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Saeid Younesi

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APPLICATION OF SMALL-SIDED GAMES IN PROFESSIONAL SOCCER

UNDERSTANDING THE USEFULNESS OF SMALL-SIDED GAMES FOR TRAINING AND MONITORING

Tese no âmbito do Doutoramento em Ciências do Desporto, Ramo de Treino Desportivo, orientada pelo Professor Doutor António José Barata Figueiredo, Professor Doutor Filipe Manuel Batista Clemente e pelo Professor Doutor Alireza Rabbani e apresentada à Faculdade de Ciências do Desporto e Educação Física de Coimbra.

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Projeto de Doutoramento em Ciências do Desporto apresentado à Faculdade de Ciências do Desporto e Educação Física da Universidade de Coimbra

Orientador: António José Barata Figueiredo PhD

Co-orientadores: Filipe Manuel Clemente PhD, and Alireza Rabbani PhD

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ABSTRACT

Large within-player variations in internal and external training load measures have been reported in small-sided games (SSGs). The analysis of session-to-session variation of players' training load demands during SSGs must be addressed, and the use of SSGs as an integrated approach for monitoring soccer players' fitness status must be further analyzed. Specifically, the relationships between different SSG formats and physical fitness performance are yet to be determined. The aims of this thesis were: (i) to analyze the between-interval and session-to-session variations of internal and external load measures during different SSGs; (ii) to test the relationships between aerobic performance, hemoglobin levels, and training load during SSGs; and (iii) to analyze the dose-response relationships between training load measures and physical fitness in professional soccer players. Between sixteen and twenty-two professional soccer players (mean ± SD; age 28.1 ± 4.6 years old, height 176.7 ± 4.9 cm, body mass 72.0 ± 7.8 kg, and body fat percentage 10.3 ± 3.8%) and (mean ± SD; age 27.2 ± 3.4 years, height 174.2 ± 3.6 cm, body mass 69.1 ± 6.4 kg, and body fat 10.4 ± 4.1%, 3.1 ± 1.5 years in the club), took part in the four studies conducted. All players were monitored daily for internal load based on session-rate of perceived exertion (sRPE), heart rate (HR), hemoglobin levels, while external load measures were taken using a global positioning system (GPS) during the 2018/2019 season. Physical assessments were the 30-15IFT, VAMEVAL, 20-meter sprint, and CMJ protocols. SSGs presented trivial differences in all internal loads. Edwards' TRIMP and Red Zone had higher coefficients of variation (2.0-9.7%) than HR average (HRavg) (0.9-1.7%). Using touch limitations and goalkeepers (GK) decreased typical errors (TE). External loads had small-to-large TE between-sessions. TD.min^{-1} had relatively little variability (2.2 to 4.6% CV%), while the overall measures had CV values ranging from 7.2% to 29.4%. Trivial differences were found in TD.min^{-1} and HIR.min^{-1} for all SSGs and in HSR.min^{-1} and MW.min^{-1} for the overall between-interval SSGs formats. No between-sessions variations were found when using touch limitations or GK. VIFT had large-to-very large relationships with total distance (TD; r = 0.69; 0.87), high-intensity running (HIR; r = 0.66; 0.75), and MW (r = 0.56; 0.68). Hemoglobin levels had moderate-to-large associations with internal loads. Moderate-to-large negative relationships were found between hemoglobin levels and Edwards' TRIMP (r = −0.36; −0.63), maximal heart rate (HRmax; r = −0.50; −0.61), and Red Zone (r = −0.50; −0.61).

Very large relationships were observed between VIFT and VAMEVAL for pre ($r = 0.76$), post ($r = 0.80$) and pooled-data ($r = 0.81$). VAMEVAL presented less sensitivity (−22.4%, [−45.0 to 9.4]), ES −0.45 [−1.05 to 0.16]) than VIFT. Also, VIFT had moderate correlations with objective internal and external measures and unclear associations with all sRPE. Meanwhile, VAMEVAL's relationships with all sRPE varied between large and very large, whereas unclear associations were detected with all other selected training loads. In conclusion, these findings suggest that coaches need to include more traditional running-based drills concurrent with SSGs if the aim is to less internal load variability at higher intensities. This statement also reflects the high intensity of external loads, as they produce higher variability. Coaches can use touch limitations and GK to produce less noise, but this does not hold for external loads. VIFT and hemoglobin levels can be used to monitor players' performance and physiological status during SSGs. Given that, the use of SSGs as a monitoring complement of the 30-15IFT is suggested.

Keywords: Association football, monitoring, match performance, noise

RESUMO

Grandes variações nos jogadores em medidas de carga de treino internas e externas foram reportadas em jogos reduzidos (JRs). A análise da variação entre sessões das cargas de treino nos jogadores durante JRs deve ser abordada. O uso de JRs como uma abordagem integrada para monitorizar o estado físico dos jogadores deve ser analisado detalhadamente. As relações entre os diferentes formatos de JRs e performance ainda não foram determinadas. Os objetivos desta tese foram: (i) analisar as variações entre intervalos e entre sessões da carga interna e externa durante diferentes JRs; (ii) testar as relações entre performance aeróbia, níveis de hemoglobina e carga de treino durante JRs; e (iii) analisar as relações dose-resposta entre as cargas de treino e a aptidão física em jogadores profissionais de futebol. Entre dezasseis e vinte e dois jogadores de futebol profissional (média ± DP; idade 28,1 ± 4,6 anos, altura 176,7 ± 4,9 cm, massa corporal 72,0 ± 7,8 kg e percentagem de gordura corporal 10,3 ± 3,8%) e (média ± DP; idade 27,2 ± 3,4 anos, altura 174,2 ± 3,6 cm, massa corporal 69,1 ± 6,4 kg e gordura corporal 10,4 ± 4,1%, 3,1 ± 1,5 anos no clube), fizeram parte dos quatro estudos realizados. Todos os jogadores foram monitorizados diariamente para as cargas internas: perceção subjetiva de esforço (PSE), medidas de frequência cardíaca (FC), níveis de hemoglobina e para as cargas externas, através de um sistema de posicionamento global (GPS) durante a época 2018/2019. As avaliações físicas foram compostas pelos protocolos 30-15IFT, Vameval, sprint de 20 metros e CMJ. Os JRs tiveram diferenças triviais em todas as cargas internas. O TRIMP de Edwards e o Red Zone tiveram maior coeficiente de variação (2,0-9,7%) do que a média de FC (0,9-1,7%). A limitação de toques e o uso de guarda-redes (GR) diminuiu a variabilidade das cargas internas. As cargas externas apresentaram pequenas a grandes variações entre sessões. A distância total (DT) apresentou menos variabilidade (2,2 a 4,6% CV%), enquanto as restantes medidas externas tiveram valores de CV entre 7,2% a 29,4%. Diferenças triviais foram encontradas para a DT e corrida de alta intensidade (CAI) para todos os JRs, e para a corrida de alta velocidade (CAV) e carga mecânica (CM) para os formatos de JRs. Nenhuma variação foi encontrada para a limitação de toques ou o uso de GR entre sessões. A VIFT teve relações grandes a muito grandes com a (DT; r = 0,69; 0,87), (CAI; r = 0,66; 0,75) e (CM; r = 0,56; 0,68). Os níveis de hemoglobina tiveram associações moderadas a grandes com as cargas internas. Relações negativas moderadas a grandes foram encontradas entre os níveis de hemoglobina e o TRIMP de Edwards (r = −0,36; −0,63), FC máxima (FCmax; r = −0,50; −0,61) e Red Zone (r = −0,50; -0,61). Relações muito grandes foram observadas entre VIFT e Vameval para pré (r = 0,76), pós (r = 0,80) e dados agrupados (r = 0,81). Vvameval mostrou menos sensibilidade (−22,4%, [−45,0 a 9,4]), ES −0,45 [−1,05 a 0,16]) do que VIFT. Além disso, VIFT teve correlações moderadas com medidas internas e externas objetivas. No entanto, teve associações pouco claras com todas as medidas de PSE. Enquanto, Vvameval variou entre relações grandes a muito grandes com todas as medidas de PSE. No entanto, teve associações pouco claras com todas as outras cargas de treino. Em conclusão, estes resultados sugerem que os treinadores necessitam de incluir exercícios baseados em corrida tradicionais simultaneamente com JRs, se o objetivo for reduzir a variabilidade da carga interna em intensidades mais altas. Esta afirmação também se mantém para as cargas externas de maior intensidade, devido ao facto de estas produzirem maior variabilidade. Os treinadores podem usar limitação de toques e GR para ter menos variabilidade das cargas internas, mas não para as cargas externas. O VIFT e os níveis de hemoglobina podem ser usados para monitorizar o desempenho e o estado fisiológico dos jogadores durante os JRs. Além disso, sugere-se o uso de JRs como um complemento ao uso do 30-15IFT para a monitorização dos atletas.

Palavras-Chave: Futebol, monitorização, performance em jogo, variabilidade

LIST OF ABREVIATIONS

CMJ	countermovement jump
COD	change of direction
CV	coefficient of variation
GK	goalkeepers
GPS	global positioning system
HIIT	high-intensity interval training
HIR	high-intensity running
HR	heart rate
HRavg	heart rate average
HRmax	maximal heart rate
HSR	high-speed running
MW	mechanical work
sRPE	session-rate of perceived exertion
SSGs	small-sided games
TD	total distance
TE	standardized typical errors
VIFT	final velocity of the 30-15 intermittent fitness test
Vvameval	final velocity of the vameval test
YYIR	yo-yo intermittent recovery test

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CHAPTER 1: GENERAL INTRODUCTION

1 INTRODUCTION

1.1 SMALL-SIDED GAMES

Association football (soccer) is an intermittent team sport that demands players to cover total distances higher than ~10 km at a high mean exercise intensity (about 80-90% of maximal HR [HR_{max}]) (Stølen et al., 2005). Soccer has become even more intense over time, and research has shown that elite professional players now cover greater high-intensity running distances and perform more sprints and technical actions (e.g., passes) than in the last decade (Barnes et al., 2014). Furthermore, soccer is an inherently complex game that requires players to possess great capacities in different performance determinant factors, including high-intensity intermittent running (Iaia et al., 2009), repeated sprinting (Ermanno Rampinini et al., 2009), sprinting (Haugen et al., 2014), and changing direction (Chaouachi et al., 2012).

Recently, congested schedules have become common in high-level soccer (Arruda et al., 2015). Given that, professional players need to develop a great physiological profile during the pre-season phase to cope with the physical demands of the sport, considering the short recovery periods (Stølen et al., 2005). In addition, the duration of the pre-season preparation phase is limited, particularly in professional soccer. (Campos-Vazquez et al., 2017; Owen et al., 2012). Given the above-mentioned characteristics of modern soccer, coaches must prepare their players for worst-case scenarios (Oliva-Lozano et al., 2020). For these reasons, SSGs have received considerable interest among academic professionals and practitioners, given their soccer-specific and efficient training characteristics (Sarmento, Clemente, et al., 2018). However, some critics have also pointed out the limitations of SSG training interventions in elite soccer (Clemente, 2020; Little, 2009). One of those limitations is the high variability of such training interventions (Stevens et al., 2016). Therefore, a deep understanding of the strong and weak factors of SSGs is essential, and this topic needs to be studied further.

1.2 THE USEFULNESS OF SMALL-SIDED GAMES

Given the specificity and ecological training intervention of SSGs, they have received great interest among scientists and practitioners during the last decade (Clemente et al., 2021; Hill-Haas et al., 2011). On the one hand, high-intensity interval training (HIIT) has been shown as a promising training protocol for improving the fitness components of athletes (Buchheit & Laursen, 2013). On the other hand, using HIIT has its limitations in soccer settings, mainly due to the lack of the specificity principle (Hill-Haas et al., 2009; Impellizzeri et al., 2006). In fact, the usefulness of this training methodology and the understanding of its related physical, technical, and tactical aspects have been previously presented (Clemente et al., 2012).

Most studies on SSGs have attempted to investigate their acute physiological effects, while only a few studies have examined the chronic effects of this type of intervention in amateur and professional soccer players (Sarmento, Clemente, et al., 2018). The lack of specificity of running-based HIIT interventions has been the main reason for the change in traditional methods to SSG interventions (Clemente et al., 2014; Clemente, 2016). However, some concerns have been raised regarding the use of SSGs. The high within-player variability is one of the most relevant disadvantages of this soccer-specific training approach (Stevens et al., 2016). However, to the best of our knowledge, no study has investigated the inherent variability of SSGs across different formats in professional soccer players.

It has been well-established that both HIIT and SSG methods have limitations when the aim is to prepare soccer players during short-term phases (Little, 2009). The lack of specificity of HIIT and the high within-individual variations in exercise intensity of SSGs have been cited as the most important limitations of these two training methods (Little, 2009). To overcome these limitations, HIIT and SSGs have been combined in an integrated approach, and promising results have been found (Harrison et al., 2015). A previous study compared the effects of SSGs and combined HIIT and SSGs on the maximal speed reached during the 30-15 intermittent fitness test ($30\text{-}15_{IFT}$, V_{IFT}), following an experimental period (Harrison et al., 2015). In this study, while the SSGs group improved their V_{IFT} performance by 4.2%, the combined HIIT and SSGs group improved their performance by 6.6%, suggesting that concurrent HIIT and SSG is a more efficient method than skill-based training alone (Harrison et al., 2015). Another recent study compared the acute responses of SSGs when implemented at the beginning or end of training sessions, and evidence showed that the within-session time of SSGs is an important consideration in the combined approach (Sanchez-Sanchez et al., 2018). However, the within-session variations of physiological and performance responses of soccer players during SSGs, when implemented before or after HIIT, have yet to be determined (Sanchez-Sanchez et al., 2018).

There is a myriad of physical fitness tests in the literature that assess the physical capacity of soccer players (Walker & Turner, 2009). The limited time available in elite soccer teams has interested practitioners in shifting from maximal tests to submaximal tests and training integrated test alternatives (Leduc et al., 2020; Rabbani et al., 2018). Interestingly, great efforts have been made to monitor elite soccer players' physiological responses (i.e., heart rate) during SSGs to predict their specific fitness statuses (Lacome et al., 2018). Therefore, understanding the magnitude of the associations between SSGs and different physical fitness capacities (e.g., aerobic fitness, sprinting, and jumping ability) helps to better understand the usefulness of SSGs for assessing soccer players' physical capacities in a time-efficient way. To the best of our knowledge, no study has investigated the relationship between physical fitness capacity and performance measures across different formats of SSGs in professional soccer players. Another useful aspect of SSGs might be their association with match performance. However, only a few studies have investigated such a relationship in professional soccer players (Clemente et al., 2019).

1.3 PHYSICAL CONDITIONING USING SMALL-SIDED GAMES

Developing soccer players' physical determinants is important to ensure better match performance (Iaia et al., 2009). In fact, Helgerud et al. (2001) showed that aerobic training programs can improve the time spent at high intensity and greater playing involvement during a match, suggesting the importance of physical conditioning to improve match physical performance.

Tactical performance is also of great importance in high-level soccer, and coaches tend to prioritize their training process based on their tactical perspective or game model (Clemente et al., 2014). Traditional training methods (i.e., prioritizing physical fitness drills) were shifted to a more ecological approach with the use of SSGs (Sarmento, Clemente, et al., 2018). As time is limited in high-level clubs, coaches desire to have the most efficient training plans that simultaneously integrate the tactical, technical, physical, and psychological aspects of training.

Hence, soccer coaches are becoming increasingly interested in incorporating SSGs into their training programs in order to get the most benefits in terms of specific fitness tests. Another important aspect of SSGs is the high level of players' compliance and motivation compared to traditional running-based conditioning (Clemente, 2016). In fact, a systematic review with meta-analysis aiming to analyze the training effects of SSGs on physical fitness and specific skills revealed that SSGs had large positive effects on maximal oxygen uptake, agility, and repeated sprint ability. Moreover, only moderate positive effects were observed for 10- and 20-m sprint, jump, and intermittent endurance performance (Hammami et al., 2018). However, another very recent meta-analytical study comparing the effects of SSGs with running-based HIIT on the physical fitness of soccer players revealed that running-based HIIT had greater positive effects on sprint performance than SSGs (Clemente et al., 2021). Meanwhile, the same authors revealed that no significant differences were found for jumps or change-of-direction (COD) performance (Clemente et al., 2021). However, some concerns regarding the efficiency of SSGs to improve the different determinants of physical performance should be addressed (Clemente, 2020).

