40.7	471.7±48.3	429.5±71.7	398.2±35	8.63 (0.01)*
High-intensity accelerations (count)	12.7±3.3	11.9±4.2	10.8±4.8	10.3±3.3	30.0±8.3	29.24 (0.01)*
High-intensity decelerations (count)	27.4±6.7	29.9±7.9	34.2±10.6	36.5±14.2	50.9±5.2	11.93 (0.01)*

Legend: M – Mean; SD - Standard deviation; * - significant difference

The greatest weekly total distance was covered by forwards (19,829 m) and central midfielders (19,095 m), but no significant differences across playing positions were found. The highest amount of high-intensity running was performed by full-backs players (742 m), while the lowest was performed by central midfielders (428 m), with significant posthoc difference between full-backs and central midfielders. The forwards and central defenders carried out the highest number of total accelerations/decelerations and high-intensity accelerations/ decelerations (Table 2).

Table 2. Comparison of running performance in weekly training sessions across playing positions

	Central defenders M±SD	Full backs M±SD	Central midfielders M±SD	Wide midfielders M±SD	Forwards M±SD	F-test (p)
Total distance (m)	18070.4±4161.7	17531.7±5376.4	19095.9±5523	18880.0±5391	19829.0±6294.8	0.43(0.79)
Low-intensity (walking + jogging) (m)	16071.4±3750.9	15271.3±4893.4	16999.3±4783.6	16589.8±4514.9	17348.4±5562.4	0.51(0.73)
Running (m)	1468.9±336.1	1517.4±423.4	1681.3±841.1	1609.8±627.5	1826.1±651.3	0.70(0.59)
High-intensity (high speed running + sprinting) (m)	529.5±204.4	742.9±253.9	428.9±278.6	679.8±390.8	654.3±227	4.76(0.01)*
Accelerations (count)	802.4±214.5	707.6±235.8	794.0±320.4	735.0±342.5	895.6±324.5	0.79(0.53)
Decelerations (count)	799.7±207.5	697.1±235.1	804.8±287.6	801.3±242.7	887.2±324.5	0.98(0.43)
High-intensity accelerations (count)	32.5±13.1	25.3±9.2	15.8±7.1	24.3±12.2	31.6±12.3	8.65(0.01)*
High-intensity decelerations (count)	63.1±25.8	41.1±11.6	35.1±21.5	35.0±17.5	66.7±27.2	7.30(0.01)*

The highest training/match ratio was evidenced for the total number of accelerations (2.09), distance covered at low speeds (7.1-14.3 km/h) (2.04) and high-intensity acceleration (2.01) total number decelerations (1.87), and for total distance covered (1.87) (Figure 1). The training/match ratio for distance covered while running at medium speed (14.4–19.7 km/h) and high speeds (19.8+ km/h) was 1.31 and 0.92, respectively (Figure 1).

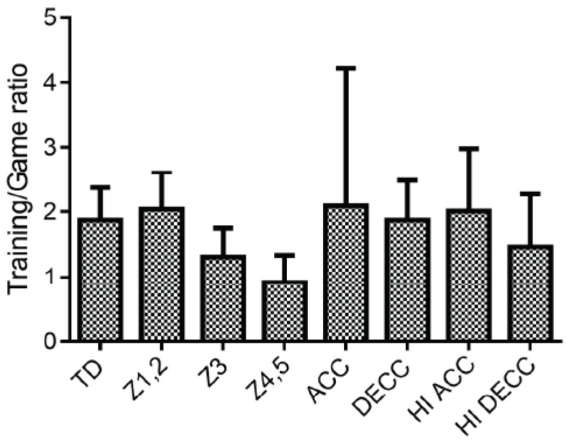

Figure 1. Training/match running performance ratio. Legend: TD – total distance; Z1,2 – low intensity running; Z3 – running; Z4,5 – high intensity running; ACC – acceleration; DECC – deceleration; HI ACC – high intensity accelerations; HI DECC – high intensity decelerations

The total distance covered (r=0.25), distance covered in running zone (r=0.39), high-intensity distance covered (r=0.48), high-intensity number of accelerations (r=0.43) and decelerations (r=0.39) from weekly training sessions were significantly correlated with values of associated match variables (Table 3).

Table 3. Pearson's correlation coefficients between running performance and weekly training performance of the corresponding variables

	Total distance (G)	Low-intensity running (G)	Running (G)	High-speed running (G)	Sprint (G)	High-intensity running (G)	Total accelerations (G)	Total decelerations (G)	High intensity-accelerations (G)	High-intensity decelerations (G)
Total distance (W)	0.25*	0.16	0.25*	0.29*	0.02	0.22	0.08	0.13	0.29*	0.30*
Low intensity (walking + jogging) (W)	0.25*	0.19	0.23*	0.25*	-0.02	0.17	0.09	0.14	0.27*	0.26*
Running (W)	0.27*	0.09	0.39*	0.45*	0.11	0.38*	0.15	0.17	0.35*	0.45*
High-intensity (high speed running + sprinting) (W)	-0.07	-0.26*	0.01	0.37*	0.51*	0.48*	-0.34*	-0.26*	0.21	0.25*
Total accelerations (W)	0.18	0.07	0.25*	0.28*	0.02	0.21	0.13	0.16	0.37*	0.39*
Total decelerations (W)	0.22	0.12	0.27*	0.28*	-0.00	0.20	0.15	0.21	0.36*	0.38*
High-intensity accelerations (W)	-0.41*	-0.48*	-0.30*	-0.02	0.33*	0.12	-0.28*	-0.30*	0.43*	0.23*
High-intensity decelerations (W)	-0.27*	-0.37*	-0.11	0.08	0.18	0.13	-0.18	-0.22	0.50*	0.39*

Legend: * - significant correlation

Table 4 presents the results of logistic regression for the binary outcome measure: match outcome. In general, most o the running performances in training were negatively related to the match outcome. Specifically, there is a lower likelihood for positive match outcome (e.g., winning the game), if players in weekly training sessions achieved higher: total distance covered (OR: 0.98; 95%CI: 0.98-0.99), low intensity (walking + jogging) distance covered (OR: 0.99, 95%CI: 0.97-0.99), running zone distance covered (OR: 0.99; 95%CI: 0.98-0.99), Z4W (OR: 0.97; 95%CI: 0.96-0.99), high-intensity (high speed running + sprinting) distance covered (OR: 0.98; 95%CI: 0.97-0.99), total number of accelerations (OR: 0.99; 95%CI: 0.98-0.99), total number of decelerations (OR: 0.98; 95%CI: 0.96-0.99), more high-intensity accelerations (OR: 0.96; 95%CI: 0.95-0.99), and more high-intensity decelerations (OR: 0.98; 95%CI: 0.97-0.99). To summarize, such associations were all generated by higher numbers of training sessions in weeks when the observed team played a game away from home (OR: 0.14, 95%CI: 0.05-0.35).