1.3.1 Physical conditioning limitations of small-sided games

Although implementing SSGs to improve players' conditioning and tactical efficiency is useful, these training methods also have some inherent variations due to their dependency on variables such as baseline fitness levels, motivation, and opponents' playing styles (Clemente et al., 2012). It has been well-established that traditional training approaches have inherent limitations, such as little tactical thinking, low levels of interrelationships between players, and a lack of opportunities to optimize the team's playing style (Clemente, 2016; Santos et al., 2016). However, SSGs also have some limitations (Little, 2009). For instance, external load measures can be achieved in running-based conditioning drills with great ease. On the other hand, SSGs may not produce the desired and recommended exposures to high-speed running (HSR), sprinting, and maximal speed (Clemente, 2020; Malone et al., 2018). Thus, suggestions to supplement SSGs with more controlled running-based conditioning drills to ensure correct exposures to some external load measures have been made (Clemente, 2020).

Furthermore, injury risk occurrence seems to be higher during SSG interventions than during running-based conditioning drills (Little, 2009). Another important limitation of SSGs is the ceiling effect for physiological adaptations among high-level players with better fitness profiles (Helgerud et al., 2001).

1.4 SMALL-SIDED GAMES: INTERNAL DEMANDS

Examining the internal loads associated with the use of different SSGs is of paramount importance to analyze the intensity of each used drill (David & Julen, 2015). Exercise intensity during SSGs has been mostly quantified using objective physiological variables, such as different heart rate (HR) measures and blood lactate concentrations, and subjective methods, such as the rating of perceived exertion (RPE) (Halouani et al., 2014; Owen et al., 2020). Some studies have shown that the HR/VO_2 relationship during SSGs is similar to the well-established laboratory-based HR/VO_2 relationship (Esposito et al., 2004). This suggests that HR is a valid indicator of intensity in soccer training. However, HR measures also have some limitations during intermittent activities such as soccer (Foster et al., 2017; Seiler & Hetlelid, 2005). The weakness of HR measures for representing exercise intensity is observed more in predominantly anaerobic SSGs of short duration with a smaller number of payers (e.g., 1v1 and 2v2 formats) (Little & Williams, 2007).

Similar to HR measures, blood lactate is unable to represent the muscle lactate concentration in intermittent activities such as soccer (Krustrup et al., 2006). However, in contrast to HR measures and blood lactate concentrations, the RPE is a non-invasive tool that has been shown to be valid and more suitable for monitoring soccer-specific exercises (Coutts et al., 2009; Impellizzeri et al., 2004). It is important to highlight that RPE is also dependent on players' honesty when answering RPE questionnaires. Therefore, monitoring SSGs intensity using objective and subjective internal training load measures is useful (Coutts et al., 2009).

The training regimen, including work and rest periods and the number of sets and repetitions, plays an important role when it comes to the physiological responses of players. It seems that coaches tend to use intermittent regimens to prevent within-session accumulated fatigue as a way to ensure that players perform tasks at their full potential (Aguiar et al., 2012). It has also been documented that the highest exercise intensities are achieved during continuous regimes (Hill-Haas et al., 2011). A study comparing three different bout durations in SSGs with 3-a-side format revealed significantly lower heart rate responses in 2-minute durations when compared to 4- and 6-minute repetitions (Fanchini et al., 2011).

It has also been reported that higher values of blood lactate concentrations can be observed during continuous vs. intermittent formats of SSGs (Köklü, 2012). However, greater high-intensity running distance covered was observed when playing in intermittent SSGs formats, reinforcing the fact that players can perform better during intermittent SSGs than continuous SSGs(Hill-Haas, Rowsell, et al., 2009).

Both aerobic and anaerobic energy systems are important performance determinants for training (Bangsbo et al., 2006). The values of blood lactate accumulated during SSGs have been reported to be between 2.6 and 8.1 mmol·L^{-1} (Dellal et al., 2012). For these reasons, to ensure a high level of performance in soccer, anaerobic training needs to be integrated into the training process to help players cope with high-intensity tasks in soccer (Buchheit & Laursen, 2013). Intensive exercises lasting between 30 seconds and 3 minutes can be used to improve a player's anaerobic capacity, including lactate production and lactate maintenance. Using 1-a-side and 2-a-side SSG formats while manipulating some factors (e.g., coach encouragements, field dimensions, presence or absence of goalkeepers) to influence the intensity of exercise provides an interesting skill-based option for improving the anaerobic capacity of soccer players (Buchheit & Laursen, 2013; Clemente et al., 2014).

1.5 SMALL-SIDED GAMES: EXTERNAL DEMANDS

The external load of soccer-specific training and, in particular, in SSGs can be examined using GPS microtechnology, which is able to quantify movement demands (e.g., total distance covered, high-intensity running distance covered, number of accelerations, number of decelerations). Several studies have reported acceptable levels of reliability for different GPS systems (Coutts & Duffield, 2010; Kelly et al., 2016). However, it is widely accepted that the reliability level is reduced when the speed movement increases (Buchheit & Simpson, 2017; Coutts & Duffield, 2010). Nevertheless, over the last decades, GPS companies have tried to upgrade their systems' accuracy with special techniques, such as by increasing the sampling rates from 1 to 15 Hz (Halson, 2014). More recently, GPS systems have had sampling rates of 18 Hz (Hoppe et al., 2018).

1.6 ACUTE RESPONSES OF SMALL-SIDED GAMES

There are a number of controllable variables that influence the exercise intensity during SSGs (Hill-Haas et al., 2011). Pitch area, the number of players, coach encouragement, training regimen (continuous vs. interval), rule modifications, and the involvement of goals and goalkeepers are among the most important and well-known influencing factors (Hill-Haas et al., 2011; Sarmento et al., 2018). In the following sections, some details about these factors will be presented.

1.6.1 Pitch area

The pitch area is an important factor influencing SSG intensity and is usually expressed in absolute or relative values. The relative pitch area is computed by dividing the total area by the number of players (Hill-Haas et al., 2011). Most studies investigating the effect of playing area on SSGs intensity have reported higher physiological responses when the pitch area is increased (Hill-Haas et al., 2011). For instance, it has been shown that the percentage of maximal HR and blood lactate concentrations and RPE were higher during SSGs played in larger pitches when the number of players kept constant (Ermanno Rampinini et al., 2007). It has also been shown that physical performance is increased on larger playing areas by means of total distance, HSR, and the number of accelerations and decelerations (Casamichana & Castellano, 2010; Hodgson et al., 2014). As the pitch dimensions increase, the number of technical actions also tends to decrease, resulting in more movements performed without the ball (Almeida et al., 2013). Therefore, coaches can decrease the intensity of SSGs by concurrently using smaller pitch sizes and involving fewer players (Joo et al., 2016).

1.6.2 Player number and Floater's role

Some studies have manipulated the number of players while keeping other variables, such as pitch area, constant. It is suggested that the fewer players involved, the higher the SSGs intensity (i.e., heart rate, blood lactate, and RPE) (Dellal et al., 2011; Duarte et al., 2009). Nevertheless, few studies have investigated the role of floaters (Clemente et al., 2020; Lacome et al., 2017). When examining the physiological responses of soccer players during SSGs, it is important to consider that floaters take part in offensive and defensive situations. For instance, floaters showed decreased external loads when compared with regular players during SSGs (Lacome et al., 2017). Also, the same authors found that floaters had slightly higher HR responses (Lacome et al., 2017).

Moreover, it has been shown that increasing the number of players and pitch area decreases the intensity of the exercise (Jones & Drust, 2007; Ermanno Rampinini et al., 2007). However, the above-mentioned studies that increased the absolute values of pitch area did not control the relative pitch area per player, which is an important factor that needs to be addressed in future studies. Interestingly, Hill-Haas et al. (2009) examined the acute responses of internal load measures in three SSGs formats (2v4, 4v4, and 6v6 formats) while keeping the relative area per player constant. The authors found that as the number of players decreases, the overall physiological and perceptual intensities increases (Hill-Haas, Dawson, et al., 2009).

Some authors have reported greater relative distances when more players are involved (Clemente et al., 2014; Dellal et al., 2011). Meanwhile, others have shown the opposite (Clemente et al., 2017; Lacome et al., 2017; Owen et al., 2014). Furthermore, some studies have shown increases in the number of technical actions performed during SSGs involving fewer players (Clemente et al., 2014; Joo et al., 2016; Owen et al., 2014). Nevertheless, it seems that as the number of players decreases, the numbers of dribbles, crosses, and shots on goals increase during SSGs (Silva et al., 2011).

1.6.3 Task Constraints

A common practice in soccer is to implement task constraints in order to train a specific technical or tactical situation (Clemente et al., 2012). These task constraints are usually implemented to overload or underload the technical, tactical, or physiological aspects of the game. Changing the orientation and position of the goal, changing the game rules, removing the goalkeeper, organizing specific zones, and limiting ball touches are some examples of task constraints commonly used by coaches (Sarmento, Clemente, et al., 2018).

Most studies that have examined players’ acute physiological responses during SSGs (with or without goalkeepers) show increased intensity when goalkeepers are not involved (Casamichana et al., 2012). It seems that the players have greater defensive actions and tend to attack less when playing with goalkeepers, resulting in decreased exercise intensity (Clemente et al., 2014). Also, limiting the number of touches per player is a very common task constraint used by coaches. Soccer coaches usually implement touch limitations in order to avoid player individualism, optimize teamwork, and increase the game speed (Sarmento, Clemente, et al., 2018). Research has shown that as the number of touches per player decreases, the objective and subjective internal loads also increase (Casamichana et al., 2014; Dellal et al., 2012). The main tactical aim of coaches when limiting ball touches is to increase the game speed and ball circulation between teammates (Casamichana et al., 2014).

Technical actions have been shown to be influenced by limiting ball touches. For instance, Dellal et al. (2011) showed greater ball possession when limiting players to one touch. However, more successful passes occurred when implementing a two-touch limitation or in free-play situations in 2v2 to 4v4 formats (Dellal et al., 2011). Another common task constraint implemented by coaches during SSGs is man-to-man marking. Casamichana et al. (2015) have shown that HR and distance covered are increased when implementing man-to-man marking across 3v3, 6v6, and 9v9 SSGs in amateur players. Also, Cihan (2015) showed increased HR, RPE, and distance covered in man-to-man marking compared to free-play situations.

1.6.4 Training regimen (game duration and work:rest ratios)

Some studies have examined the effects of training regimen during SSGs (Sanchez-Sanchez et al., 2018; Sarmento, Clemente, et al., 2018). Research have used interval formats interspersed with short rest periods, and continuous formats ranging from 10 to 30 minutes for each bout (Hill-Haas et al., 2011).

Hill-Haas et al. (2009) compared the internal and external loads between continuous (12 minutes) and intermittent (4×6-minute bouts interspersed with 1.5 minutes of passive rest) regimens of different SSGs formats (i.e., 2v2, 4v4, and 6v6). The authors found greater values of external load and lower values of objective and subjective internal loads. during intermittent regimen (Hill-Haas et al., 2009). Also, a comparison between continuous and intermittent formats of 2v2, 3v3, and 4v4 revealed no significant differences (Köklü, 2012). In fact, findings of previous studies suggested that both formats (i.e., continuous and intermittent) can be used to elicit similar aerobic adaptations in young players (Hill-Haas et al., 2011). Fanchini et al. (2011) compared the acute physiological responses and technical actions in amateur soccer players across different training regimens (3×2 min, 3×4 min, and 3×6 min) in a 3v3 format. The results of the above-mentioned study showed a significantly lower HR response in 6-min than 4-min duration, although the technical actions were not influenced by training regimen manipulations (Fanchini et al., 2011). Therefore, given the lower magnitude of differences between intermittent and continuous training regimens, coaches can use different training regimens when implementing SSGs for the purpose of aerobic conditioning.

1.6.5 Coach Encouragement

It has been shown that exercise supervision improves the quality of performance in athletes (Sarmento, Clemente, et al., 2018). The intensity of soccer training is also influenced by the coach's verbal encouragement (Ermanno Rampinini et al., 2007). In particular, higher values of HR measures, blood lactate concentrations, and RPE were observed when players were provided with coach encouragement in various SSGs formats (Ermanno Rampinini et al., 2007).

1.7 CHRONIC EFFECTS OF SSGS AND HIIT

Extensive research has been conducted on the acute effects of SSGs (Clemente et al., 2020). However, few studies have analyzed the chronic effects of HIIT and SSG interventions (Hill-Haas et al., 2011). Approaches integrating SSGs and HIIT interventions have received great interest among sport scientists (Harrison et al., 2015).

1.7.1 Chronic adaptations between SSGs and HIIT

Running-based HIIT (comprising intense work periods of 90% of HR_{peak} interspersed with low-intensity rest periods) and SSGs have been shown to be efficient training methods (Buchheit & Laursen, 2013; Hill-Haas et al., 2011). Using HIIT and SSGs interventions together promotes positive long-term improvements in players' VO_{2max} (Impellizzeri et al., 2005; McMillan et al., 2005). Also, improvements in high-intensity intermittent running performance and soccer-specific performance have been reported (Hill-Haas et al., 2009; Impellizzeri et al., 2008; Sperlich et al., 2011).

Impellizzeri et al. (2006) matched the intensity of HIIT to SSG training in youth soccer players and found similar internal load (e.g., VO_{2peak}, lactate threshold, and running economy) and external load (e.g., high-intensity running during the game) improvements following 12 weeks of training. In fact, a recent systematic review that aimed to analyze the short- and long-term effects of SSGs revealed that training interventions lasting at least 4 weeks resulted in significant improvements in different physical capacities (Bujalance-Moreno et al., 2019). Some advantages of SSGs over HIIT are the stimulation of soccer-specific parameters, including cognitive skills such as reaction time and decision-making (Young & Rogers, 2014).

Furthermore, higher levels of long-term compliance to training are usually observed when using SSGs, given their motivational and enjoyable nature. (Asier Los Arcos et al., 2015). Collectively, the results of previous studies suggest that SSGs can elicit similar physiological and aerobic chronic improvements as HIIT interventions. Therefore, using a mixed method that includes both running-based HIIT and SSG interventions can achieve the most effective outcomes when preparing soccer players for the worst-case scenario (Hill-Haas et al., 2011).

1.7.2 Combined SSGs and HIIT: An integrated approach

Small differences between SSGs and running-based HIIT interventions for eliciting the desired aerobic fitness are paramount for the training process, as soccer has become more physically demanding over time (Barnes et al., 2014). In addition, high-intensity intermittent running capacity plays an important role in reducing the risk of injury; it also shortens the recovery time required following matches, consequently resulting in improved match physical performance (McCall et al., 2015; Rabbani & Buchheit, 2016).

The intermittent nature of SSGs might not maintain an exercise intensity of > 90% of HR_{max} for as long as running-based HIIT, which has been suggested to be an important requirement for eliciting optimal aerobic adaptations (Hoff & Helgerud, 2004). However, as mentioned earlier, running-based HIIT presents some limitations, such as a lack of specificity (Clemente et al., 2014). However, research has shown that implementing this type of training has direct effects on soccer match performance (Impellizzeri et al., 2006).

To overcome the inherent limitations of SSGs and running-based HIIT training interventions, a mixed approach alternative has been proposed (Hill-Haas et al., 2011). It has also been recently shown that combined SSG and HIIT regimens are more effective at improving high-intensity intermittent running performance than using SSGs alone (Harrison et al., 2015). In the mentioned study, SSGs and the combined approach resulted in 4.2% and 6.6% improvements, respectively, in the final velocity achieved on the 30-

15 intermittent fitness test (V_{IFT}) (Harrison et al., 2015). Therefore, to overcome the limitations of SSGs and HIIT, and to maintain both the individualization and specificity of training interventions at high levels, combined HIIT+SSG approaches seem promising.

1.8 USING SSGS FOR MONITORING

As elite soccer settings have time constraints, coaches and practitioners would benefit from monitoring tools that can be integrated into training for assessing players' physical fitness (Owen et al., 2020). In fact, considering external loads, relationships between a 5v5 SSG and the YYIR1 running performance were revealed (Owen et al., 2020). The authors of the above-mentioned study found that TD during SSGs was very strongly associated with YYIR1 performance (Owen et al., 2020). Also, another study that tested the relationships between external load measures during SSGs interventions and players' performance during a Yo-Yo intermittent recovery test (YYIR) found large relationships between HIR and the YYIR test (Stevens et al., 2016). However, the latter study suggested that using SSGs as a monitoring tool to assess players' fitness status is neither valid nor reliable. In fact, the authors revealed a percentage of coefficient of variation (CV%) ranging between 8-14% for all high-intensity external load measures during SSGs, revealing its high variability (Stevens et al., 2016).

Regarding internal load measures, unclear associations were observed between HR measures (HR average) during SSGs and the same HR measures during soccer matches (Aquino et al., 2019). However, other studies revealed large-to-very large inverse correlations between HR measures during SSGs and YYIR test performance (Owen et al., 2020; Stevens et al., 2016). As inconsistent findings were reported regarding the relationships between HR measures during SSGs and intermittent aerobic field tests, analyzing hemoglobin levels can be useful for monitoring exercise intensity (Bekris et al., 2015). However, no study so far has analyzed the relationships between hemoglobin levels and training load measures during SSGs. For these reasons, analyzing such relationships may help coaches and practitioners understand the best practices for monitoring training using SSGs during the training sessions as the test itself.

For the reasons mentioned in the above sections, it is of paramount importance to conduct comprehensive studies quantifying within-players internal and external load variations during different SSG formats. Furthermore, examining the relationships between soccer players' performance during SSGs and their physical capacity during fitness tests may be helpful to better understand the usefulness of SSGs. Hence, this thesis proposes novel studies that can provide useful information for sport scientists, practitioners, and coaches in terms of the different applications of SSGs for training and monitoring in professional soccer settings.

CHAPTER 2: PURPOSE AND STUDY RELEVANCE

2 MAIN GOALS

This thesis proposes four different studies that may help to understand the usefulness of SSGs as a training-integrated monitoring tool to assess the general or specific performance of soccer players. The specific aims of each study have been defined to better elucidate the application of SSGs for training and monitoring in elite soccer settings. These are described in detail below.

2.1 FIRST STUDY AIM: SESSION-TO-SESSION VARIATIONS OF INTERNAL LOAD DURING DIFFERENT SMALL-SIDED GAMES: A STUDY IN PROFESSIONAL SOCCER PLAYERS

i. To analyze session-to-session variations of different internal load measures across small-sided games

ii. To examine differences between different internal load measures during within-session intervals in professional soccer players.

2.2 SECOND STUDY AIM: SESSION-TO-SESSION VARIATIONS IN EXTERNAL LOAD MEASURES DURING SMALL-SIDED GAMES IN PROFESSIONAL SOCCER PLAYERS

i. To analyze session-to-session variations in external load measures

ii. To examine the differences between within-session intervals across SSG formats among professional players.

2.3 THIRD STUDY AIM: RELATIONSHIPS BETWEEN AEROBIC PERFORMANCE, HAEMOGLOBIN LEVELS, AND TRAINING LOAD DURING SMALL-SIDED GAMES: A STUDY IN PROFESSIONAL SOCCER PLAYERS

i. To analyze between-session variations of external and internal load measures during SSGs

ii. To analyze the relationships between VIFT, hemoglobin levels, and training load measures during SSG intervals among professional soccer players.

2.4 FORTH STUDY AIM: DOSE-RESPONSE RELATIONSHIPS BETWEEN TRAINING LOAD MEASURES AND PHYSICAL FITNESS IN PROFESSIONAL SOCCER PLAYERS

i. To analyze the within-group changes of VIFT, VAMEVAL, 20-m sprint, and CMJ

ii. To explore the relationships between VIFT and VAMEVAL tests as well as their changes (i.e., ΔVIFT and ΔVAMEVAL) with accumulated training load indices.

2.5 STUDY HYPOTHESIS

2.5.1 First Study Hypothesis

It was hypothesized that using SSGs for training at high intensities would show higher between-session internal load variability and that different constraints would show different levels of variability.

2.5.2 Second Study Hypothesis

It was hypothesized that high-demanding external load measures would be more variable than low-demanding measures and that some constraints may have a greater effect than others on controlling variability.

2.5.3 Third Study Hypothesis

It was hypothesized that selected internal and external load measures would present no meaningful between-session changes and that a relationship would be observed between training load in SSGs and the physical and hematological characteristics of players.

2.5.4 Fourth Study Hypothesis

It was hypothesized that beneficial changes would occur in the fitness performance, while sRPE would be the measure with a better dose-response relationship since it represents both dimensions of load (internal and external).

2.6 STATEMENT OF CONTRIBUTION

It has been well-established that SSGs are a well-structured training intervention used to improve soccer players' technical skills, tactical behaviors, and decision-making, as well as specific physical fitness levels (Sarmento, Clemente, et al., 2018). However, there are some limitations that must be addressed when using SSGs. The differences between SSGs and running-based HIIT interventions must also be highlighted, given the session-to-session variability in terms of internal and external load measures (Stevens et al., 2016). However, only a few studies have considered such limitations (Sanchez-

Sanchez et al., 2018; Stevens et al., 2016). Also, to the best of our knowledge, no study has yet compared the different formats of SSGs across an entire in-season phase in the same professional soccer players. Understanding the noise of different SSG formats may assist coaches when using these soccer-specific interventions. Accordingly, the findings of the four papers included in the present thesis may improve the understanding of internal and external load measures responses during SSGs, both within and between sessions.

Furthermore, there are only a few reports in terms of the association between time-motion characteristics during SSGs and the physical fitness of soccer players (Hill-Haas et al., 2011). Testing the relationships between physical fitness performance observed during field tests, hemoglobin levels, and training load measures during SSGs may assist coaches and practitioners in selecting the most appropriate field tests for monitoring players' fitness statuses. Also, the usefulness of SSGs can be demonstrated as an integrated monitoring method that might impact the common logistic and time-constraint issues in professional soccer settings.

For these reasons, the present thesis aims to provide a better understanding of the within- and between-session variations of different training load measures and their relationships with physical performance changes during SSGs.

CHAPTER 3: MATERIALS AND METHODS

3 INSTRUMENTAL CONSIDERATIONS

3.1 METHODS

3.1.1 Study Variables

The dependent variables in all four papers of the present thesis are time-motion characteristic and heart rate response variables during different formats of SSGs. Thus, the dependent variables include:

a) **Total distance covered** (TD: total of distances covered)
b) **High-intensity running** (HIR: distances covered > 14.4 $km \cdot h^{-1}$)
c) **High-speed running** (HSR: distances covered >19.8 $km \cdot h^{-1}$)
d) **Mechanical work** (MW: sum of the number of accelerations and decelerations above and below 2.2$m.s^2$)
e) **Average heart rate** (HRavg: mean of heart rate beats per minute)
f) **Maximal heart rate** (HRmax: highest number of beats per minute)
g) **Time spent in Red Zone** (>80% of individual HRmax)
h) **Edwards' TRIMP**
i) **Session rating of perceived exertion** (sRPE)
j) **Muscular session rating of perceived exertion** (sRPE[M])
k) **Respiratory Session rating of perceived exertion** (sRPE[R])

These variables (i.e., time-motion characteristic and heart rate response variables) depended on the variables listed below:

a) Different SSGs formats
b) Different SSGs formats when applied after running-based HIIT
c) General fitness tests (e.g., maximal aerobic speed test, sprinting test and jumping tests)
d) Match physical performance (e.g., total distance covered, high-intensity running performance)

3.1.2 Participants

The papers conducted on the present thesis analyzed data derived from the Qatari professional team competing in the Qatar Stars League, during the 2018/2019 season.

For papers 1 and 2 of this thesis, twenty professional soccer players (mean ± SD; age 28.1 ± 4.6 years old, height 176.7 ± 4.9 cm, body mass 72.0 ± 7.8 kg, and body fat percentage 10.3 ± 3.8%) participated in both studies. All players were members of the same team. Baseline fitness levels of players revealed a VIFT (i.e., maximal velocity achieved during the last stage of 30–15 Intermittent Fitness Test) with an average of 17.9 ± 1.2 km.h−1. For paper 3 of this thesis, sixteen professional soccer players (mean ± SD; age 27.2 ± 3.4 years, height 174.2 ± 3.6 cm, body mass 69.1 ± 6.4 kg, and body fat 10.4 ± 4.1%, 3.1 ± 1.5 years in the club), all members of the same above-mentioned professional club, participated in this study. For paper 4, twenty-two professional soccer players (mean ± SD; age 27.2 ± 3.4 years, height 174.2 ± 3.6 cm, body mass 69.1 ± 6.4 kg, and body fat 10.4 ± 4.1%, 3.1 ± 1.5 years in the club).

For all four papers of the present thesis, the inclusion criteria were (i) participation in all the moments of assessment and games; (ii) absence of injuries, physical constraints, or illnesses exhibited during sessions occurred in the period and two weeks prior to the data collection; and (iii) absence of signals of fatigue on assessment days. Players were assigned to different teams (of three elements), and comparisons between teams revealed no meaningful changes in the main outcome (aerobic performance). All players were informed of the experimental procedures and related risks and gave informed consent before commencing the study. The study protocol was approved by the Scientific Committee of School of Sport and Leisure (Melgaço, Portugal) with the code number CTC-ESDL-CE00118. The study followed the ethical standards of the Declaration of Helsinki.

3.1.3 Experimental approach to the problem

For paper 1, a repeated measure descriptive design was used to quantify session-to-session variations of objective internal load of SSGs (3v3, 4v4, and 6v6 formats) with different task constraints (with and without goalkeepers as well as with and without touch limitations). To measure session-to-session variation in different formats, a three-trial repeated measure design was used and each condition was repeated during a three consecutive week phase with at least 72 h no hard training prior to experimental session (i.e., normally MD+3). There was almost similar condition for repeated measures of each format. HR measures were obtained using heart rate monitor synchronized to GPS systems during all SSG sessions.

For paper 2, a cohort design was used to analyze the session-to-session variation of external load measures in different formats of SSGs (3v3, 4v4, and 6v6) under different conditions (with and without touch limitations and goalkeepers). The same formats were tested consecutively to reduce the influence of readiness and physical status on the performance. A three-trial repeated measure design was implemented to examine noise. The same configuration (i.e., same teams, same players, same days) was maintained across all sessions. Data related to external load measures were obtained using global positioning systems during all SSGs sessions.

For paper 3, an observational analytic cohort design was followed. Players were assessed during the 1st week of data collection for hemoglobin levels and aerobic performance. After that, 3 weeks of training sessions were monitored, in which repeated-measures design was tested for specific SSGs (3v3), employed with the same conditions (same players and teams, with the same number of resting days in between). The data collection occurred in the first 4 weeks of the pre-season. Data related to external load measures were obtained using global positioning systems during all SSG sessions, while internal load was monitored using heart rate monitors.

For paper 4, an observational analytic cohort design was implemented. First fitness assessments of the players were conducted one week prior to the beginning of pre-season, and the second test was performed immediately after preparation phase. During training intervention phase, which lasted 47 days, the external and internal loads were obtained using global positioning and HR monitoring systems, respectively. The sRPE was also collected after each training session.

3.1.4 Training load measurements

During all training sessions, movement characteristics and heart rate responses were collected using a 15 Hz (interpolated from 5 Hz sampling) microtechnology device (SPI Pro X, GPSports, Canberra, Australia) synchronized with a HR monitor recorded at 1-second intervals (Polar T34, Polar Electro Oy, Kempele, Finland). Synchronization between SPI units and HR chest straps for all individual players were checked before training sessions by one of coaching staff. Session-Rate of perceived exertion (sRPE) was recorded during all training sessions and matches. The Borg's CR-10 scale was used in which 1 is "very light activity" and 10 is the "maximal exertion" in order to determine the perception of effort from the session (Borg, 1998). Players will rate the session individually to minimize the influence of hear or observe the ratings of their colleagues. The players will be familiarized with the scale before commencing the study to increase the accuracy of the ratings.

3.1.5 30-15 Intermittent Fitness Test

After familiarization, each player's high-intensity intermittent running capacity was assessed using the 30-15 Intermittent Fitness Test (30-15_{IFT}). The 30-15IFT test consisted of 30-s shuttles interspersed by 15-s periods of passive recovery. The initial velocity was set at 8 km.h−1 for the first run, and speed was increased by 0.5 km/h for each subsequent run. Players had to run back and forth between two lines positioned 40 m apart. Running pace was set by an automatic beeper to control the running speed when players entered a 3-m zone placed in the middle and at both extremities of the field. During the recovery period, players walked toward the closest line, either at the middle or one of the ends of the running area, depending on where they stopped in the last run. The test ended when a player reached exhaustion or was unable to reach the next 3 m cone on the audio signal for three consecutive occasions. The final velocity recorded in the last stage of the test determined the player's velocity of the intermittent fitness test (VIFT) score, which was used for further analysis (Buchheit et al., 2009). This test has been shown to be valid, reliable, and sensitive to training adaptations (Grgic et al., 2020). Before the test, all players completed a standardized warm-up comprising 15 min of low-intensity running and dynamic stretching.

3.1.6 Jump Assessment

For the vertical jump assessments, the countermovement jump (CMJ) with free arms protocol was used (Markovic et al., 2004a). The CMJ tests were performed on a force plate (Force Decks v1.2.6109, Vald Performance, Albion, Australia). Players were told to start from a standing position and were allowed to do a knee flexion at their comfortable depth before jumping. The athletes had to jump as high as possible while maintaining hip, knee and ankle extension. Also, players were instructed to try to land with their tip toes in the same place they took off. Before jump assessment, all players performed 2-3 familiarization trials interspersed by 1 minute of rest in-between, and the best jump were recorded for further analysis. Three maximal trials were made and the jump heights (cm) were recorded for further analysis.

3.1.7 Sprint Assessment

Sprint performance was assessed through the 20-m sprint test, with 5-m, 10-m and 15-m split times. To record sprinting times, two pairs of timing gates (Smart Speed, Fusion Sport, Queensland, Australia) were used (Buchheit et al., 2012). Before the test started, a standardized sprint specific warm up was completed. A 20-m straight line was marked by a cone at the beginning (0-m) and at the end (20-m) of the space outlined for the test. The athletes started from a static position with one foot in front of the other, with the front foot behind the starting line. The athletes were instructed to start the test after a "3,2,1, go" verbal signal. After the signal, the athletes had to maximally accelerate and reach the 20-meter line as fast as possible. Each athlete completed three 20-m sprint trials interspersed with 3 min of rest. The total time in seconds to complete each 20-m sprint was recorded for further analysis.

3.1.8 Time Motion Characteristics

External load measures were recorded during all sessions using portable 10-Hz VX Sport GPS units (VX Sport, Wellington, New Zealand), which was previously considered a valid and reliable GPS device (Buchheit et al., 2014). External load measures included total distance (TD), high-intensity running (HIR, distance > 14.4 km.h-1), high-speed running (HSR, distance > 19.8 km.h-1), and mechanical work (MW) that summed the numbers of acceleration and deceleration efforts above 2.2 m.s^2. The thresholds used for acceleration/deceleration efforts (2.2 m.s^2) were selected based on practical experiences using the VX GPS system by the coaching staff. All external load measures were relativized per minute (e.g., TD.min-1) prior to the analysis so that they could be compared across different SSG formats.

3.1.9 Heart rate-based variables

Heart rate (HR) data were recorded during all SSG sessions using Bluetooth HR sensors (Polar H10, Polar-Electro, Kempele, Finland) (recorded in 5-second intervals) which were synchronized to a portable 10-Hz VX Sport 350 GPS units (VX Sport, Wellington, New Zealand). HR measures including heart rate average (HRavg), Edwards'TRIMP, and time spent in red zone (>80% of individual HRmax) were analyzed following each training session. To standardize Edwards'TRIMP and red zone measures to be fairly compared between different SSGs formats, they were divided by minutes played (Edwards'TRIMP.min^{-1} and red zone.min^{-1}).

3.1.10 Session rating of perceived exertion (sRPE)

Approximately 10 to 30 minutes after the end of each training session, the Foster's 10-point scale of the rate of perceived exertion (RPE) was used (Foster et al., 2001). The athletes had to score from 1 to 10, were 1 corresponds to "very light activity" and 10 corresponds to "maximal exertion". The athletes scored the RPE individually without the presence of other athletes. Also, the athletes rated their perceived level of exertion separately for respiratory (sRPE[R]) and leg musculature (sRPE[M]) efforts, as previously described (Borg et al., 2010; Los Arcos et al., 2014). All athletes were allowed to score the RPE in decimals (e.g., 1.5). The sRPE was then obtained by multiplying each athlete's RPE score by the total duration of the soccer training session in minutes and was expressed in arbitrary units (A.U.) (Haddad et al., 2017).

3.2 STATISTICAL PROCEDURES

The results were presented in all papers in form of text, tables and figures, and were expressed as Mean ± SD or 90% confidence intervals (CI), where specified.