Table 4. Logistic regressions between running performance during week and number of training sessions with match outcome

	OR	95%CI
Total distance	0.98	0.98-0.99
Low intensity (walking + jogging)	0.99	0.98-0.99
Running	0.99	0.98-0.99
High intensity (high speed running + sprinting)	0.98	0.97-0.99
Total number of accelerations	0.99	0.98-0.99
Total number of decelerations	0.98	0.96.0.99
High-intensity accelerations	0.96	0.95-0.99
High-intensity decelerations	0.98	0.97-0.99
Training sessions per week	0.14	0.05-0.35

2.3.4 Discussion

There are several significant findings of this study, which will be discussed in the following. First, playing positions differed considerably in specific running performances during training and matches. Next, the results indicated significant correlations between corresponding running performances obtained at training and match. Finally, the training load was significantly associated with the match outcome.

Differences among playing positions in running performances

Our results evidenced significant differences between playing positions for total distance covered in soccer matches. These findings are in accordance with the results of previous studies in which authors reported that distance covered during the match varies considering the position-specific tactical roles (Di Salvo et al., 2007; Modric et al., 2019). In detail, while central defenders covered the lowest total distance (8880 m in average), central midfielders total distance covered (10,944m in average) was statistically greater compared to central defenders, full-backs and forwards ($p<0.05$). Similar results are discussed in previous studies in which it was reported that central midfielders usually cover significantly more distance than players in all other playing positions due to their tactical roles (Di Salvo et al., 2007; Modric et al., 2019).

It has already been noted that high-intensity distance covered (above speeds of 20 km/h) in matches is one of the most important elements in successful soccer performance (Di Salvo et al., 2009). Specifically, external players (wide midfielders and full-backs) and front players (forwards) cover the greatest amount of high-intensity distance (Di Salvo et al., 2007; Mallo et al., 2015). Our results indicated that central defenders high-intensity distance covered is statistically lower when compared to all other playing positions ($p<0.05$), while the greatest amount of high-intensity distance in matches was covered by forwards (894 m in average), followed by wide midfielders and full-backs (823 m and 709 m, respectively). Therefore, we may say that our findings are in accordance with previous studies when authors reported similar results for Italian Serie A, Spanish La Liga, and English Premier League (Di Salvo et al., 2007; Di Salvo et al., 2009; Mallo et al., 2015).

The central midfielders have the highest numbers of accelerations and decelerations in the soccer matches (on average 477 and 471, respectively), while forwards have the highest number of high-intensity accelerations and decelerations (in average 30 and 50, respectively). In general, it is difficult to compare our acceleration data with the literature, since there is currently little consensus regarding the use of acceleration thresholds in team sports (Johnston et al., 2014). Moreover, a comparison between acceleration variables measured with different tracking systems (and system versions) would also be difficult (Buchheit et al., 2014).

Although we did not find evidence of significant differences between playing positions, forwards and central midfielders tend to have the highest average weekly total distance (19,829 m and 19,095 m in average, respectively), while full-backs have the lowest (17,531 m in average). The greatest weekly high-intensity distance covered by full-backs (742 m on average) was higher compared to central midfielders, which covered the lowest distance at high speeds through weekly training sessions.

Accordingly, it seems that full-backs weekly training drills contain more high-intensity running, while conversely, central midfielders training sessions tend to stimuli greater distance covered without many high-intensity efforts. Furthermore, our results evidenced that central midfielders has the lowest number of high-intensity accelerations (n=15) and decelerations (n=35). As already reported that central midfielders soccer success is more influenced by soccer variables (Modric et al., 2019) it seems that central midfielders training sessions are generally more focused on soccer skills than on running performances.

Training/match ratio

Compared to running performances from the matches, the average total distance from weekly training sessions was higher by 1.74 times for central midfielders, 1.81 times for wide midfielders, 1.80 for full-backs, 2.04 times for central defenders and 2.05 for forwards. Weekly high-intensity distance covered for full-backs and central defenders was higher (1.05 and 1.30 times, respectively), while for central midfielders, wide midfielders and forwards it was lower (0.63, 0.81, and 0.77, respectively) compared to match values. Acceleration/deceleration load were higher in weekly training sessions compared to the match values. Specifically, the training/match ratio was 2.09 for the total number of accelerations, 1.87 for the total number of decelerations, 2.01 for of high-intensity accelerations and 1.47 for of high-intensity decelerations. This suggests that, through weekly training sessions, the total distance covered and accelerations/decelerations were more emphasized than the high-intensity distance covered. Similar findings were previously discussed in the recent study of Clemente et al. (2019), in which it was presented that "specific variables (e.g. high-speed running distance and sprinting distance) were associated with substantially lower ratios than other variables".

Correlates of match outcome

A strong correlation between the weekly number of training sessions and match outcomes indicated a higher possibility for winning the matches when preceding weeks had lower numbers of training sessions. Furthermore, our results evidenced an inverse association of almost all running performances in weekly training sessions with match outcomes. These findings emphasize that external weekly load values were lower when the team won in subsequent matches. Since it previously was highlighted that the higher weekly number of training sessions provoke a higher weekly external training load (Clemente et al., 2019), a team's positive achievement would be greater in weeks with lower numbers of training sessions and lower values of external training load.

Typical training sessions in weeks with short time until the next games (i.e., weeks with lower numbers of training sessions) are more focused on the recovery and development of soccer skills (e.g., technical and tactical skills) than on strength and conditioning (i.e., adaptation of conditioning abilities cannot be optimal if there is a short period between matches). Consequently, in such weeks the players experienced less external training load, which possibly resulted in better recovery and superior overall fitness status in subsequent matches. Altogether, it allowed players to execute technical and tactical requirements during game situations at a higher level (Borges et al., 2017). Collectively, it logically could result even in better overall achievement and, finally, positive results.

Supportively, previously it was highlighted that soccer players' work rate was lower when winning than losing a match (Castellano et al., 2011). Also, low-ranked teams have greater high-intensity distance covered compared to top-ranked teams (Di Salvo et al., 2009; Rampinini et al., 2009). Considering the results of our study in which we evidenced correlation for almost all running parameters (e.g., total distance covered, high-intensity distance covered, distance covered in the zone of running, number of high-intensity accelerations and decelerations) obtained at training and matches, it seems that external load in matches was affected with external load from training sessions. In other words, if players perform lower external load values in training, lower values of associated external load variables will occur in matches. In accordance with previously cited studies, this could imply that positive results were more affected with technical and tactical skills than with running performances from both training sessions and matches.

Strengths and limitations

This study was based on results obtained from a team in Croatian competition (top-level competition in the country); therefore, results may be generalized to similar qualitative ranks. Also, we did not present any specific data about physical conditioning status, which will allow more detailed discussion. Finally, in this study, we included only those players who participated in all matches and all training sessions; this was necessary due to methodological reasons. Meanwhile, this is one of the first studies where training running performances were simultaneously correlated with: (i) match running performances, and (ii) match outcome. Also, the level of players observed is a significant strength of the investigation. Finally, throughout the study, the same team of professionals (coaches, physicians) managed the observed team, which consequently reduced the possibility that factors other than those observed influenced the results of the study.

2.3.5 Conclusion

The results of this study confirmed that most of the variables of external match load in soccer vary according to the different playing positions. Through weekly training sessions, variables that determine intensity (e.g., high-intensity distance covered (+19.8 km/h), and the number of high-intensity accelerations/decelerations) distinguished players between their playing positions, while no differences were found for volume variables (e.g. total distance covered and the total number of accelerations and decelerations), low-intensity variables (e.g., walking + jogging) and moderate-intensity variables (e.g., distance covered in the zone of running).