In article 1, all data were first log-transformed to reduce bias arising from non-uniformity error. To examine the reliability and session-to-session variation of internal load measures over three trials across different SSG formats with different task constraints, the intraclass correlation coefficient (ICC) and typical error (TE) of measurement either expressed as coefficient of variation or standardized using Cohen's approach (Cohen, 1988; Hopkins, 2007). ICC results were interpreted based on the classification scale: *trivial* (0.00–0.09), *small* (0.10–0.29), *moderate* (0.30–0.49), *high* (0.50–0.69), *very high* (0.70–0.89) and *nearly perfect* (0.9–1.0). Values of internal load measures of sets over three trials were averaged for standardized comparison between sets. To examine standardized differences between SSG intervals, smallest worthwhile change was considered using multiplying between-subject standard deviation by 0.2 approach (Hopkins, 2004). Threshold values for standardized differences were >0.2–<0.6 (*small*), >0.6–<1.2 (*moderate*), >1.2–<2.0 (*large*) and *very large* (>2.0) (Hopkins et al., 2009). Red zone**.**min−1 and Edwards'TRIMP**.**min−1 were computed by dividing playing time of each SSG in minutes to standardize comparing formats with different playing times. The statistical power of the present study was 80%.

In article 2, TD.min-1, to analyze the reliability and session-to-session variation of the external load measures across the three trials, the average measures-consistency intraclass correlation coefficient (ICC) and typical error (TE) of measurements—expressed either as a coefficient of variation or using Cohen's approach (i.e., standardized effect) were analyzed using a spreadsheet designed for this purpose (Cohen, 1988; Hopkins, 2007). ICC results were interpreted based on the following classification scale: trivial, small (0.10–0.29), *moderate* (0.30–0.49), *high* (0.50–0.69), *very high* (0.70–0.89), and *nearly perfect* (0.9–1.0) (Hopkins, 2000). To examine standardized differences between SSGs intervals, the smallest worthwhile change was considered by multiplying between-subject standard deviation by 0.2 (Hopkins, 2004). Threshold values for standardized differences were categorized as *small* (> 0.2– < 0.6), *moderate* (> 0.6– < 1.2), *large* (> 1.2– < 2.0), and *very large* (> 2.0) (Hopkins et al., 2009). TD.min-1, HIR.min-1, HSR.min-1, and MW.min-1 were computed by dividing the initial measure by the playing time (in minutes) in order to standardize comparisons.

In article 3, the differences between sessions in terms of training load measures were analyzed using standardized differences or effect size (ES; Cohen, 1988). Qualitative thresholds for interpreting the ES were as follows: <0.2 = *trivial*, <0.60 = *small*, <1.2 = *moderate*, <2.0 = *large*, and ≥2.0 = *very large* (Hopkins et al., 2009). A magnitude-based inference approach using the smallest worthwhile difference or change (SWC, 0.2 × between-subject SD) was used to analyze the likelihood that the true changes were clear. Pearson's correlation coefficients were used to determine the relationships between VIFT and hemoglobin levels with internal and external load measures during SSG. Qualitative thresholds for correlations were categorized as follows: <0.1 = *trivial*, <0.3 = *small*, <0.5 = *moderate*, <0.7 = *large*, <0.9 = *very large*, and ≤1.0 = *near perfect* (Hopkins et al., 2009). If the 90% confidence intervals of the Pearson's correlation coefficients and standardized difference overlapped by small positive and negative values (±0.1 and ±0.2 for *r* and ES, respectively), the relationship was deemed *unclear*; otherwise, the obtained magnitude was deemed to be the observed magnitude (Hopkins et al., 2009). The statistical analysis was performed using a dedicated Excel spreadsheet (Hopkins, 2007).

In article 4, within-group changes in changes of VIFT, Vvameval, 20-m sprint and CMJ were expressed as percentage changes and standardized differences as Cohen's d (effect size, ES, 90% CI) [27]. No missing data occur in within group analysis. Between-group differences in changes of VIFT, Vvameval tests was also expressed based on Cohen's d (effect size, ES, 90% CI) (Cohen, 1988a). Magnitude-based inference approach was used for interpreting data (Batterham & Hopkins, 2006b). Threshold values for ES were <0.2: trivial; 0.20–0.59: small; 0.60–1.19: moderate; >1.2: large (Batterham & Hopkins, 2006b). Probabilities were calculated to indicate whether the true change was lower than, similar to, or higher than the smallest worthwhile change (SWC) (Hopkins et al., 2009). The scale of probabilities was as follows: 25–75%: possible; 75–95%: likely; 95–99%: very likely; >99%: almost certain (Hopkins et al., 2009).

The probabilities were used to make a qualitative probabilistic mechanistic inference about the true effect: if the probabilities of the effect being substantially positive and negative were both >5%, the effect was reported as unclear; the effect was otherwise clear and reported as the magnitude of the observed value. Person correlation coefficient was also used to measure the association between VIFT and VVameval outcomes as well as their changes (i.e., ΔVIFT and ΔVvameval) with accumulated training load indices. The correlation coefficient (r, 90% confidence limits, CL) was ranked as trivial (<0.1), small (0.1–0.29), moderate (0.3–0.49), large (0.5–0.69), very large (0.7–0.89) and nearly perfect (0.9–0.99) (Batterham & Hopkins, 2006b). The statistical procedures were conducted in propre-designed Excel spreadsheets (Hopkins, 2007).

3.3 GANTT CHART

Some deadlines were defined to organize this work in a suitable way to achieve the goals of the PhD. The main tasks were described on a *Gantt Chart* represented in Figure 3.1.

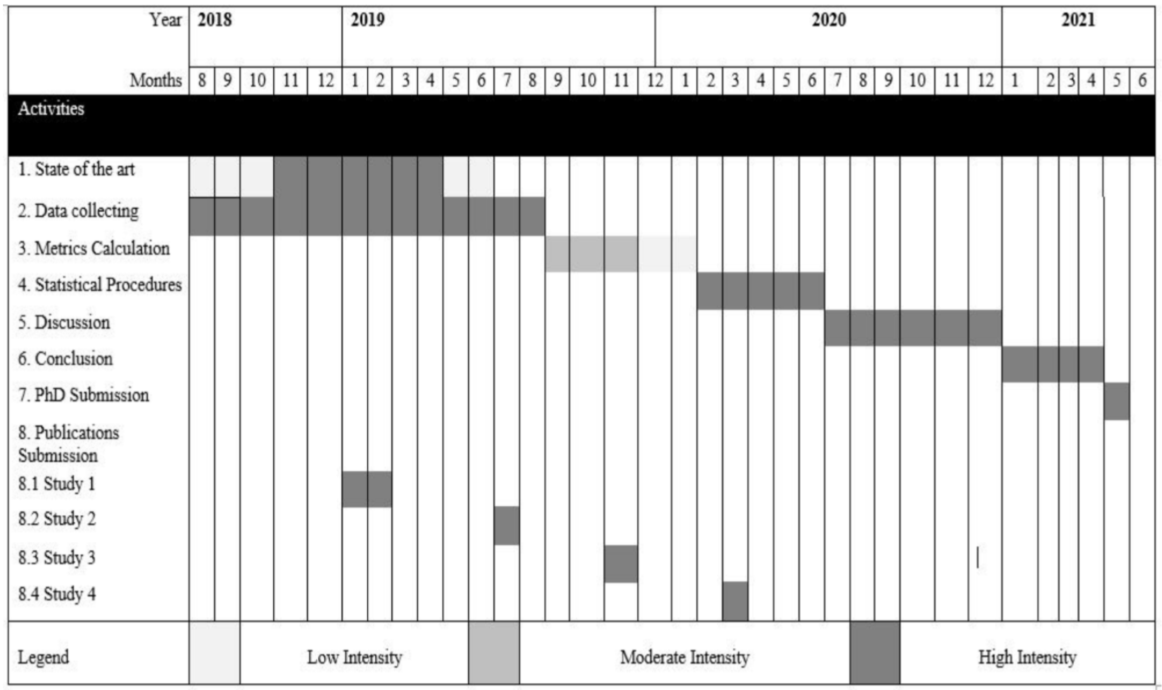

Figure 3.1 Gantt Chart of the PhD work

CHAPTER 4: PUBLISHED ARTICLES

4 PAPERS

4.1 PAPER 1: SESSION-TO-SESSION VARIATIONS OF INTERNAL LOAD DURING DIFFERENT SMALL-SIDED GAMES: A STUDY IN PROFESSIONAL SOCCER PLAYERS

Saeid Younesi[a], Alireza Rabbani[b], Filipe Manuel Clemente[c,d], Hugo Sarmento[a] And António Figueiredo[a]

[a]University of Coimbra, Research Unit for Sport and Physical Activity, Faculty of Sport Sciences and Physical Education, Coimbra, Portugal; [b]Department of Exercise Physiology, Faculty of Sport Sciences, University of Isfahan, Isfahan, Iran; [c]Escola Superior Desporto e Lazer, Instituto Politécnico de Viana do Castelo, Viana Do Castelo, Portugal; [d]Instituto de Telecomunicações, Covilhã, Portugal

ABSTRACT

The aim of this study was to analyse variations of internal load across small-sided games (SSG) in professional soccer. Twenty players (mean ± SD; age 28.1 ± 4.6 yo, height 176.7 ± 4.9 cm, weight 72.0 ± 7.8 kg) performed 3v3, 4v4, and 6v6 formats with/without goalkeeper and touch limitations. Each condition was repeated over three sessions and heart rate (HR) measures including average HR (HRavg), Edwards' training impulse (Edwards' TRIMP) and time in red zone (>80% of maximal HR) were recorded. All measures had *trivial*-to-*moderate* typical error (TE) and *trivial* differences were observed within intervals. The HRavg showed less coefficient of variations (0.9% to 1.7%) compared to Edwards'TRIMP**.**min−1 and red zone.min−1 (2% to 9.7%). A reduction trend in TE was observed when touching limitations or using goalkeepers. Practitioners can use different SSG formats but if the aim is to have less noise at higher intensities, more controlled drills are recommended.

Introduction

Soccer is an intense intermittent team sport with average intensity of 80 % to 90% of maximal heart rate (HRmax) demanding players to develop a high level of physical fitness (Stolen et al., 2005). Aiming to stimulate the fitness development of players while seeking for employing greater specificity in sessions, coaches often tend to integrate into the same drill both physical and technical/tactical demands (Aguiar et al., 2012). Consequently, small-sided games (SSGs) as an integrated approach have received great interests both from research and practice in recent years to prepare professional soccer players (Aguiar et al., 2012; Williams, 2006). Indeed, there seems to be an increasing shift among coaches from using running-based conditional drills to do more specific SSG interventions thanks to their almost similar acute and chronic physiological effects (Hill-Haas et al., 2009). In SSGs-based research (Ade et al., 2014; Aquino et al., 2019; Bredt et al., 2016; Hill-Haas, Rowsell, Dawson et al., 2008; Hill-Haas, Rowsell, Coutts et al., 2008; Ngo et al., 2012), the objective internal load intensity measured in different formats and conditions have been mostly investigated using the average HR (HRavg) as absolute (beats.min−1) or a percentage of HRmax.

The intensity of SSGs is, however, influenced by many factors including, but not limited to, coach encouragement (Rampinini et al., 2007), the number of players (Aguiar et al., 2012), playing area/size of the pitch (Rampinini et al., 2007), touch limitations (Dellal et al., 2011), and tactical rules (Ngo et al., 2012). As an example, Rampinini et al. (2007) have shown that the % of HRmax during SSGs is higher in larger pitches when the number of players is kept constant. It has also been shown that touch limitations can increase the intensity of SSG during 4v4 format (Dellal et al., 2011). It also seems that the use of goalkeepers during SSGs can influence the HR response of players rather than ball possession drills without goalkeepers (Aguiar et al., 2012; Köklü et al., 2015). Ngo et al. (2012) also showed ~4.5% increase in heart rate response by using the man-marking during 3v3 format of SSG.

Despite acute physiological response of players during an SSG session, consistency in internal load intensity plays an important role for chronic adaptations and to ensure predictability in the stimulus across the sessions (Clemente, 2020). Reliability, session-to- session variation, inter-session variability, and noise of SSGs have been the terms used to quantify training intensity consistency in the literature (Aquino et al., 2019; Clemente et al., 2019; Filipe Manuel; Ngo et al., 2012). Such consistency in the intensity in terms of objective internal training load has been mostly investigated by tracking HRavg in multiple previous research (Ade et al., 2014; Aquino et al., 2019; Bredt et al., 2016; Hill-Haas, Rowsell, Dawson et al., 2008; Hill-Haas, et al., 2008; Milanović et al., 2020) although blood lactate concentrations have also been taken into consideration in some studies (Ade et al., 2014; Hill-Haas, Rowsell, Dawson et al., 2008). The noise of blood lactate concentrations has been normally reported higher than that for HRavg in the literature (Ade et al., 2014; Rampinini et al., 2007). Therefore, although some authors have defended from acceptable noises of HRavg (e.g., coefficient of variations, CV ranging from 0.9% to 5.4%), very high values have been reported for blood lactate concentrations in their studies (e.g., CV; 9.9% to 43.7%) (Ade et al., 2014; Rampinini et al., 2007).

Research has shown that high internal load intensity variables rather than only HRavg, close or above lactate thresholds such as time spent close to VO2max or red zone (>80–- 85% of HRmax) are more important when eliciting chronic physiological adaptations or performance improvements (Castagna et al., 2011, 2013; Rabbani, Kargarfard et al., 2019). Taking into account that blood lactate concentrations show a higher session-to-session variability than HRavg during SSGs (Ade et al., 2014; Rampinini et al., 2007), it is also important to quantify other higher intensity HR measures such as time spent in red zone or general HR-derived total internal load as Edwards' training impulse (Edwards'TRIMP) (Edwards, 1994). Nevertheless, to the best our knowledge, there is no study yet that has quantified session-to-session variations of different HR zones or total internal load variable such as Edwards'TRIMP in SSGS among professional soccer players. Only a very recent study (Milanović et al., 2020) has examined the reproducibility of different HR zones in recreational soccer players and showed very high variabilities in each HR zone (CV ranging from 36.2% to 128.4%). A better understanding of the between-session variability of high- intensity HR zones and Edwards'TRIMP during SSGs may help researchers and coaches to identify the most appropriate drills or formats to consistently employ in soccer training aiming to promote chronic adaptations. In fact, such information about consistency will help coaches to more accurately periodize and plan the training load of the sessions. For that reason, the aims of this study were a) to analyze session-to-session variations of different internal load measures across small-sided games and b) to examine differences in different internal load measures during within-session intervals in professional soccer players.

Methods

Experimental approach

A repeated measure descriptive design was used to quantify session-to-session variations of objective internal load of SSGs (3v3, 4v4, and 6v6 formats) with different task constraints (with and without goalkeepers as well as with and without touch limitations). The formats were selected by representing the most common small-to-medium SSGs used in the literature (Bujalance-Moreno et al., 2019; Sgrò et al., 2018). All data were collected during 2018–2019 season, between 10 July until 9 April period. During in-season players had five to six training sessions per week and normally one official match during the weekend. To measure session-to-session variation in different formats, a three-trial repeated measure design was used and each condition was repeated during at most three consecutive week phase with at least 72 h no hard training prior to experimental session (i.e., normally MD+3). Although training time (between 17:00-to-20:00) and environmental conditions (i.e., ambient temperature and relative humidity ranging between 25oC to 38oC and 50–80%, respectively) varied substantially throughout total experimental phase, there were almost similar condition for repeated measures of each format. HR measures were obtained using heart rate monitor synchronized to GPS systems during all SSG sessions. Players were all professional and familiarized with all SSG formats and task constraints from their experience during previous training years.

Participants

Twenty professional soccer players all members of a professional club competing in the 2018–2019 season of Qatar Star League (Qatar first division) (mean ± SD; age 28.1 ± 4.6 years old, height 176.7 ± 4.9 cm, body mass 72.0 ± 7.8 kg, and body fat percentage 10.3 ± 3.8%) participated in this study. Baseline fitness levels of players revealed a VIFT (i.e., maximal velocity achieved during the last stage of 30–15 Intermittent Fitness Test) with an average of 17.9 ± 1.2 km.h−1. All players were informed of the experimental procedures and related risks and gave informed consent before commencing the study. The study protocol was approved by the university research ethics committee. The study followed the ethical standards of Declaration of Helsinki.

Procedures

Small-sided games

The formats of 3v3, 4v4 and 6v6, with and without goalkeepers, were used in this study. Additionally, touch limitation was used as task constraint (maximum three consecutive touches by each player vs. free touch condition) for all formats. Working interval durations were three, four and six min for 3v3, 4v4, and 6v6 formats, respectively, interspersed with two min rest. Two sets (intervals) per format were employed in each session. Playing area was standardized (~90 m2 per player, excluding goalkeeper) among different formats to ensure stabilization under all conditions, thus the following pitch dimensions were employed: (1) 3v3 (20 × 27 m); (2) 4v4 (22 × 32 m); and (3) 6v6 (28 × 40 m). During working intervals, enough balls were placed close to each side of the pitch for coaches to restart the game quickly when the ball is left the playing area. All games were played under supervision and encouragement of the same coaching staff. All games were performed at the beginning of training session to avoid any fatiguing condition preceded by a standardized warm-up protocol including 5 min jogging, 5 min of dynamic stretching, and 5 min of explosive actions (e.g., short sprints). The same players for each team in different formats played and teams were balanced based on physical fitness data (based on pre-season maximal test) and technical ability decided by the coach. For each format and condition, specific teams were arranged and kept the same across the three trials aiming to ensure the same conditions of data collection across the days. Participants were also informed about the objective of the experimental approach (testing consistency of load). Additionally, verbal encouragement was provided by the coach to ensure the most adequate stimulus for keeping the highest commitment as possible from the players.

Heart rate measures

Heart rate data were recorded during all SSG sessions using Bluetooth HR sensors (Polar H10, Polar-Electro, Kempele, Finland) (recorded in 5-second intervals) synchronized to a portable 10-Hz VX Sport 350 GPS units (VX Sport, Wellington, New Zealand). HR measures including HRavg, Edwards'TRIMP, and time spent in red zone (>80% of individual HRmax) were analyzed following each session. The HRmax of each individual was extracted from maximal field-based test (30–15 Intermittent Fitness Test) conducted during the pre- season. The test seems to be valid for extracting the HRmax (Čović et al., 2016). To standardize Edwards'TRIMP and red zone measures to be fairly compared between different SSG formats, they were divided by minutes played (Edwards'TRIMP**.**min−1 and red zone**.**min−1).

Statistical procedures

Results in text, table, and figures are presented as means and 90% confidence limits (CL) or standard deviation (SD) where specified. Red zone.min−1 and Edwards'TRIMP.min−1 were computed by dividing playing time of each SSG in minutes to standardize comparing formats with different playing times. Data were firstly log-transformed to reduce bias arising from non-uniformity error. To examine the reliability and session-to-session variation of internal load measures over three trials across different SSG formats with different task constraints, the intraclass correlation coefficient (ICC) and typical error (TE) of measurement either expressed as coefficient of variation or standardized using Cohen's approach (Cohen, 1988) were analyzed using a specific-designed spreadsheet (W. Hopkins, 2007). ICC results were interpreted based on the classification scale: *trivial* (0.00–0.09), *small* (0.10–0.29), *moderate* (0.30–0.49), *high* (0.50–0.69), *very high* (0.70–0.89) and *nearly perfect* (0.9–1.0). Values of internal load measures of sets over three trials were averaged for standardized comparison between sets. To examine standardized differences between SSG intervals, smallest worthwhile change was considered using multiplying between-subject standard deviation by 0.2 approach (W. G. Hopkins, 2004). Threshold values for standardized differences were >0.2–<0.6 (*small*), >0.6–<1.2 (*moderate*), >1.2–<2.0 (*large*) and *very large* (>2.0) (W. G. Hopkins, 2004). The statistical power of the present study was 80%.

Results

Large-to-*nearly perfect* ICCs were observed for SSGs with different task constraints ranging from 0.65 to 0.97 (Table 1). The lowest CVs were observed in HRavg compared to other internal load measures ranging from 0.9% to 1.7% (Table 1). Red zone.min−1 showed the highest CVs ranging from 3.8% to 9.7% (Table 1). The CVs of Edwards'TRIMP.min−1 also ranged from 2% to 5.4% (Table 1).

Standardized TE for all internal load measures ranged from *trivial*-to-*moderate* size (range, ES; 0.19 to 0.77) (Figure 4.1). Standardized TE for almost all formats and internal load measures were slightly lower when having touch limitation (Figure 4.1).

When comparing standardized differences between intervals even with different task constraints, *trivial* differences were observed for all formats except *small* standardized differences for Edwards'TRIMP.min−1 in 3v3 format with free touch (ES;

0.32 [CI, 0.12; 0.51]) and touch limitation (ES; 0.22 [0.07; 0.37]) as well as red zone.min−1 in 3v3 format for free touch (ES; 0.24 [0.08; 0.40]) (Figure 4.2).

Discussion

The purpose of this study is to describe the session-to-session variations of different internal load measures across small-sided games and to analyse the variations of different internal load measures during within-session intervals in professional soccer players. The main findings of the present study were that all internal load measures had *trivial*-to-*moderate* standardized typical error (Figure 4.1) and *trivial* differences were observed between intervals (Figure 4.2) in almost all SSG formats. It was also observed that session-to-session variations in internal load measures are variable dependent on HRavg showing the less variability compared to Edwards'TRIMP.min−1 and red zone.min−1 (Figure 4.1). A reduction trend in standardized typical error was also observed for almost all formats when implementing touch limitation rather than free touch task constraints and also when using goalkeeper compared to ball possession drills (Figure 4.1).

The CV of HRavg observed in this study was between 0.9% and 1.7% for selected formats (Table 1). The noise observed in our study is slightly lower than previous reports in the literature for selected formats ranged from 2% to 5.4% (Aquino et al., 2019; Hill-Haas, Rowsell, Dawson et al., 2008; Milanović et al., 2020; Ngo et al., 2012; Rampinini et al., 2007; Stevens et al., 2016; Williams, 2006). The lower values observed in the present study might have been due to well-controlled design of our study (e.g., similar players for each team, condition) and also more than two trials implemented (i.e. 3 trials) as it has been addressed before that the higher number of trials, the lower noise in the variable (W. G. Hopkins, 2004). Indeed, almost all previous authors have used two-trial designs in their studies to measure session-to-session variability (Aquino et al., 2019; Hill-Haas, Rowsell, Dawson et al., 2008; Milanović et al., 2020; Ngo et al., 2012; Rampinini et al., 2007; Williams, 2006).

Table 1. Day to day variations in different internal load measures for different small-sided game formats with different task constraints.

Format	Task constraints	Internal load metric	Trial 1 Mean (SD)	Trial 2 Mean (SD)	Trial 3 Mean (SD)	All trials Mean (SD)	ICC (90% CL)	CV (noise) (90% CL)
3V3	Free touch	HR_{avg} (beats·min^{-1})	157.7 (7.5)	157.1 (7.0)	157.4 (7.0)	157.4 (7.2)	0.89 (0.77; 0.95)	1.6 (1.2; 2.2)
		Red zone·min^{-1}	0.58 (0.09)	0.57 (0.08)	0.57 (0.12)	0.57 (0.10)	0.71 (0.47; 0.86)	9.7 (7.6; 13.5)
		Edwards'TRIMP·min^{-1}	3.4 (0.2)	3.3 (0.2)	3.3 (0.3)	3.3 (0.3)	0.67 (0.44; 0.83)	4.5 (3.6; 6.3)
	Touch limitation	HR_{avg} (beats·min^{-1})	157.3 (7.7)	156.6 (8.2)	156.4 (7.3)	156.7 (7.7)	0.94 (0.87; 0.97)	1.3 (1.1; 1.8)
		Red zone·min^{-1}	0.56 (0.08)	0.58 (0.10)	0.55 (0.11)	0.56 (0.10)	0.80 (0.62; 0.90)	8.2 (6.4; 11.4)
		Edwards'TRIMP·min^{-1}	3.3 (0.2)	3.3 (0.2)	3.3 (0.3)	3.3 (0.2)	0.82 (0.66; 0.91)	3.0 (2.4; 4.1)
3V3 + Gk	Free touch	HR_{avg} (beats·min^{-1})	159.1 (7.3)	159.1 (8.0)	159.6 (7.6)	159.3 (7.6)	0.96 (0.92; 0.98)	1.0 (0.8; 1.4)
		Red zone·min^{-1}	0.73 (0.16)	0.71 (0.16)	0.69 (0.14)	0.71 (0.16)	0.96 (0.92; 0.98)	5.8 (4.6; 8.0)
		Edwards'TRIMP·min^{-1}	3.8 (0.4)	3.7 (0.4)	3.6 (0.4)	3.7 (0.4)	0.96 (0.92; 0.98)	2.2 (1.7; 3.0)
	Touch limitation	HR_{avg} (beats·min^{-1})	157.4 (8.3)	158.4 (8.6)	158.8 (8.3)	158.2 (8.4)	0.97 (0.93; 0.99)	1.0 (0.8; 1.4)
		Red zone·min^{-1}	0.70 (0.14)	0.71 (0.16)	0.69 (0.14)	0.70 (0.15)	0.92 (0.83; 0.96)	7.3 (5.8; 10.2)
		Edwards'TRIMP·min^{-1}	3.6 (0.3)	3.7 (0.3)	3.7 (0.4)	3.7 (0.3)	0.86 (0.71; 0.93)	3.7 (3.0; 5.2)
4V4	Free touch	HR_{avg} (beats·min^{-1})	157.3 (8.2)	157.5 (8.1)	158.1 (8.0)	157.6 (8.1)	0.94 (0.88; 0.97)	1.2 (1.0; 1.7)
		Red zone·min^{-1}	0.55 (0.10)	0.56 (0.11)	0.58 (0.12)	0.56 (0.11)	0.91 (0.81; 0.96)	7.5 (5.9; 10.4)
		Edwards'TRIMP·min^{-1}	3.3 (0.2)	3.4 (0.2)	3.4 (0.3)	3.4 (0.2)	0.86 (0.73; 0.93)	2.8 (2.2; 3.9)
	Touch limitation	HR_{avg} (beats·min^{-1})	158.5 (7.2)	158.3 (7.6)	158.4 (7.6)	158.4 (7.5)	0.96 (0.91; 0.98)	0.9 (0.7; 1.3)
		Red zone·min^{-1}	0.62 (0.15)	0.64 (0.14)	0.62 (0.14)	0.63 (0.14)	0.96 (0.92; 0.98)	5.7 (4.5; 7.9)
		Edwards'TRIMP·min^{-1}	3.5 (0.3)	3.5 (0.3)	3.5 (0.2)	3.5 (0.3)	0.84 (0.70; 0.92)	3.2 (2.5; 4.4)
4V4 + Gk	Free touch	HR_{avg} (beats·min^{-1})	160.3 (8.2)	161.6 (5.7)	160.5 (7.5)	160.8 (7.2)	0.65 (0.38; 0.82)	2.6 (2.1; 3.6)
		Red zone·min^{-1}	0.62 (0.17)	0.61 (0.14)	0.62 (0.16)	0.62 (0.16)	0.75 (0.50; 0.87)	9.4 (7.4; 13.2)
		Edwards'TRIMP·min^{-1}	3.5 (0.4)	3.6 (0.3)	3.5 (0.3)	3.5 (0.3)	0.66 (0.39; 0.83)	5.4 (4.3; 7.5)
	Touch limitation	HR_{avg} (beats·min^{-1})	161.4 (6.0)	160.8 (7.0)	161.0 (7.2)	161.1 (6.8)	0.78 (0.61; 0.88)	1.7 (1.4; 2.4)
		Red zone·min^{-1}	0.62 (0.12)	0.63 (0.14)	0.62 (0.14)	0.63 (0.13)	0.88 (0.77; 0.94)	8.5 (6.7; 11.8)
		Edwards'TRIMP·min^{-1}	3.6 (0.3)	3.5 (0.3)	3.5 (0.3)	3.5 (0.3)	0.86 (0.73; 0.93)	3.4 (2.7; 4.7)

(*Continued*)

Table 1. (Continued)

Format	Task constraints	Internal load metric	Trial 1 Mean (SD)	Trial 2 Mean (SD)	Trial 3 Mean (SD)	All trials Mean (SD)	ICC (90% CL)	CV (noise) (90% CL)
6V6	Free touch	HR_{avg} (beats·min^{-1})	161.2 (7.6)	161.6 (7.6)	159.4 (7.0)	160.7 (7.4)	0.83 (0.69; 0.92)	1.7 (1.3; 2.3)
		Red zone·min^{-1}	0.68 (0.17)	0.67 (0.17)	0.62 (0.20)	0.66 (0.18)	0.78 (0.61; 0.88)	6.4 (5.1; 8.9)
		Edwards'TRIMP·min^{-1}	3.7 (0.4)	3.7 (0.4)	3.6 (0.4)	3.7 (0.4)	0.77 (0.60; 0.88)	4.9 (3.8; 6.8)
	Touch limitation	HR_{avg} (beats·min^{-1})	159.4 (7.6)	159.5 (7.2)	158.8 (7.4)	159.2 (7.4)	0.88 (0.76; 0.94)	1.6 (1.3; 2.2)
		Red zone·min^{-1}	0.63 (0.12)	0.64 (0.11)	0.65 (0.11)	0.64 (0.11)	0.92 (0.84; 0.96)	5.4 (4.3; 7.5)
		Edwards'TRIMP·min^{-1}	3.6 (0.3)	3.7 (0.3)	3.7 (0.2)	3.7 (0.3)	0.82 (0.67; 0.91)	3.0 (2.4; 4.1)
6V6 + Gk	Free touch	HR_{avg} (beats·min^{-1})	163.8 (7.1)	164.0 (6.1)	164.1 (6.9)	164.0 (6.7)	0.93 (0.86; 0.97)	1.4 (1.1; 1.9)
		Red zone·min^{-1}	0.75 (0.14)	0.68 (0.12)	0.73 (0.14)	0.72 (0.13)	0.85 (0.70; 0.93)	8.4 (6.6; 11.7)
		Edwards'TRIMP·min^{-1}	3.9 (0.3)	3.8 (0.3)	3.9 (0.3)	3.9 (0.3)	0.92 (0.84; 0.96)	2.2 (1.8; 3.1)
	Touch limitation	HR_{avg} (beats·min^{-1})	164.4 (6.1)	164.0 (6.6)	164.1 (6.5)	164.2 (6.4)	0.93 (0.86; 0.97)	1.0 (0.8; 1.4)
		Red zone·min^{-1}	0.71 (0.14)	0.71 (0.13)	0.73 (0.13)	0.72 (0.13)	0.97 (0.93; 0.99)	3.8 (3.0; 5.2)
		Edwards'TRIMP·min^{-1}	3.9 (0.3)	3.9 (0.3)	3.9 (0.3)	3.9 (0.3)	0.93 (0.85; 0.97)	2.0 (1.6; 2.7)

Gk: Goal keeper; HR_{avg}: average heart rate; Red zone·min^{-1}: time spent > 80% of maximal heart rate per min; Edwards'TRIMP·min^{-1}: Edwards' training impulse per min; ICC: Intraclass correlation coefficient; CL; confidence limits; CV: Coefficient of variation.

The ICC of HRavg in the present study ranged from 0.65 to 0.97. These values are similar to the findings of other studies reporting *moderate*-to-*very high* ICC values ranging from 0.58 to 0.90 (Aquino et al., 2019; Beato et al., 2018; Bredt et al., 2016, 2016; Milanović et al., 2020; Ngo et al., 2012; Stevens et al., 2016). However, in seven out of twelve ICCs in the present study, HRavg showed values higher than 0.90 (Table 1), superior than values reported in the literature (Aquino et al., 2019; Beato, 2018; Beato et al., 2018; Bredt et al., 2016; Milanović et al., 2020; Ngo et al., 2012; Stevens et al., 2016), most likely because of three-trial design implemented in our study compared to previous studies that almost all used two-trial design. The HRavg showed *trivial*-to-*moderate* standardized typical error in all formats in this study. This result is in line with the only study that has analyzed standardized typical error and reported *small*- to-*moderate* variability in various speed-endurance drills in youth soccer players (Ade et al., 2014).

Edwards'TRIMP**.**min−1 and red zone.min−1 also showed *trivial*-to-*moderate* standardized TE but with values of CV and ICC ranged higher than HRavg in almost all formats and conditions (Table 1). Such result suggests that the noise of internal load variables in SSGs is variable dependent. Furthermore, this is the first study analyzing these two internal load measures (Edwards'TRIMP.min−1 and red zone.min−1) when examining session-to-session variations of SSGs in professional soccer players. However, our results are somehow in agreement with Milanovic et al. (Milanović, et al.) demonstrating the higher noise of time spent in higher heart rate zones compared to HRavg among untrained individuals.