Since training/match ratios were higher for total distance covered, distance covered in low speeds, the number of total accelerations/decelerations and the number of high-intensity accelerations, it seems that these variables were more stimulated through training sessions than distance covered at moderate (14.4–19.7 km/h) and high speeds (+20 km/h).

Positive correlations between some external training and match load variables highlighted that if a team performs higher values of total distance covered, distance covered in the running zone, high-intensity distance covered, high-intensity number of accelerations and decelerations in weekly training sessions, higher values of same variables will occur in subsequent matches. Finally, correlations between the weekly number of training sessions and weekly running performances with match outcome demonstrated that the chances of positive achievement at the game were greater in weeks when the team participated in fewer training sessions and consequently had lower values of external training load.

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Conflict of Interest

The authors declare the absence of conflict of interest.

2.3.6 References

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2.4 Study 4: Does aerobic performance define match running performance among professional soccer players? A position-specific analysis

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Does aerobic performance define match running performance among professional soccer players? A position-specific analysis

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Abstract

Aerobic performance is considered an important determinant of match running performance in soccer, but studies have rarely investigated this issue in top-level players. This study examined the possible associations between direct measures of aerobic performance and match running performance in elite soccer players. Aerobic performance was tested at the beginning of the season in laboratory settings. The match-running performance was measured by a global positioning system over a competitive half-season for a total of 82 match performances in professional players from Croatia (age: 23.76 ± 2.64; body height: 181.62 ± 7.09 cm; body mass: 77.01 ± 6.34 kg) and clustered as central player (n = 57) and side player (n = 25) performance. No significant differences in aerobic performance were noted between central and side players. The anaerobic threshold was correlated with high-speed running (19.8–25.1 km/h), sprint running (>25.1 km/h), and high-intensity running (>19.8 km/h) among side players (r = 0.52, 0.53, and 0.59, respectively; $p < 0.01$). For central players, the aerobic threshold was correlated with the total distance covered, low-intensity running (<14.3 km/h), and distance covered in the zone of running (14.4–19.7 km/h) (r = 0.47, 0.49, and 0.39; p < 0.01, 0.01, and 0.03, respectively). Conditioning for central players should include activities with intensities corresponding to aerobic thresholds, while conditioning of side players should be focused on the development of anaerobic thresholds.

Keywords: Aerobic fitness; aerobic threshold; anaerobic threshold; football; relationships

2.4.1 Introduction

Soccer (football) is a sport that requires excellent tactical, technical, and physical performance skills (Hoff et al., 2002). It is known that elite soccer players can cover 9–14 km of total distance during a soccer match (Bekris et al., 2020; Merlin et al., 2020; Milanović et al., 2017; Modric et al., 2020b). However, elite soccer players spend the majority of match play performing low-intensity activities (e.g., standing, walking, jogging), while high-intensity efforts (e.g., high-speed running, sprinting) constitute approximately 10% of the total distance covered (Andrzejewski et al., 2016). Therefore, the energy used by soccer players is mainly produced by aerobic metabolism (Garcia-Tabar et al., 2019; Silva et al., 2011), so it is important for players to have well-developed aerobic fitness (aerobic performance – P) (Modric et al., 2020a). Currently, it is generally accepted that well-developed AP helps soccer players maintain repetitive high-intensity actions in a soccer match, accelerate the recovery process, and maintain their physical condition at an optimum level during the entire game and season (Slimani et al., 2019).

The most important parameters for the evaluation of AP are maximal oxygen uptake (VO2max) and anaerobic threshold (AnT) (Mehmet et al., 2017). VO2max is defined as the highest oxygen uptake that can be achieved during dynamic exercise with large muscle groups (Wagner, 1996). Currently, professional soccer players' VO2max varies from 55 to 65 ml kg−1 min−1 (Metaxas, 2021; Silva et al., 2011). AnT is defined as the highest exercise intensity, heart rate, or oxygen uptake working dynamically with large muscle groups in which the production and clearance of lactate are approximately the same (Hoff et al., 2002). AnT can be evaluated from blood lactate level changes (i.e., metabolic acidosis) or from non-invasive gas exchange measurements due to the nonlinear increase in carbon dioxide production and ventilation (Beaver et al., 1986; Mehmet et al., 2017; Wasserman et al., 1973). It has been reported that AnT in soccer players occurs at velocities ranging from 13.0 to 15.0 km/h (Silva et al., 2011) and at 55–75% of VO2max (Chmura et al., 2015).

The importance of VO2max in modern soccer is heavily debated. Slimani et al. indicated that VO2max performance is the most powerful discriminator between higher- and lower-level soccer players (Slimani et al., 2019). Reilly et al. highlighted that VO2max >60 ml kg−1 min−1 represents a threshold to possess the physiological attributes for success in men's elite soccer (Reilly et al., 2000). Basically, players with higher VO2max values have better lactate-removal capability and phosphocreatine regeneration (Haugen et al., 2014). In addition, early studies have demonstrated a significant relation between VO2max and distance covered during a soccer match (Bangsbo, 1994) and placement in competitions (Wisloeff et al., 1998), emphasizing the importance of AP in soccer performance. More recently, studies have investigated the correlation between match running performances (MRP) and AP in more detail, taking into account not only the total distance covered but also distances covered at different intensities (e.g., walking, jogging, running, high-speed running, sprinting) (Bradley et al., 2013; Krustrup et al., 2003; Mehmet et al., 2017; Metaxas, 2021; Slimani et al., 2019). However, all studies evaluated AP throughout indirect tests (e.g., field-based tests), and to best of our knowledge, only one investigation correlated MRP with VO2max measured in laboratory settings (Metaxas, 2021). Specifically, Metaxas investigated sub-elite soccer players and did not identify a correlation between VO2max and MRP at any speed intensity. The author himself clearly noted the necessity of further investigations taking into account other indices of AP, not exclusively VO2max (Metaxas, 2021).

The main objective of this study was to examine possible associations between various direct measures of AP (e.g., VO2max, AnT, AeT) and MRP (e.g., total distance covered and covered distances in different speed zones) among professional soccer players stratified by playing position. We hypothesized that AP will be significantly associated with MRP. Additionally, we examined differences in MRP and AP between and among playing positions in soccer. Detailed information about relationships that may exist between AP and MRP in top-level soccer players will allow for the accurate identification of important parameters of aerobic endurance in regard to MRP and consequently success in soccer.

2.4.2 Methods

In this investigation, we observed players performing at the highest national competitive level (1st Division players), tested their AP (independent variables) at the beginning of the competitive season, and observed their MRP over one half-season. Later, we examined the correlation between AP and MRP while taking into account playing position.