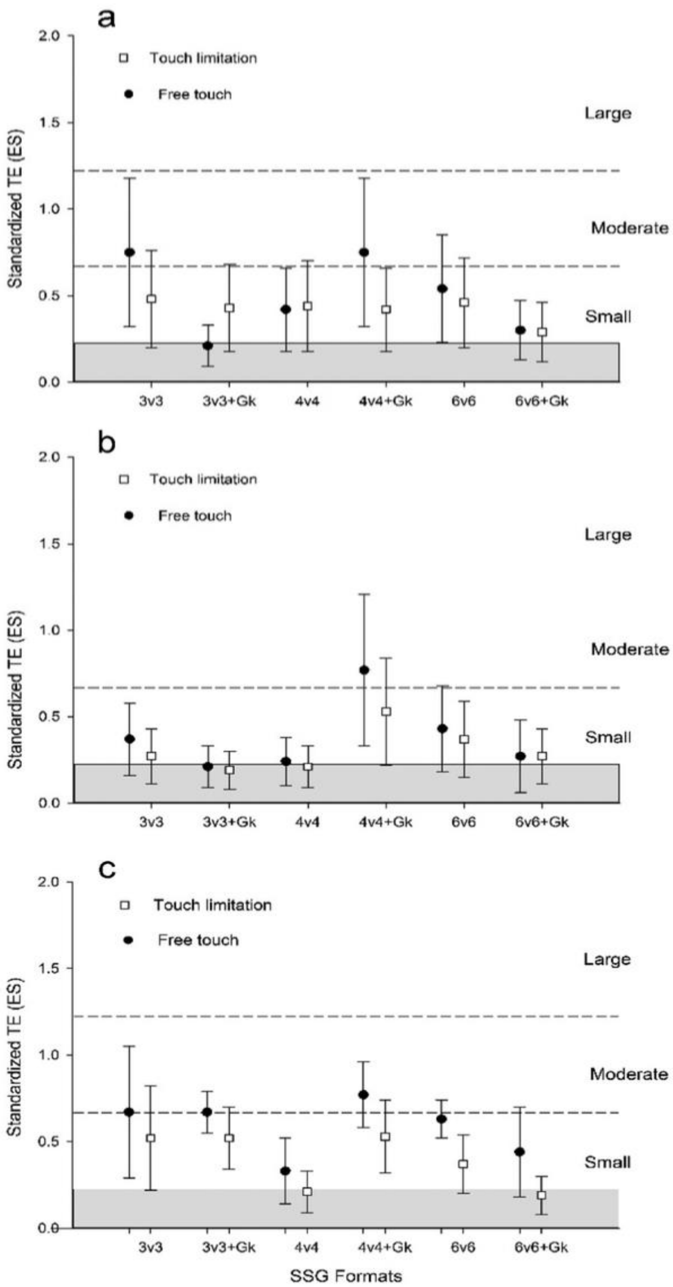

Figure 4.1. Standardized typical error [TE] across different small-sided game (SSG) formats with different task constraints for internal load measures: (a) Edwards' training impulse per min; (b) average heart rate; and (c) Red zone per min. Note. ES; effect size.

Despite methodological differences in the literature, when analysing the variation of blood lactate concentration in SSGs, higher CVs have been reported com- pared to HRavg variation (Ade et al., 2014; Hill-Haas, Rowsell, Dawson et al., 2008; Rampinini et al., 2007). Higher noises for both blood lactate concentrations reported in the literature and red zone.min−1 observed in the present study are not surprising as blood lactate threshold happens at a higher percentage of maximal heart rate (Garcia- Tabar et al., 2015). Higher noise observed for Edwards'TRIMP is also simply influenced by time spent in higher heart rate zones as they have larger coefficients in computation (Edwards, 1994).

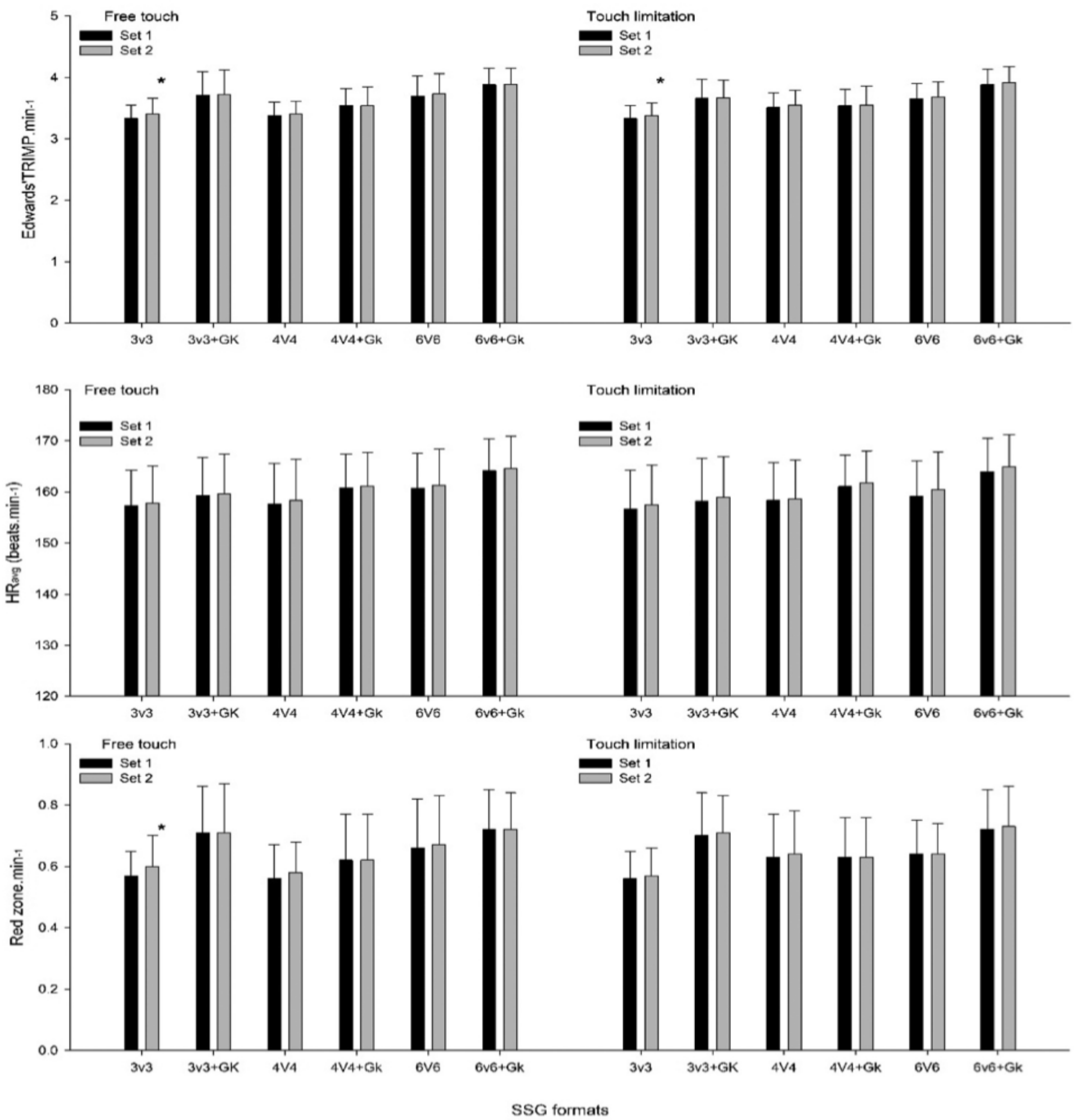

Figure 4.2. Standardized comparison between different intervals across different small-sided game (SSG) formats with different task constraints. *Small standardized difference.

The noises of Edwards'TRIMP.min^{-1} and red zone.min^{-1} are of paramount importance in training process as it has been recently highlighted by showing larger relationships with fitness improvement for these variables (i.e., dose-response relationships) in soccer players (Castagna et al., 2011, 2013; Rabbani, Kargarfard et al., 2019).

When analysing standardized differences between intervals, only three out of 36 conditions showed *small* increase in the intensity of SSGs in the second set and *trivial* differences were observed in other conditions. Therefore, based on these results, it seems that, in general, at least the second interval does not increase the intensity substantially. However, our finding is not in agreement with the study of Da Silva et al. (2011) that showed significant increased intensity in the second and third intervals compared to first interval (~86% vs. ~89% of HRmax). This discrepancy can be explained by different age, competitive level, fitness status and technical level of subjects in our study vs. that study (adult professional vs. young amateur) as it seems that experienced and professional players might perform better in pacing strategies (i.e., managing their efforts during different intervals) (Gabbett et al., 2015). Our results are, however, supported by the study of Ngo et al. (2012) demonstrating less noise when comparing inter-interval (CV range; 1.94; 3.16) vs. inter-session (CV range; 3.26; 4.62) in HR responses.

A reduction trend in session-to-session variation was observed in the present study for 3v3 and 6v6 formats when implementing touch limitation rather than free touch task constraint as well as using goalkeeper compared to ball possession drill (Figure 1). These results are not surprising as it has been suggested before that these two conditions (i.e., touch limitation and using goalkeeper) increase exercise intensity (Aguiar et al., 2012) and subsequently increased intensity reduces the noise of SSG drills (Ngo et al., 2012). However, such trend was not observed for 4v4 format in terms of using goalkeeper and further research is needed to clarify this area more. Nevertheless, it seems that by manipulating factors affecting internal load responses of SSGs to increase intensity we can have less noise; assuring that players are exposed to more consistent internal load during longitudinal phases. It seems that to assure that players are training consistently at intensities near to maximal oxygen uptake (i.e., red zone), practitioners need to implement more controlled running-based conditional strategies, at least concurrent to SSG drills (Rabbani, Clemente et al., 2019). This is well supported by the study of Ade et al.

(2014) that showed speed endurance production drills using generic running have less noise compared to its equivalent in the SSGs (CV; 0.9 vs 1.3%).

This study is limited by the small sample size as it has only been executed by one soccer team and further research on different clubs is needed to generalize the results. It is suggested to examine the noise of internal and external load measures across other smaller (<3v3) or larger sized (>6v6) SSG formats and manipulating other influential factors (e.g., different tactical formations, different task constraints) in the future studies. Moreover, variations in interval duration and interactions with fitness levels of players can be explored in future studies. Finally, this study was conducted in-season, and this may support the more stable and consistent findings. Therefore, it is possible that such consistency may not be found in other periods of the season (e.g., pre-season) due to the greater heterogeneity of fitness level and this should be considered by coaches. Despite these limitations, the results of this study suggest that practitioners can use different SSG formats to train players but if the aim is to be strictly consistent about higher intensities (i.e., red zone) SSGs show high variabilities and therefore more con- trolled running-based conditional drills can be recommended. Otherwise, practitioners can also manipulate factors affecting physiological response of SSGs such as touch limitations and usage of goalkeepers to increase the intensity and subsequently have less session-to-session variability in internal load measures.

Practical implications

This is the first study that examined session-to-session variations of Edwards'TRIMP.min−1 and red zone.min−1 of SSGs in professional soccer players. Our study showed that the noises of Edwards'TRIMP.min−1 and red zone.min−1 are higher than HRavg and these results are of paramount importance in training process as it has been recently high- lighted through showing larger relationships with fitness improvement for high-intensity zones of HR (i.e., dose-response relationships) in soccer players (Castagna et al., 2011, 2013; Rabbani, Kargarfard et al., 2019). As it has been well documented before that players need to train consistently in intensities near to maximal oxygen uptake (i.e., red zone), strength and conditioning coaches need to implement more controlled running-based conditional strategies, at least concurrent to SSG drills, if the main aim is to improve high- intensity running performance (Rabbani, Clemente et al., 2019). Task constraints should be also considered for controlling the variability of the stimulus. Therefore, practitioners can manipulate factors affecting internal load responses of SSGs to increase intensity to achieve less noise; assuring that players are exposed to more consistent internal load during longitudinal phases.

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Disclosure statement

The authors declare no conflict of interest.

ORCID

Alireza Rabbani http://orcid.org/0000-0002-1500-0447

Filipe Manuel Clemente http://orcid.org/0000-0001-9813-2842

Hugo Sarmento http://orcid.org/0000-0001-8681-0642

António Figueiredo http://orcid.org/0000-0001-6956-0514

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4.2 PAPER 2: SESSION-TO-SESSION VARIATIONS IN EXTERNAL LOAD MEASURES DURING SMALL-SIDED GAMES IN PROFESSIONAL SOCCER PLAYERS

AUTHORS: Saeid Younesi[1], Alireza Rabbani[2], Filipe Manuel Clemente[3,4], Hugo Sarmento[1], António J. Figueiredo[1]

[1] University of Coimbra, Research Unit for Sport and Physical Activity. Faculty of Sport Sciences and Physical Education

[2] Department of Exercise Physiology, Faculty of Sport Sciences, University of Isfahan, Isfahan, Iran

[3] Escola Superior Desporto e Lazer, Instituto Politécnico de Viana do Castelo, Rua Escola Industrial e Comercial de Nun'Álvares, 4900-347, Viana do Castelo, Portugal

[4] Instituto de Telecomunicações, Delegação da Covilhã, Covilhã, Portugal

ABSTRACT: The aims of this study were 1) to analyse session-to-session variations in different external load measures and 2) to examine differences in within-session intervals across different small-sided game (SSG) formats in professional players. Twenty professional soccer players (mean ± SD; age 28.1 ± 4.6 years, height 176.7 ± 4.9 cm, body mass 72.0 ± 7.8 kg, and body fat 10.3 ± 3.8%) participated in 3v3, 4v4, and 6v6 SSGs under different conditions (i.e., touch limitations and presence of goalkeepers vs. free touch and ball possession drill) over three sessions. Selected external load measures—including total distance (TD), high- intensity running (HIR, distance covered > 14.4 km.h-1), high-speed running (HSR, distance covered > 19.8 km.h-1), and mechanical work (MW, accelerations and deceleration > 2.2 m.s2)—were recorded using GPS technology during all SSG sessions. Small to large standardized typical errors were observed in session-to-session variations of selected measures across SSGs. TD.min-1 showed less variability, having a coefficient of variation (CV) of 2.2 to 4.6%, while all other selected external load measures had CV values ranging from 7.2% to 29.4%. Trivial differences were observed between intervals in TD.min-1 and HIR.min-1 for all SSGs, as well as in HSR.min-1 and MW.min-1 for most SSG formats. No reductions or incremental trends in session-to-session variations were observed when employing touch limitations or adding goalkeepers. The increased noise observed in higher speed zones (e.g., high-speed running) suggests a need for more controlled, running-based conditional drills if the aim is greater consistency in these measures.

Key words: Association football; Performance; High-intensity running; High-speed running; Reliability; Noise

INTRODUCTION

The small-sided game (SSG) is an integrated training approach that combines the technical, tactical, and physiological aspects of soccer. It is very popular among scientists and practitioners as a result of its proven benefits (Hill-Haas et al., 2011; Sarmento et al., 2018). Researchers have investigated the acute responses and chronic physiological adaptations of soccer players following SSG interventions (Clemente et al., 2012; Hill-Haas et al., 2009; Hill-Haas et al., 2011; Sarmento et al., 2018), as well as the transfer of the physiological effects of SSGs to match performance (Little & Williams, 2006). Others, however, have criticized SSGs in recent years, claiming that they offer less controlled physical load than some running-based conditional interventions (Ade et al., 2014; Sarmento et al., 2018). It has also been noted that SSGs cannot simulate all the physical demands of a soccer match and, for that reason, are limited in their ability to prepare players for real competitions (Clemente, 2020). Among all limitations, the reduced frequencies of high-demanding efforts (e.g., sprinting) during SSGs as well as the dependency of the physical status of players are part of the issues when implementing SSGs (Castillo et al., 2020). Moreover, it is also known that even considering similarities between SSGs and the match, the latter promotes greater high-demanding speeds in terms of external loads (Castillo et al., 2021).

Session-to-session variations in training load variables have an essential role in ensuring that a training intervention is effective and maximizes physiological stimulus at an individual level (Hill-Haas et al., 2008; Hill-Haas et al., 2008). Reducing variation, or noise, in exercise intensity increases the consistency of the stimulus and consequently assures improvements in players' physiological adaptation and performance improvement (Buchheit, 2014). While studying the noise of internal load variables (e.g., average heart rate, blood lactate concentration) during SSGs is important primarily for metabolic aspects (Ngo et al., 2012; Rampinini et al., 2007), session-to-session variations in external load measures (e.g., total distance, sprinting distance) are also relevant—especially from a neuromuscular point of view (Clemente et al., 2019). For instance, it has been reported that higher speed zones of distance covered (e.g., high-speed running) put more strain on hamstring muscles, while high-intensity actions (e.g., accelerations and decelerations) require more use of the quadriceps, adductors, and gluteal muscles (Mujika et al., 2018). These relationships are of paramount importance to strength and conditioning coaches, who aim to prevent injuries and improve athletes' physical performance by targeting specific muscle groups (Mujika et al., 2018).