Participants

The 16 subjects in this research were professional soccer players from Croatia (mean ± SD, age: 23.76 ± 2.64; body height: 181.62 ± 7.09 cm; body mass: 77.01 ± 6.34 kg), all of whom were members from the same team. The players were observed over one competitive half-season, resulting in 82 match performances that were used as cases for this study. The players' performances were grouped (i) as previously suggested (Metaxas, 2021) as central players (n = 57) (i.e., central defenders, central midfielders and forwards) and side players (n = 25) (i.e., full backs and wingers) and (ii) according to the soccer-specific playing positions in the game as central defenders (n = 17), full backs (n = 22), central midfielders (n = 32), wide midfielders (n = 3) and forwards (n = 8). The MRP data were collected during 14 matches of the Croatian Soccer League 2018/2019 season. For the purpose of this study, only the results of those players who participated in the whole game were analysed. All players were fully informed about the nature of the study and signed an informed consent form agreeing to participate in the study. The study was approved by the Ethical Board of the University of Split, Faculty of Kinesiology (Split, Croatia). Participants' characteristics are shown in Table 1.

Table 1. Participants' physical characteristics (mean ± SD).

Age (y)	23.76 ± 2.64
Body mass (kg)	77.01 ± 6.34
Height (cm)	181.62 ± 7.09
VO2max (ml kg^{-1} min^{-1})	57.63 ± 3.48
VO2max at anaerobic threshold (ml kg^{-1} min^{-1})	52.77 ± 2.98
Maximal heart rate (beat · min^{-1})	191.3 ± 8.65
Heart rate at anaerobic threshold (beat · min^{-1})	182.96 ± 8.47
Aerobic threshold (km/h)	13,59 ± 1.12
Anaerobic threshold (km/h)	16.11 ± 0.86

Procedures

The variables in this study included players' age, body height, weight, match running performance and measures of aerobic performance. Specifically, MRP was measured during official matches and included the total distance covered during the match (m) and the distance covered in five speed categories: low-intensity running (<14.3 km/h), running (14.4–19.7

km/h), high-speed running (19.8–25.1 km/h), sprinting (≥25.2 km/h), and high-intensity running (>19.8 km/h). All MRP data were collected by GPS technology (Optim-Eye S5 & X4, Catapult, Melbourne, Australia) with a sampling frequency of 10 Hz. The average number of satellite signals was 12.03 ± 0.5, whereas the horizontal dilution of precision was 0.83 ± 0.1. The reliability and validity of the equipment have previously been described in detail (Johnston et al., 2014).

AP measures included VO2max, running speed at AeT, running speed at AnT, VO2max at anaerobic threshold, heart rate at anaerobic threshold and maximal heart rate. The AP of the players was determined before the preseason and immediately after the off-season period using a progressive intensity and continuous effort treadmill protocol (Cosmos h/ p, Nussdorf – Traunstein, Germany). VO2max was accepted when at least three of the following criteria were met: (i) the HR during the last minute exceeded 95% of the expected maximal HR predicted 220-age; (ii) levelling off (plateau) of VO2max, despite an increase in treadmill speed, VO2 < 150 ml O2; (iii) a respiratory gas exchange ratio (VCO2 < VO2) at or higher than 1.1 was reached; and (iv) the subjects were no longer able to continue the running despite verbal encouragement (Metaxas, 2021). VO2max was expressed in relative values (ml kg−1 min−1). AeT was defined as the first nonlinear increase in the ventilatory equivalent for oxygen without a simultaneous increase in the ventilatory equivalent for C2, whereas AnT was defined as the simultaneous nonlinear increase in both ventilatory equivalents according to previously described recommendations (Beaver et al., 1986; Wasserman et al., 1973). Both AeT and AnT were expressed in km/h.

Statistics

All data were log-transformed to reduce the nonuniformity of error, and normality was tested using the Kolmogorov–Smirnov test procedure. Homoscedasticity was checked by the Levene test. The statistical analyses were performed on log-transformed data, but the results in tables and figures are presented as true-value means and standard deviations. Differences between the playing positions in terms of MRP and AP were analysed by one-way analysis of variance (ANOVA). Following the ANOVA calculations, effect size differences were established by ANOVA-derived partial eta squared (>0.02, small; >0.13, medium; >0.26, large).

To identify the associations between AP and MRP, Pearson's correlation coefficients were calculated for the observed half-season period with the r coefficient classification as previously suggested: $r \leq 0.35$ indicates a low or weak correlation, r = 0.36 to 0.67 indicates a modest or moderate correlation, r = 0.68 to 1.0 indicates a strong or high correlation, and $r > 0.90$ indicates a very high correlation (Taylor, 1990). For all analyses, Statistica (Version 13; TIBCO Software, Palo Alto, CA, USA) was used. A significance level of $\alpha = 0.05$ was applied.

2.4.3 Results

Playing position differences in aerobic performance and match running performance

Side players had significantly greater high-speed running distance, sprint distance and high-intensity running distance than central players (all $p < 0.01$). In detail, side players had 22% greater high-speed running distances (526 m and 429 m, respectively) and 102% greater sprint distances (237 m and 152 m, respectively) than central players. High- intensity distance (high-speed running + sprint) was 39% greater among side players than among central players (763 m and 613 m, respectively) (Table 2).

Table 2. Descriptive statistics of match running performance and aerobic performances (data are given as Means ± SD) and differences between players playing at central and side of the pitch (F-test).

	All players (n = 73)	Central-players (n = 57)	Side-players (n = 25)	F-test (p)	η2
Running performances					
Total distance (m)	10364.34±961.30	10401.51±1098.49	10279.60±540.84	0.27 (0.60)	0.03
Low intensity running (m)	8368.90±654.47	8438.32±736.76	8210.64±376.17	2.13 (0.14)	0.02
Running (m)	1377.93±336.08	1411.74±376.22	1300.84±205.03	1.91 (0.17)	0.02
High-speed running (m)	459.17±136.29	429.77±134.57	526.20±117.06	9.62 (0.01)	0.11
Sprint (m)	153.96±90.21	117.28±58.74	237.60±94.51	49.36 (0.01)	0.38
High intensity running (m)	613.13±197.80	547.05±162.93	763.80±189.97	27.75 (0.01)	0.26
Aerobic performances					
VO2max (ml kg^{-1} min^{-1})	57.63±3.48	57.19±3.94	58.64±1.75	3.09 (0.08)	0.04
Aerobic threshold (km/h)	13.59 ± 1.12	13.57±1.30	13.64±0.48	0.05 (0.82)	0.00
Anaerobic threshold (km/h)	16.11 ± 0.86	16.01±0.91	16.32±0.69	2.17 (0.14)	0.03

Legend: Aerobic threshold – running speed at aerobic threshold; Anaerobic threshold – running speed at anaerobic threshold; VO2max – maximal oxygen uptake

Table 3 presents differences in match running performance and aerobic performance between players at soccer-specific playing positions. Central defenders achieved the greatest total distance covered (11,160 m), and central defenders achieved the lowest total distance covered (9257 m). Low-intensity distance covered was highest among central midfielders, while high-speed running, sprinting and high-intensity distance covered were highest among wide midfielders. AnT speed was highest for central midfielders, followed by full backs and wide midfielders (16.5 km/h, 16.4 km/h, and 16 km/h, respectively). AeT speed was highest for central midfielders (14.3 km/h) and lowest for forwards (11.9 km/h). No significant post hoc differences were found for the VO2max values.

Table 3. Descriptive statistics of match running performance and aerobic performances (data are given as Means ± SD) and differences between players at soccer- specific playing positions.

	Central defenders (n = 17)	Full backs (n = 22)	Central midfielders (n = 32)	Wide midfielders (n = 3)	Forwards (n = 8)	F-test	(p)	η2
Running performances								
Total distance (m)	9257.6±690.2 FB, CM	10305.5±562.0 CD, CM	11160.4±644.7 CD, FB, FW	10089.3±363.6	9796.8±703.7 CM	27.43	0.01	0.59
Low intensity running (m)	7814.2±522.4 CM	8259.5±371.0 CM	8876.4±545.4 CD, FB, WM, FW	7852.0±182.7 CM	8012.1±608.6 CM	15.64	0.01	0.45
Running (m)	1021.1±215.9 FB, WM	1287.5±213.9 CD, WM	1676.1±229.6 CD, FB, FW	1398.7±89.2	1184.4±207.9 CM	28.88	0.01	0.60
High-speed running (m)	312.4±56.5 FB, CM, WM	521.1±119.1 CD	484.9±134.6 CD	563.7±114.6 CD	458.8±94.8	9.72	0.01	0.33
Sprint (m)	107.8±61.6 FB, WM	233.0±95.2 CD, CM, FW	117.4±60.2 FB, WM	271.7±100.5 CD, CM	137.1±47.0 FB	12.55	0.01	0.39
High intensity running (m)	420.1±103.5 FB, CM, WM	754.0±194.5 CD, CM	602.3±165.8 FB, CD	835.3±164.9 CD	595.9±101.6	12.12	0.01	0.39
Aerobic performances								
VO2max (ml kg^{-1} min^{-1})	57.3±1.3	58.2±1.4	57.7±5.0	61.9±0.0	54.8±1.9	2.87	0.03	0.12
Aerobic threshold (km/h)	13.0±0.7 CM	13.7±0.5 FW	14.3±0.9 CD, FW	13.0±0.0	11.9±1.6 FB, CM	16.93	0.01	0.49
Anaerobic threshold (km/h)	15.5±0.5 FB, CM	16.4±0.7 CM, FW	16.5±0.8 CD, FW	16.0±0.0 FB, CM	15.3±1.0	7.74	0.01	0.29

Legend: Aerobic threshold – running speed at aerobic threshold; Anaerobic threshold – running speed at anaerobic threshold; VO2max – maximal oxygen uptake; Superscripted letters indicate significant post-hoc differences when compared to specific playing position (CD – central defenders; FB – full backs; CM - central midfielders; WM - wide midfielders; FW - forwards); η2 – partial eta squared

Associations between aerobic performance and match running performance

Side players' AnT was significantly correlated with high-speed running ($r = 0.52$; $p < 0.01$, moderate correlation), sprinting ($r = 0.53$; $p < 0.01$, moderate correlation) and high- intensity running (r = 0.59; p < 0.01, moderate correlation). For central players, we found that the total distance covered and low-intensity distance covered were correlated with AeT (r = 0.47 and 0.49, respectively; both moderate correlations) and AnT (r = 0.42 and 0.50, respectively; both moderate correlations). Additionally, central players' running distance covered was correlated with AeT (r = 0.39; moderate correlation; Table 4).

Table 4. Pearson's correlations between match running performances and measures of aerobic performances.

		VO2max	Aerobic threshold	Anaerobic threshold
Total distance (m)	Total (n = 82)	0.25¥	0.45¥	0.39¥
	Central players (n = 57)	0.28¥	0.47¥	0.42¥
	Side players (n = 25)	0.04	0.30	0.33
Low intensity running (m)	Total (n = 82)	0.38¥	0.46¥	0.40¥
	Central players (n = 57)	0.49¥	0.49¥	0.50¥
	Side players (n = 25)	-0.21	0.22	0.06
Running (m)	Total (n = 82)	-0.03	0.37¥	0.19
	Central players (n = 57)	-0.02	0.39¥	0.22
	Side players (n = 25)	0.15	0.22	0.22
High speed running (m)	Total (n = 82)	-0.10	-0.03	0.22¥
	Central players (n = 57)	-0.27¥	0.13	0.09
	Side players (n = 25)	0.30	0.15	0.52¥
Sprint (m)	Total (n = 82)	-0.16	0.13	0.26¥
	Central players (n = 57)	-0.03	-0.12	0.06
	Side players (n = 25)	0.38	0.12	0.53¥
High intensity running (m)	Total (n = 82)	0.00	0.08	0.28¥

Legend: VO2max – maximal oxygen uptake; Aerobic threshold – running speed at aerobic threshold; Anaerobic threshold – running speed at anaerobic threshold; ¥ - denotes significant correlations (p < 0.05)

Table 5 presents correlations between match running performance and measures of aerobic performance for soccer-specific playing positions. The full back's high-speed running, sprinting and high-intensity distance covered were correlated with AnT (r = 0.58, 0.60 and 0.65, respectively). Forwards' low-intensity distance covered correlated with AeT (r = 0.78).

Table 5. Pearson's correlations between match running performances and measures of aerobic performances for soccer-specific playing positions.

		VO2max	Aerobic threshold	Anaerobic threshold
Total distance (m)	CD	0.18	-0.18	-0.69*
	FB	0.19	0.28	0.32
	CM	0.40*	-0.16	0.04
	WM	/	/	/
	FW	0.64	0.64	0.64
Low intensity running (m)	CD	0.29	-0.03	-0.65*
	FB	0.05	0.06	-0.01
	CM	0.67*	-0.06	0.31
	WM	/	/	/
	FW	0.78*	0.78*	0.78*
Running (m)	CD	0.06	-0.35	-0.74*
	FB	0.04	0.37	0.26
	CM	-0.26	-0.18	-0.45
	WM	/	/	/
	FW	-0.16	-0.16	-0.16
High speed running (m)	CD	-0.26	-0.33	-0.06
	FB	0.31	0.26	0.58*
	CM	-0.38*	-0.16	-0.30
	WM	/	/	/
	FW	0.06	0.06	0.06
Sprint (m)	CD	-0.42	-0.27	0.37
	FB	0.43*	0.23	0.60*
	CM	0.04	-0.16	-0.01
	WM	/	/	/
	FW	0.17	0.17	0.17
High intensity running (m)	CD	-0.39	-0.34	0.19
	FB	0.40	0.27	0.65*
	CM	-0.29	-0.19	-0.24
	WM	/	/	/
	FW	0.13	0.13	0.13

Legend: VO2max – maximal oxygen uptake; Aerobic threshold – running speed at aerobic threshold; Anaerobic threshold – running speed at anaerobic threshold; CD – central defenders; FB – full backs; CM – central midfielders; WM – wide midfielders; FW – forwards; * – denotes significant correlations ($p < 0.05$); /- correlations were not calculated due to small number of observations

2.4.4 Discussion

We examined the associations between AP and MRP in elite soccer players. Our results evidenced several important findings. First, AT and AnT discriminate playing positions better than VO2max. Second, AnT is an important determinant of MRP, especially for side players. Finally, the AeT is related to MRP in central players. Therefore, we may accept our initial study hypothesis.