Research has shown that manipulating factors like touch limitations (Dellal et al., 2011), pitch size (Rampinini et al., 2007), goalkeeper presence (Köklü et al., 2015), and even tactical rules (Ngo et al., 2012) can influence acute physiological responses to SSGs. For instance, Ngo et al. (2012) showed an increase in heart rate response (~4.5%) when using man-marking. Interestingly, the same study found that increased intensity leads to decreased variation (i.e., noise) in physiological response (i.e., internal load) (Ngo et al., 2012). Although several studies have examined the session-to-session variability of external load measures during SSGs (Ade et al., 2014; Aquino et al., 2019; Hill-Haas et al., 2008; Hůlka et al., 2015; Stevens et al., 2016), researchers have not yet determined the effects that some factors (e.g., touch limitations, goalkeeper presence) have on noise in different SSG formats. Examining a 5 vs. 5 format played at different pitch sizes (38x26 vs. 53vs.37m), coefficient of variations showed very high values for sprinting (133% and 75%, in smaller and larger pitch, respectively), moderate values in jogging and cruising (27-43 and 22-28%, in smaller and larger pitch, respectively) and small values in walking (<9%). When evaluating two formats of play (3 vs. 3 and 4 vs. 3) [24] weak reliability (intra-class correlation test) of peak speed (0.08 and 0.09 in 3 vs. 3 and 4 vs. 3 formats, respectively), and weak-to-moderate reliability of distances covered between 7.3 and 14.3 $km{\cdot}h^{-1}$ and 14.4 and 21.5 $km{\cdot}h^{-1}$ (0.56 and 0.54; 0.74 and 0.28, respectively in 3 vs. 3 and 4 vs. 3 formats) were found. These are examples of differences in the external load measures in terms of variability and reliability when comparing different formats and pitch sizes. Furthermore, other concurrent factors should also be considered, namely the use of specific conditions that aims to strengthen the tactical dimension of the games.

Furthermore, only a few studies have investigated within-interval external load changes during SSGs with soccer players (Clemente et al., 2020; Dellal et al., 2011). More research is needed to clarify whether the manipulation of influential factors causes any changes between intervals in different SSG formats. Addressing these issues will help coaches to understand the effects of different task conditions on external load variability and choose drills accordingly. For these reasons, the aims of this study were 1) to analyze session-to-session variations in external load measures, and 2) to examine the differences in within-session intervals across SSG formats among professional players. We hypothesized that high-demanding external load measures will be more variable than low-demanding measures as well as some constraints may have more effect on controlling the variability.

METHODS

Experimental Approach to the Problem

A cohort design was used to analyze the session-to-session variation of external load measures in different formats of SSGs (3v3, 4v4, and 6v6) under different conditions (with and without touch limitations and goalkeepers). The data collection phase lasted from 10 July to 9 April. The same format was tested consecutively to reduce the influence of readiness and physical status on the performance. A three-trial repeated measure design was implemented to examine noise. Training time and environmental conditions were almost similar for repeated measures of each SSG format with special condition (e.g., 3v3+Gk and touch limitation) employed maximally during three consecutive week phase. The same configuration (i.e., same teams, same players, same days) was maintained across all sessions. However, training time (between 17:00 and 20:00) and environmental conditions (ambient temperature and relative humidity ranging between 25 to 38°C and 50 to 80%, respectively) varied greatly over the data collection phase. Data related to external load measures were obtained using global positioning systems during all SSG sessions. All players involved in the study were professional and were familiar with SSGs prior to the experimental period.

Subjects

Twenty professional soccer players (mean ± SD; age 28.1 ± 4.6 years old, height 176.7 ± 4.9 cm, body mass 72.0 ± 7.8 kg, and body fat percentage 10.3 ± 3.8) participated in this study. All were members of a team competing in the 2018–2019 season of the Qatar Star League (Qatar First Division). Inclusion criteria were (i) at least three years' experience training in professional clubs prior to the start of the study, (ii) a minimum age of 18 years, and (iii) no serious injuries during the data collection phase (following a complete cardiovascular health examination). All players were aware of the experimental procedures and gave informed consent. The study protocol was approved by the university's scientific committee.

Procedures

Small-sided games

SSGs—including 3v3, 4v4, and 6v6 formats—were used in this study. Each format was repeated over three trials with a different special condition. The conditions were touch limitations (with a maximum of three consecutive touches permitted to each player) or free-touch task constraints, as well as adding goalkeepers or performing ball position drills. Three-, four-, and six-minute working intervals were implemented for 3v3, 4v4, and 6v6 SSG formats, respectively. Two minutes were allotted for recovery between intervals. Pitch dimensions included 20 × 27 m; 22 × 32 m; and 28 × 40 m for 3v3, 4v4, and 6v6 SSGs, respectively, and the playing areas were standardized (~90 m^2 per player, excluding the goalkeeper). Goal size (i.e., real match size) were kept consistent in all game interventions. All SSG formats excluded offside rule and the same coaching staff gave coach encouragement as consistent as possible in all sessions. All throw-ins for restarting the game were performed using goal keepers from their standard positions.

The first two intervals in each format were selected for analysis. The coaching staff, which included one of the authors (a strength and conditioning coach), were directed to ensure consistency in their supervision during all SSG sessions. Balls were kept near the SSG pitch so that coaches could restart the game immediately if a ball left the playing area. For each format, the teams were balanced based on their members' physical and technical abilities (as determined by the coach) to reduce any possible strength or weakness bias.

External load measures

External load measures were recorded during all sessions using portable 10-Hz VX Sport GPS units (VX Sport, Wellington, New Zealand), which are valid and reliable according to Buchheit et al. (2014). External load measures included total distance (TD), high-intensity running (HIR, distance > 14·4 $km \cdot h^{-1}$), high-speed running (HSR, distance > 19·8 $km \cdot h^{-1}$), and mechanical work (MW) that summed the numbers of acceleration and deceleration efforts above and below 2.2 m·s^2 thresholds. The thresholds used for acceleration/deceleration efforts (2.2 m·s^2) were selected based on practical experiences using VX GPS system by the coaching staff. All external load measures were standardized by being divided by minutes played (e.g., TD·min^{-1}) prior to the analysis so that they could be compared across different SSG formats.

Statistical analyses

The results in the text, tables, and figures herein are presented as means using a 90% confidence limit (CL) or standard deviation (SD) as specified. TD·min^{-1}, HIR·min^{-1}, HSR·min^{-1}, and MW·min^{-1} were computed by dividing the initial measure by the playing time (in minutes) in order to standardize comparisons. To analyze the reliability and session-to-session variation of the external load measures across the three trials, the average measures-consistency intraclass correlation coefficient (ICC) and typical error (TE) of measurements—expressed either as a coefficient of variation or using Cohen's approach (i.e., standardized effect) (Cohen, 1988b)—were analyzed using a spreadsheet designed for this purpose. ICC results were interpreted based on the following classification scale: trivial, small (0.10–0.29), *moderate* (0.30–0.49), *high* (0.50–0.69), *very high* (0.70–0.89), and *nearly perfect* (0.9–1.0) (Hopkins, 2000b). To examine standardized differences between SSG intervals, the smallest worthwhile change was considered by multiplying between-subject standard deviation by 0.2 (Hopkins, 2004). Threshold values for standardized differences were categorized as *small* (>0.2–<0.6), *moderate* (>0.6–<1.2), *large* (>1.2–<2.0), and *very large* (>2.0) (Hopkins et al., 2009).

RESULTS

The results of this study (Tables 2 and 3) showed that TD·min^{-1} had ICCs ranging from *high*-to-*nearly perfect* (0.67; 0.95) and CVs between 2.2 and 4.6% across all SSG formats. HIR·min^{-1} also showed ICCs ranging from *high*-to-*nearly perfect* (0.58; 0.96) and CVs between 7.2 and 16.4%. HSR·min^{-1} had ICCs that ranged from *moderate*-to-*nearly perfect* (0.48; 0.94) and CVs between 12.2 and 29.4%. MW·min^{-1} had *moderate* to *very large* (0.47; 0.87) ICCs and CVs between 9.4 and 22.5%.

Table 2. Day to day variations in different external load measures for different small-sided game formats without goalkeeper.

Format	Task constraints	External load	Trial 1 Mean (SD)	Trial 2 Mean (SD)	Trial 3 Mean (SD)	All trials Mean (SD)	ICC (90% CL)	CV (noise) (90% CL)
3V3	Free touch	TD·min^{-1}	127.1 (11.4)	130.5 (12.5)	134.1 (14.5)	130.6 (12.9)	0.80 (62; .90)	4.3 (3.4; 6.0)
		HIR·min^{-1}	14.0 (4.2)	14.4 (4.6)	14.9 (3.6)	14.4 (4.2)	0.92 (0.83; 0.96)	9.3 (7.3; 12.9)
		HSR·min^{-1}	1.6 (0.4)	1.7 (0.4)	1.9 (0.5)	1.7 (0.5)	0.49 (0.15; 0.73)	21.4 (16.6; 30.4)
		MW·min^{-1}	4.0 (0.4)	4.0 (0.5)	4.1 (0.6)	4.1 (0.5)	0.48 (0.15; 0.71)	9.4 (7.4; 13.1)
	Touch limitation	TD·min^{-1}	129.4 (7.5)	127.4 (11.3)	129.8 (8.6)	128.9 (9.3)	0.74 (0.51; 0.87)	4.1 (3.3; 5.7)
		HIR·min^{-1}	14.5 (3.7)	15.0 (4.0)	14.8 (3.8)	14.8 (3.8)	0.89 (0.77; 0.95)	10.3 (8.1; 14.4)
		HSR·min^{-1}	2.0 (0.3)	2.0 (0.5)	1.7 (0.4)	1.9 (0.4)	0.51 (0.18; 0.73)	17.7 (13.8; 25.0)
		MW·min^{-1}	4.4 (0.6)	4.5 (0.5)	4.1 (0.5)	4.3 (0.6)	0.47 (0.14; 0.70)	9.8 (7.7; 13.8)
4V4	Free touch	TD·min^{-1}	125.3 (10.1)	124.4 (10.0)	129.8 (10.0)	126.5 (10.0)	0.67 (0.42; 0.83)	4.6 (3.6; 6.4)
		HIR·min^{-1}	15.0 (2.8)	15.1 (3.0)	14.5 (3.8)	14.9 (3.2)	0.78 (0.59; 0.89)	11.6 (9.1; 16.3)
		HSR·min^{-1}	1.9 (0.4)	1.9 (0.4)	2.1 (0.4)	1.9 (0.4)	0.60 (0.30; 0.79)	14.2 (11.1; 19.9)
		MW·min^{-1}	4.4 (0.6)	4.4 (0.7)	5.2 (0.9)	4.6 (0.7)	0.61 (0.34; 0.79)	10.2 (8.0; 14.3)
	Touch limitation	TD·min^{-1}	115.1 (9.5)	117.1 (10.7)	118.1 (10.4)	116.8 (10.2)	0.83 (0.66; 0.91)	3.7 (2.9; 5.1)
		HIR·min^{-1}	17.5 (3.9)	16.8 (3.9)	17.7 (3.8)	17.3 (3.9)	0.90 (0.80; 0.95)	8.8 (6.9; 12.2)
		HSR·min^{-1}	2.7 (0.7)	2.3 (0.5)	2.6 (0.6)	2.5 (0.6)	0.79 (0.60; 0.90)	12.2 (9.5; 17.1)
		MW·min^{-1}	6.8 (1.7)	6.9 (1.3)	6.9 (1.3)	6.9 (1.4)	0.74 (0.52; 0.87)	12.4 (9.7; 17.3)
6V6	Free touch	TD·min^{-1}	117.5 (9.3)	118.3 (8.7)	117.0 (9.6)	117.6 (9.2)	0.92(0.83; 0.96)	2.3 (1.8; 3.2)
		HIR·min^{-1}	10.3 (3.4)	10.5 (3.6)	10.8 (3.8)	10.5 (3.6)	0.92 (0.84; 0.96)	10.5 (8.3; 14.7)
		HSR·min^{-1}	1.9 (0.5)	1.7 (0.5)	1.8 (0.6)	1.8 (0.6)	0.48 (0.23; 0.69)	29.4 (22.5; 43.0)
		MW·min^{-1}	6.1 (2.0)	6.6 (2.5)	6.2 (2.0)	6.3 (2.2)	0.79 (0.61; 0.89)	17.0 (13.3; 24.2)
	Touch limitation	TD·min^{-1}	108.0 (8.9)	107.7 (8.7)	108.3 (8.9)	108.0 (8.9)	0.87 (0.75; 0.94)	2.7 (2.1; 3.7)
		HIR·min^{-1}	9.9 (2.6)	10.3 (2.6)	9.6 (2.6)	9.9 (2.6)	0.84 (0.69; 0.92)	11.1 (8.7; 15.5)
		HSR·min^{-1}	1.7 (0.7)	1.8 (0.7)	1.8 (0.6)	1.8 (0.6)	0.91 (0.83; 0.96)	13.7 (10.7; 19.2)
		MW·min^{-1}	6.6 (1.9)	6.6 (1.6)	6.3 (1.7)	6.5 (1.7)	0.83 (0.66; 0.92)	11.8 (9.3; 16.6)

Note. TD: total distance; HIR: high-intensity running (> 14.4 km·h^{-1}); HSR: high-speed running (> 19.8 km·h^{-1}); MW: number of accelerations plus decelerations (> 2.2 m·s^{2}); ICC: intraclass correlation coefficient; CL; confidence limits; CV: coefficient of variation.

Table 3. Day to day variations in different external load measures for different small-sided game formats with goalkeeper.

Format	Task constraints	External load	Trial 1 Mean (SD)	Trial 2 Mean (SD)	Trial 3 Mean (SD)	All trials Mean (SD)	ICC (90% CL)	CV (noise) (90% CL)
3V3 +Gk	Free touch	TD·min^{-1}	125.5 (14.9)	127.0 (14.3)	126.8 (11.7)	126.4 (13.7)	0.92 (0.84; 0.96)	3.1 (2.5; 4.3)
		HIR·min^{-1}	20.3 (6.3)	19.6 (5.8)	18.5 (6.6)	19.5 (6.3)	0.88 (0.77; 0.94)	13.9 (10.9; 19.6)
		HSR·min^{-1}	2.1 (0.5)	2.4 (0.7)	2.6 (0.7)	2.3 (0.7)	0.79 (0.59; 0.90)	18.2 (14.2; 25.8)
		MW·min^{-1}	5.3 (1.4)	5.2 (1.3)	5.4 (1.5)	5.3 (1.4)	0.84 (0.69; 0.92)	10.6 (8.3; 14.8)
	Touch limitation	TD·min^{-1}	115.3 (14.8)	115.7 (14.4)	121.2 (15.4)	117.4 (14.9)	0.95 (0.89; 0.97)	2.9 (2.3; 4.0)
		HIR·min^{-1}	16.3 (8.0)	16.2 (7.6)	16.9 (8.4)	16.5 (8.0)	0.96 (0.92; 0.98)	8.8 (6.9; 12.3)
		HSR·min^{-1}	1.6 (0.6)	2.0 (0.6)	2.7 (0.9)	2.1 (0.7)	0.81 (0.62; 0.91)	16.0 (12.5; 22.6)
		MW·min^{-1}	4.6 (1.5)	4.9 (1.4)	5.9 (2.4)	5.1 (1.8)	0.71 (0.50; 0.85)	16.2 (12.6; 23.0)
4V4 +Gk	Free touch	TD·min^{-1}	135.1 (7.3)	128.4 (9.5)	132.4 (8.2)	132.0 (8.4)	0.85 (0.70; 0.93)	2.7 (2.2; 3.8)
		HIR·min^{-1}	18.5 (3.7)	15.3 (3.6)	17.6 (3.3)	17.2 (3.5)	0.58 (0.27; 0.78)	16.4 (12.8; 23.2)
		HSR·min^{-1}	3.2 (0.8)	2.5 (0.8)	2.8 (0.9)	2.8 (0.8)	0.76 (0.54; 0.88)	19.0 (14.8; 26.9)
		MW·min^{-1}	6.5 (1.5)	6.2 (2.1)	6.5 (1.3)	6.4 (1.7)	0.56 (0.26; 0.77)	22.5 (17.4; 32.0)
	Touch limitation	TD·min^{-1}	126.1 (10.0)	122.5 (12.7)	122.8 (12.0)	123.8 (11.6)	0.92 (0.83; 0.96)	2.9 (2.3; 4.0)
		HIR·min^{-1}	17.4 (3.5)	17.0 (3.5)	17.8 (3.9)	17.4 (3.7)	0.90 (0.80; 0.95)	7.2 (5.7; 10.1)
		HSR·min^{-1}	2.5 (0.8)	2.6 (0.8)	2.6 (0.9)	2.6 (0.8)	0.75 (0.55; 0.87)	16.7 (13.0; 23.7)
		MW·min^{-1}	7.2 (3.0)	7.3 (3.3)	6.8 (3.0)	7.1 (3.1)	0.87 (0.75; 0.94)	14.7 (11.4; 20.7)
6V6 +Gk	Free touch	TD·min^{-1}	116.4 (8.7)	115.4 (8.7)	115.8 (8.8)	115.8 (8.7)	0.84 (0.68; 0.92)	3.2 (2.5; 4.4)
		HIR·min^{-1}	11.8 (4.4)	12.8 (2.9)	12.1 (4.4)	12.2 (4.0)	0.76 (0.55; 0.88)	15.9 (12.5; 22.5)
		HSR·min^{-1}	2.4 (1.3)	2.4 (1.1)	2.2 (1.3)	2.3 (1.2)	0.77 (0.57; 0.89)	26.3 (20.4; 37.8)
		MW·min^{-1}	5.9 (1.8)	5.0 (1.8)	5.2 (1.1)	5.4 (1.6)	0.72 (0.49; 0.86)	18.4 (14.4; 26.1)
	Touch limitation	TD·min^{-1}	111.0 (8.4)	112.0 (8.8)	111.0 (8.8)	111.3 (8.7)	0.93 (0.85; 0.97)	2.2 (1.8; 3.1)
		HIR·min^{-1}	13.6 (3.8)	13.9 (3.3)	13.7 (3.4)	13.8 (3.5)	0.92 (0.84; 0.96)	7.8 (6.1; 10.8)
		HSR·min^{-1}	3.3 (2.3)	3.4 (2.1)	3.4 (1.9)	3.3 (2.1)	0.94 (0.88; 0.97)	16.1 (12.6; 22.8)
		MW·min^{-1}	6.6 (1.9)	6.4 (1.9)	5.8 (2.0)	6.3 (1.9)	0.81 (0.63; 0.91)	14.3 (11.2; 20.1)