Aerobic performance and playing positions in soccer

We did not identify significant differences between side and central players in AP. These findings are supported by previous studies that investigated professional soccer players and did not identify a significant difference among defenders, midfielders and forwards in VO2max (Al'Hazzaa et al., 2001; Bangsbo et al., 1991). In addition, an in-depth post hoc analysis of VO2max conducted in the present study according to soccer-specific positions (e.g., central defenders, full backs, central midfielders, wide midfielders, and forwards) revealed no differences in VO2max values among players playing in different positions. The authors of this study believe that the relative non-applicability of VO2max should be contextualized in explaining these findings.

Previous studies found that VO2max is not the best discriminator of performance in predominantly aerobic events (Hoff et al., 2002; Silva et al., 2011). The reason is probably that VO2max does not permit the determination of performance in soccer due to its intermittent nature, different patterns of variable intensities that increase the request of anaerobic metabolism and different recovery periods (Silva et al., 2011). Moreover, VO2max values could be affected by other factors, such as running economy, AnT and morphological components (Metaxas, 2021; Ziogas et al., 2011). This finding could also explain why players with the same values of VO2max covered different distances in running tests and had different match running performances in soccer matches (Metaxas, 2021).

Anaerobic threshold and match running performance in soccer

It has already been noted that players with higher AnT are able to cover a greater distance with high-intensity running during a soccer match because highly developed AnT enables them to perform high-intensity work without continued blood lactate accumulation in the body (steady-state) (Helgerud et al., 2001). In addition, the results of an in-depth analysis conducted according to the soccer-specific positions in this study indicated that midfield (central and side) and full back players had the highest AnT as well as the highest amount of high-intensity running. Supportively, our results revealed moderate correlations between AnT and distances covered at higher speeds (e.g., high-speed running, sprint, and high-intensity running) during soccer matches.

However, our study extends previous knowledge emphasizing that the association between AnT and high-intensity running in soccer is actually a consequence of the correlation that exists between these variables only among side players (see Table 3 for details). In detail, the side players group consists of wide midfielders and full backs; therefore, the identified correlation basically refers to them. Given the very small sample of observations for wide midfielders (n = 3), it can only be partially supported by the moderate correlations established between AnT and distances covered at higher speeds.

The main explanation for such associations should be found in the physiological position-specific demands of soccer. As discussed previously, side players engage in the highest amount of high-intensity running (Di Salvo et al., 2007). In other words, side players with better AnT can maintain work at a high intensity longer, while those with less developed AnT experience metabolic acidosis earlier because of the increased H+ ion concentrations, and enzymes essential to muscle contraction are inhibited, which decreases players' abilities to perform high-intensity work (Hall, 2010).

The previous finding is important from the aspect of specific conditioning in soccer for two reasons. First, the amount of high-intensity running during a soccer match is one of the key factors for success (Mallo et al., 2015; Modric et al., 2019). Therefore, it appears that AnT should be observed as a highly important indicator of both (i) the running performance of side players and (ii) the game achievement of the soccer team.

Aerobic threshold and match running performance in soccer

The results indicated positive associations between AeT and (i) the total distance covered and (ii) the distance covered at low and moderate speeds. However, this correlation is actually a consequence of correlations that exist between these variables only among central players. In other words, the total distance covered and distance covered at low and moderate intensities in central players may be limited by their AeT.

In explaining these relationships, a brief overview of the game duties and the consequent MRP of central players is needed. Previous studies reported that central players exhibit the greatest total distance covered (e.g., central midfielders) or spend the most time engaged in low-intensity running (e.g., central defenders and forwards) (Modric et al., 2019; Di Salvo et al., 2007). In other words, central players perform most of their duties at low or moderate intensities. This finding can be directly supported by the analysis of soccer-specific positions, which in the present study indicated that of all playing positions, central defenders and forwards spent the greatest time in low-intensity running (84% and 81% of the total distance covered, respectively), while central midfielders had the greatest distance covered in the running zone (see Table 4 for details). Therefore, the quality of AeT of central players is an important determinant of their MRP. Physiologically, AeT defines players' capacity to perform efficiently at a lower intensity (i.e., the intensity at which the first significant activation of anaerobic glycolysis occurs; first increased accumulation of lactates above the resting level) (Silva et al., 2011). Central players spend most of their time during a soccer match in activities that are related to AeT (i.e., low and moderate activities), resulting in a correlation between AeT and running at moderate and low speeds.

At this moment, we cannot speculate whether central players developed their AeT during their playing career (because of their involvement in game duties at low and moderate intensities, which consequently improved their AeT) or whether players with a high AeT were oriented towards playing at central positions (simply due to their superior AeT, which allowed them to perform efficiently at low and moderate intensities). Irrespective of causality, it is clear that central players must have a well-developed AeT to perform their duties efficiently during a soccer match. This finding is especially important for the forwards in which an association has been found between AeT and low-intensity distance covered. In particular, analysis of soccer-specific positions revealed a strong correlation between AeT and low-intensity running ($r = 0.78$). On the other hand, other correlations analysed according to soccer-specific positions were not evidenced likely due to differences in AeT values and running performance among players in different positions, as demonstrated previously in a very recent study (Modric et al., 2020a).

Strengths and limitations

The main limitation of this study is derived from the fact that data were collected from only one team. Therefore, the results are generalizable only to similar samples of subjects and levels of competition. In addition, only players who played entire matches during one half-season were analysed, which could have affected the MRP results. Additionally, this study did not observe a running economy, which can affect the MRP results. Further, AP testing was conducted after approximately 20 days of off-season, and the observed half-season lasted 20 weeks. As a result, it is possible that the AP changed over the half-season.

This is the first study that observed elite-level soccer players and determined the association between AP obtained by a direct testing method and MRP obtained by a global positioning system. Second, this study analysed several AP indicators, which has not been done so far. In addition, clustering of the players into central and side player groups provides information to the coaches regarding whether the players respond to the physical demands of the specific playing position or not.

2.4.5 Conclusion

A higher AnT is directly related to the amount of running at higher speeds in side players, which allows them to perform a greater amount of high-intensity running during a match. Therefore, conditioning of side players should be focused on the development of AnT.

Central players with higher AeT covered a greater total distance and distances at low and moderate speeds. Accordingly, the training process for central players should include activities with intensities corresponding to their AeT or intensities that correspond with running speeds slightly above their AeT.

The insights provided from this study can give coaches guidance regarding whether players are able to properly respond to the physical demands at a specific playing position. Therefore, coaches should be very careful when they move central players to play by the side of the pitch (for instance, moving a central defender to full back or central midfielder to winger) because central players with lower AnT may not be able to perform at an appropriate level if they are placed in a side position.

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3 GENERAL CONCLUSION

This research yielded several important conclusions: (i) An increased MRP may directly provoke increased soccer match performance when assessed by the InStat index, (ii) an increased weekly external training load may provoke increased MRP, (iii) an increased weekly external training load may negatively affect match outcomes in subsequent match, (iv) and increased aerobic performance may provoke increased MRP (Figure 1). These findings provide new knowledge on factors affecting running performance in elite-level soccer, consequently enabling soccer practitioners to design training programs that could optimize the whole training process and maximize player performance.

The associations between different variables of MRP and the InStat index found in Study 1 show that increased MRP may provoke increased soccer match performance for players n specific playing positions. Specifically, since the InStat index can be considered as valid measure of technical–tactical effectiveness (Modric, Versic, & Jelicic, 2022), positive correlations between the InStat Index and MRP variables for players in specific playing positions indicate that increased MRP may enable some players to play more efficiently. Accordingly, it seems that increased MRP may be important determinant of successful soccer match performance for players in specific playing positions.

Considering that soccer match performance is demonstrated to be an important determinant of success in soccer (Castellano, Casamichana, & Lago, 2012; Kempe, Vogelbein, Memmert, & Nopp, 2014; Lago-Peñas, Lago-Ballesteros, Dellal, & Gómez, 2010), enabling players to achieve an increased MRP may be crucial for success in matches for players in specific playing positions. One efficient method that may enable players to achieve an increased MRP is by increasing the weekly external training load. Specifically, the significant positive correlations between the weekly external training load and MRP found in Study 2 indicate that an increased weekly external training load may provoke increased MRP for players in specific playing positions. This approach would almost certainly allow players to better adapt their running performance during the training, which may consequently maximize their MRP.

However, it is important to emphasize that the findings from Study 3 indicated that an increased weekly external training load may be associated with negative match outcomes (i.e., losses and draws) in subsequent matches. Although not investigated in the current research, it is possible that, due to inadequate microcycle periodization, an increased weekly external training load led to overtraining of the players, consequently impairing optimal performance on the match day (Jaspers, Brink, Probst, Frencken, & Helsen, 2017; Swallow, Skidmore, Page, & Malone, 2021). Irrespective of causality, considering the findings from Study 2, the weekly external training load must still be high but at the same time balanced and controlled to avoid overtraining effects.

Another efficient method that may enable players to achieve an increased MRP is by increasing their aerobic performance. Specifically, Study 4 revealed positive correlations between the aerobic threshold and MRP at lower intensities among central players (e.g., CDs, CMs, and FWs). On the other hand, for side players (e.g., FBs and WMs), positive correlations were found between MRP at higher intensities and the player's anaerobic threshold. Therefore, increased aerobic performance may provoke increased MRP, underscoring that aerobic performance may be an important determinant of MRP, which, as shown in Study 1, may be another important determinant of soccer match performance.

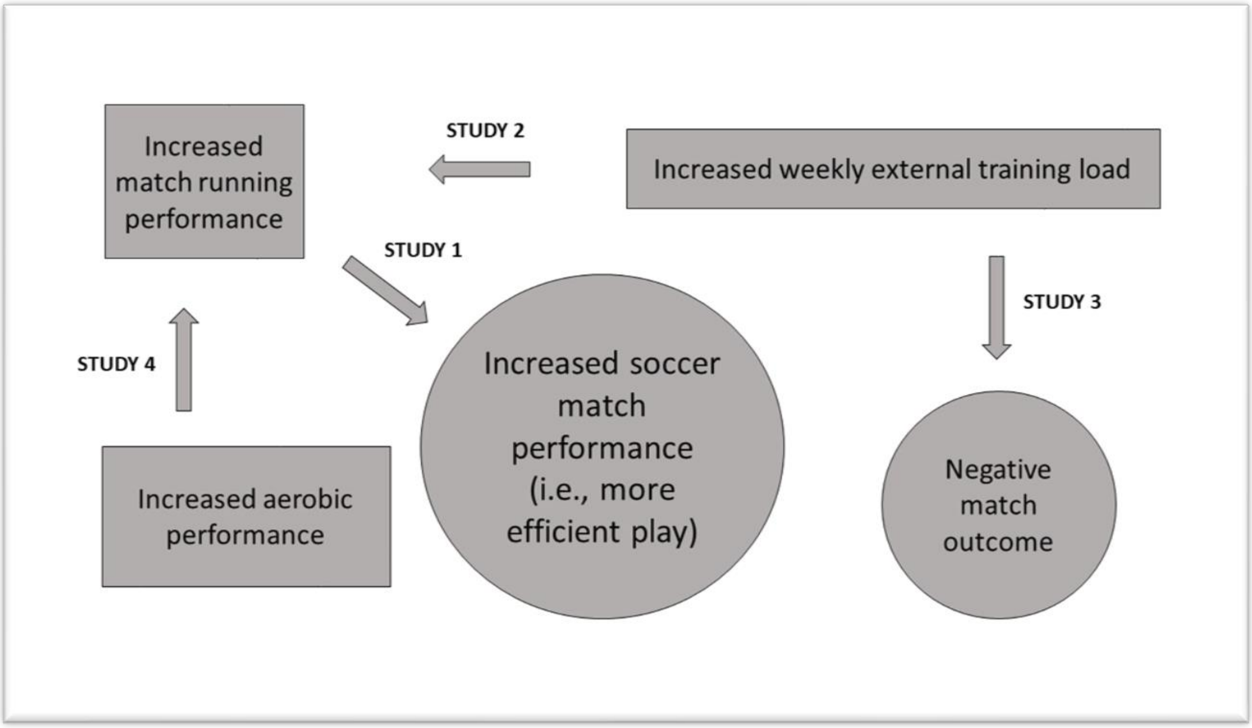

Figure 1. Schematic summary of the main conclusions from this doctoral dissertation.

3.1 Strengths and Limitations

The main limitation of this research is that data were collected from only one team; therefore, the results are generalizable only to similar samples of subjects and levels of competition. Additionally, for methodological reasons, only players who played the whole match were included, which reduced the number of observations and may have affected the MRP. However, using a relatively small sample is a very common obstacle in studies involving players who compete at the highest level of soccer (Paul S Bradley et al., 2011; P. S. Bradley, Dellal, Mohr, Castellano, & Wilkie, 2014; V. Di Salvo et al., 2010). Finally, in this research, we did not consider contextual factors such as match location, team, and opposition quality or team formation, which have been shown to influence MRP (Aquino, Carling, Vieira, et al., 2020; Castellano, Blanco-Villaseñor, & Alvarez, 2011; Chmura et al., 2021; Riboli, Semeria, Coratella, & Esposito, 2020; Staufenbiel, Lobinger, & Strauss, 2015).

This is also the first research that investigated the association between MRP and indicators of technical–tactical performance, weekly training loads, and aerobic performance obtained using a direct testing method among elite-level soccer players. The findings from this research revealed new knowledge on factors affecting running performance in elite-level soccer, consequently enabling soccer coaches to evaluate training programs that may ultimately increase the possibility of achieving positive competitive results in soccer. Finally, it should be emphasized that this research, for the first time, analysed the MRP of players that competed in the Croatian first division, providing a detailed understanding of the position-specific demands placed on players during matches and training.

3.2 Perspectives for future research

MRP in soccer is highly variable. Additionally, without a stable measure of performance, it may be difficult to evaluate the effectiveness of a training intervention programme. Therefore, future research should continue to investigate factors that may be associated with MRP. This research will enable us to design proper soccer-specific training programs, consequently allowing training processes to be optimized and player performance to be maximized. Thus, biochemical markers, mental fatigue, or motivation level may be worth further researching (i.e., factors that could potentially affect MRP but have not yet been deeply investigated). In addition, future studies should confirm the present findings considering contextual and environmental factors such as match location, match outcome, opponent quality, team formation, and weather conditions (i.e., temperatures, altitude, and humidity). Finally, to provide a detailed understanding of physical performance in soccer, future research should include a more extensive analysis of MRP. Specifically, it would be desirable to analyse (i) the average calculated values of all players who played, (ii) the values in the first and second half of the game, (iii) the values achieved in attack and defence, (iv) the values achieved in different periods of matches, and (v) the relative and peak running outputs.

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5 Biography

Toni Modrić; born on 28th of January 1988, in Split, Croatia. In 2011, he graduated at Faculty of Kinesiology University of Split, with specialization in “Strength & conditioning”, and earned the title Master of Kinesiology.

During the study, he was twice awarded by Faculty of Kinesiology for excellent results and grades. He received the Deans and Rectors award, and was selected in top 100 best students in Croatia in 2011. In 2020 he enrolled in a postgraduate doctoral study at Faculty of Kinesiology University of Split.

For more than 20 years he is engaged in football (soccer), first as player and later as fitness coach. During his 10-year professional career, he worked as first-team fitness coach in many elite football clubs such as HNK Hajduk Split, Galatasaray SK, Riga FC, Pafos FC, RNK Split, Kardemir Karabukspor, and cooperated with some of world-elite football players and coaches.

Currently he works as research assistant at Faculty of Kinesiology at University of Split. His main scientific interest is performance analysis in football. Up to date, he published more than 30 papers in journals indexed in the Web of Science, and was awarded with University Science Award for Young Investigators by University of Split.

6 Curriculum vitae

Personal information

Croat, born on 28 January 1988, in Split, Croatia

E-mail: toni.modric@yahoo.com

Mother tongue: Croatian. Other languages: English (advanced)

Education

2020 – today PhD student (Faculty of Kinesiology, University of Split, Croatia)

2009 – 2011 Master of Kinesiology (Faculty of Kinesiology, University of Split, Croatia)

2006 – 2009 Bachelor of Kinesiology, specialization in „Strength & conditioning" (Faculty of Kinesiology, University of Split, Croatia)

Grants and awards

University Science Award for Young Investigators (University of Split, Croatia)

Dean's award for excellent results and grades at college

Rector's award for excellent results and grades at college

Twice awarded by Faculty of Kinesiology for excellent results and grades

Member of TOP 100 students in Croatia (competition of 200 000 students)

Recipient of state scholarship on the basis of excellence (Ministry of Education and Sports, Croatia)

Recipient of city scholarship on the basis of excellence (City of Split, Croatia)

Recipient of university scholarship on the basis of excellence (University of Split, Croatia)

Work experience

06/2022 – today	First team head fitness coach of football club „Riga FC“, Latvian first division, Split, Croatia
09/2020 – today	Research assistant at Faculty of Kinesiology, Split, Croatia)
07/2019 – 03/2021	First team head fitness coach of football club „HNK Hajduk Split“, Croatian first division, Split, Croatia
11/2018 – 06/2019	First team head fitness coach of football club „Pafos FC“, Cypriot first division, Paphos, Cyprus
06/2018 – 09/2018	First team head fitness coach of football club „HNK Hajduk Split“, Croatian first division, Split, Croatia
02/2017 – 12/2017	First team head fitness coach of football club „Galatasaray SK“, Turkish first division, Istanbul, Turkey
07/2016 – 02/2017	First team head fitness coach of football club „Kardemir Karabukspor, Turkish first division, Karabuk, Turkey
06/2014 – 07/2016	First team head fitness coach of football club „RNK Split“, Croatian first division, Split, Croatia
06/2013 – 06/2014	Youth academy fitness coach of football club „RNK Split“ U12 - U17 teams, Split, Croatia
2010 – 2013	Individual work with professional and recreational athletes
06/2010 – 06/2013	Fitness instructor at Fitness center „Guliver Energija“ Solin, Croatia
2013	Head fitness coach of U17 Croatian national team in preparation phase for European championship in Slovakia
2013	Fitness coach in youth camp of Croatian national teams U15 – U18
2012	Assistant and lecturer at course „Strength & conditioning“ at Faculty of Kinesiology, Split, Croatia
09/2009 – 09/2010	Physical education teacher at Elementary school „Ravne Njive“, Split, Croatia

04/2008 – 03/2009 Head fitness coach of gymnastic club „Salto Solin“ Solin, Croatia

Selected publications

1. **Modric, T.**, Versic, S., Winter, C., Coll, I., Chmura, P., Andrzejewski, M., Konefał, M., & Sekulic, D. (2022). The effect of team formation on match running performance in UEFA Champions League matches: implications for position-specific conditioning. *Science & medicine in football*, 1–8. Advance online publication. https://doi.org/10.1080/24733938.2022.2123952

2. **Modric T.**, Versic S., Stojanovic, M., Chmura, P., Andrzejewski, M., Konefał, M., Sekulic, D. (2022) Factors affecting match running performance in elite soccer: Analysis of UEFA Champions League matches. *Biology of Sport*. 2023;40(2):409–416. https://doi.org/10.5114/biolsport.2023.116453

3. **Modric, T**., Malone, J. J., Versic, S., Andrzejewski, M., Chmura, P., Konefał, M., Drid, P., & Sekulic, D. (2022). The influence of physical performance on technical and tactical outcomes in the UEFA Champions League. *BMC sports science, medicine & rehabilitation*, 14(1), 179. https://doi.org/10.1186/s13102-022-00573-4

4. **Modric, T**., Versic, S., Alexe, D. I., Gilic, B., Mihai, I., Drid, P., Radulovic, N., Saavedra, J. M., & Menjibar, R. B. (2022). Decline in Running Performance in Highest-Level Soccer: Analysis of the UEFA Champions League Matches. *Biology*, 11(10), 1441. https://doi.org/10.3390/biology11101441

5. Versic, S., **Modric, T**., Katanic, B., Jelicic, M., & Sekulic, D. (2022). Analysis of the Association between Internal and External Training Load Indicators in Elite Soccer; Multiple Regression Study. *Sports (Basel, Switzerland)*, 10(9), 135. https://doi.org/10.3390/sports10090135

6. **Modric, T.**, Versic S., Chmura P., Konefał M., Andrzejewski M., Jukic I., Drid P., Pocek S., Sekulic, D. (2022) Match Running Performance in UEFA Champions

League: Is There a Worthwhile Association with Team Achievement? *Biology*, 11(6), 867. https://doi.org/10.3390/biology11060867

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8. Radzimiński, Ł., Padrón-Cabo, A., **Modric, T**., Andrzejewski, M., Versic, S., Chmura, P., Sekulic, D., & Konefał, M. (2022). The effect of mid-season coach turnover on running match performance and match outcome in professional soccer players. *Scientific reports*, 12(1), 10680. https://doi.org/10.1038/s41598-022-14996-z

9. Jerkovic, Z., **Modric, T**., & Versic, S. (2022). Analysis of the Associations between Contextual Variables and Match Running Performance in Croatian First Division Soccer. *SportMont*, 20(2), 125-130. https://doi.org/10.26773/smj.220619

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