Note. TD: total distance; HIR: high-intensity running (> 14.4 km·h^{-1}); HSR: high-speed running (> 19.8 km·h^{-1}); MW: number of accelerations plus decelerations (> 2.2 m·s^{2}); ICC: intraclass correlation coefficient; CL; confidence limits; CV: coefficient of variation.

Analyses of TD·min^{-1} standardized TE showed 11 small ES values and only one moderate ES value across all SSG formats (Figure 4.3/A). Eleven small standardized TE values and one moderate standardized TE value were also observed for HIR·min^{-1} (Figure 4.3/B). For HSR·min^{-1}, there were eight small and four moderate standardized TE values (Figure 4.3/C). When analyzing MW·min^{-1}, standardized TE included seven small values, four moderate values, and one large value (Figure 4.3/D).

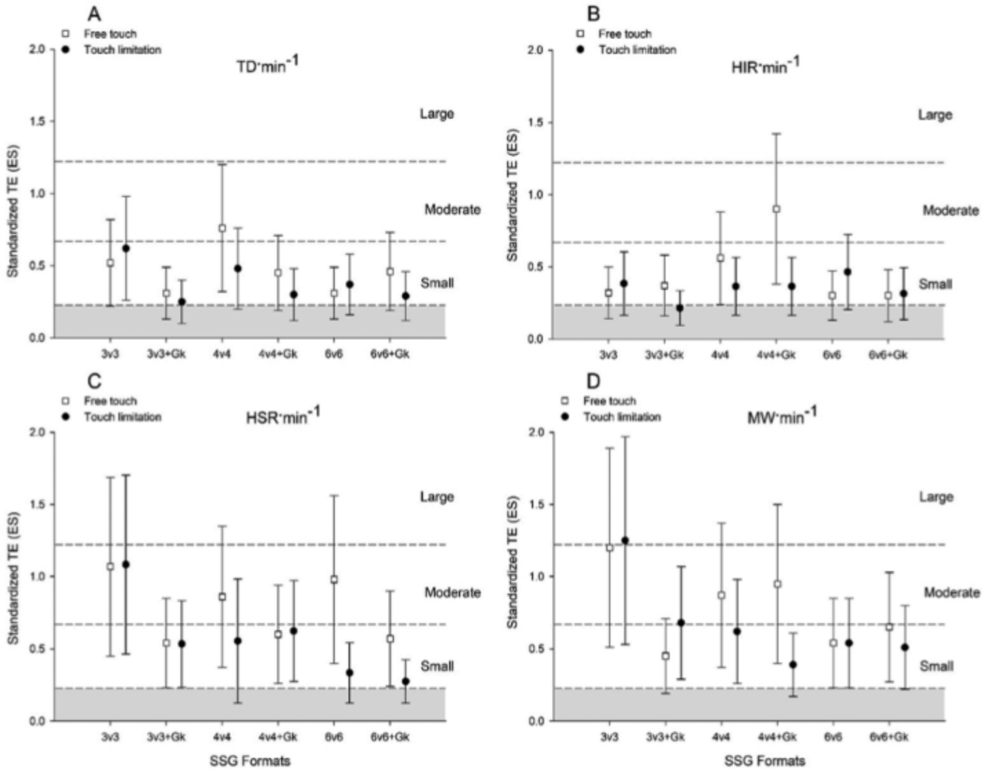

Figure 4.3. Standardized typical error [TE] across different small-sided game (SSG) formats with different task constraints for external load measures. *Note*. A) TD: total distance; B) HIR: high-intensity running (>14.4 km·h^{-1}); C) HSR: high-speed running (>19.8 km·h^{-1}); D) W: mechanical work (the number of accelerations and decelerations > 2.2 m·s^{2}); ES: effect size.

When analyzing the differences between intervals across all SSG formats, the results showed *trivial* standardized differences for TD·min^{-1} and HIR·min^{-1} (Figure 4.4/A and B). For HSR·min^{-1}, small standardized differences were observed for 4v4 (ES; 0.27) and 4v4+Gk (-0.21) under free-touch conditions, while the results for all other SSG formats with different conditions were *trivial* (Figure 4.4/C). For MW·min^{-1}, there were small standardized decreases in the second interval of 6v6+Gk (ES: -0.22) under free-touch conditions, as well as in 3v3 (ES: -0.53) and 6v6+Gk (ES: -0.26) with touch limitation task constraints (Figure 4.4/D). The results showed *trivial* differences between intervals for the remaining SSG formats and conditions in the MW·min^{-1} measure.

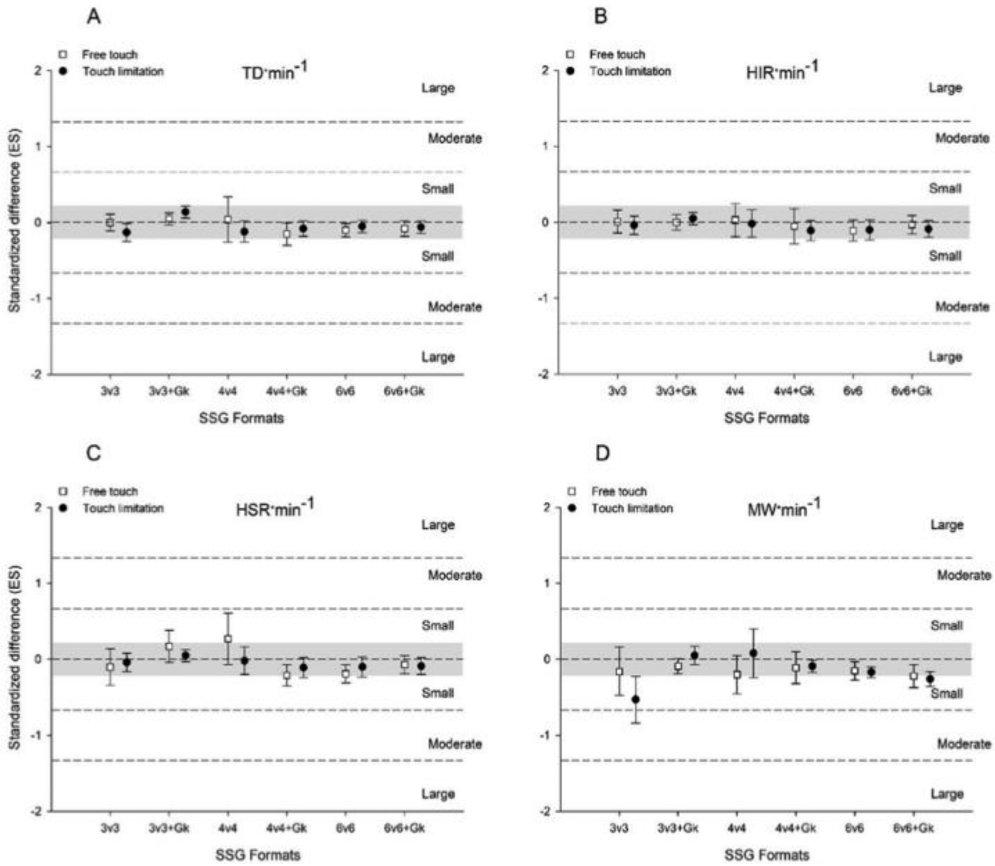

Figure 4.4. Standardized comparison between different intervals across different small-sided game (SSG) formats with different task constraints. *Note*. A) TD: total distance; B) HIR: high-intensity running (>14.4 km·h^{-1}); C) HSR: high-speed running (>19.8 km·h^{-1}); D) W: mechanical work (the number of accelerations and decelerations > 2.2 m·s^{2}); ES: effect size.

DISCUSSION

This study aimed to examine session-to-session variations among professional soccer players in terms of their external load measures across different SSGs. Also, standardized differences were analyzed during within-session intervals. A wide range of standardized TE values were observed in session-to-session variations of selected external load measures across all SSG formats (Figure 4.3). However, TD·min^{-1} showed, in general, the less variability than all other external load measures (Tables 2 and 3). Our results also showed *trivial* differences between the intervals for TD·min^{-1} and HIR·min^{-1} (Figure 4.4 A and B) and small differences between HSR·min^{-1} and MW·min^{-1} for some SSGs (Figure 4.4 C and D).

We observed that the ICC for TD·min^{-1} ranged from *high*-to-*nearly perfect* across different SSG formats (Tables 1 and 2). This result is in agreement with previous studies examining session-to-session variations in 3v3+Gk SSGs (ICC: 0.68) (Bredt et al., 2016), 4-a-side indoor SSGs (ICC: 0.76) (Hůlka et al., 2015), and 6-a-side format SSG (ICC: 0.84; 0.89) (Aquino et al., 2019; Stevens et al., 2016). The CV of TD·min^{-1} ranged from 2.2 to 4.6% in all SSG formats (Tables 1 and 2). These values are in line with other studies that reported values of ~3–5% (Aquino et al., 2019; Bredt et al., 2016; Hill-Haas, et al., 2008; Stevens et al., 2016), but slightly lower than those reporting ~6–8% [6, 16, 22]. The higher CV values reported in other studies may be related to different influential factors, including the SSG format (<3v3) [6], the type of technology used to capture the external load measure (GPS vs. video motion tracker) (Hůlka et al., 2015), and the experience level of the participants (amateur vs. professional) (Clemente et al., 2019).

Our study showed a small standardized TE for TD·min^{-1} in almost all SSG formats (Figure 1/A), which is lower than the moderate effect reported by Clemente et al. [2019], who examined the noise of the 5v5+Gk format. The slightly higher values of ICC (> 0.90) in some formats of our study, lower CVs (~2 to 4%), and lower standardized TE may be, in general, associated with the three-trial design adopted in this research, whereas many previous studies used two-trial designs (Aquino et al., 2019; Clemente et al., 2019; Hůlka et al., 2015). Increasing the number of trials reduces the noise in the monitoring variable (Hopkins, 2004).

The ICC of HIR·min^{-1} in this study ranged from *high*-to-*nearly perfect* across all SSG formats (Tables 1 and 2). This range is supported by the *large*-to–*very large* ICCs reported in the literature related to the noise of 3v3+Gk (ICC: 0.54) (Hůlka et al., 2015), and 6-a-side (ICC: 0.74; 0.78) (Aquino et al., 2019; Stevens et al., 2016) SSGs. HIR·min^{-1} across selected SSGs showed CVs ranging from 7.2 to 16.4% (Tables 1 and 2). This range is similar to values reported in most previous studies (8.1 to 16.6%) (Aquino et al., 2019; Stevens et al., 2016) but lower than the values reported by Clemente et al. (CV: 54; 146%). HIR·min^{-1} also showed small standardized TE values in almost all SSG formats (Figure 1/B), which were lower than the moderate standardized TE values (ES: 0.83; 1.09) reported by Clemente et al. (2019). Such discrepancies may be explained by Clementine et al. (2019) use of a two-trial design and amateur participants, whereas our study used a three-trial design and professional soccer players.

HSR·min^{-1} had ICCs ranging from *moderate*-to-*nearly perfect* across different SSG formats in this study (Tables 1 and 2). Aquino et al., (2019) observed a *very high* ICC value (0.78) when examining the noise of individualized high-speed running (>60% of maximum speed) in a 6-a-side format. However, the wide range of ICCs for HSR·min^{-1} in this study is not surprising, given the variety of SSG formats and conditions employed. HSR·min^{-1} showed CVs between 12.2 and 29.4%, which is in agreement with some previous studies in which CV values ranged from ~26 to 33% (Hill-Haas, et al., 2008). However, this CV range is higher than the ~8% reported by Aquino et al., (2019) and lower than the range of ~30–60% reported by other investigators (Ade et al., 2014). These differences might be related to the use of relative versus absolute thresholds, different SSG formats (<3v3), or the low sampling rate (1 Hz) of the GPS technology used in previous studies.

MW·min^{-1} showed ICCs ranging from *moderate*-to-*very large* (0.47; 0.87) range of ICCs for all SSG formats (Tables 1 and 2). These results align with previous studies that reported *large*-to-*very large* values (0.66; 0.80) (Ade et al., 2014). MW·min^{-1} also had CVs between 9.4 and 22.5% across different SSG formats. Previous studies have reported values of between 8.4 and 12.6% (Aquino et al., 2019). Almost all previous studies have used acceleration or deceleration measures separately, and these measures have been based on the distance covered, whereas we based this measure on the number of efforts (Aquino et al., 2019). Therefore, it is difficult to compare our results to those of previous studies.

Interestingly, across the games with the use of goalkeepers, the values of ICCs were similar irrespective of the conditions (formats and ball touch limitations). However, smaller values of ICC in games without goalkeepers were found when comparing the same external load measures. Thus, it seems that the use of goalkeepers may increase the reliability of external load measures and coaches may consider that for employing SSGS. However, it seems that the greatest cause to justify weaker or stronger reliability is not the conditions used, but the intensity of the measure.

In our analysis of the differences between intervals across SSGs, almost all conditions showed *trivial* changes in the second interval, and only five out of 24 conditions revealed *small* standardized changes (Figure 2). *Trivial* changes were observed within intervals in almost all cases. This is in agreement with recent studies reporting *trivial*-to-*small* changes in the second interval (Clemente et al., 2020; Clemente et al., 2019; Dellal et al., 2011). Dellal et al. (2011) showed a significant reduction from the first to fourth intervals (but not from the first to second intervals) in high- and *very high*-intensity activities (~-26; -37%). Therefore, based on our results, it seems that external load measures do not typically change substantially in the second interval. The reductions that do occur during SSGs are likely influenced primarily by other factors, such as training regimens compared to the interval set number *per se*. For instance, Clemente et al. (2019) examined variations in external load within different intermittent regimens (6×3 min and 3×6 min). They showed that longer intervals contribute to more substantial decreases in total distance, running distance, and total values of accelerations and decelerations.

This study had some limitations. Though our data was collected from a large number of sessions and conditions, our participant pool was small and represented only a single context. More consistent inferences could be drawn if more participants were involved. Additionally, interactions with readiness levels were not conducted. These interactions should be incorporated into future studies to identify associations between readiness levels and variations in physical demands. Finally, tactical behaviors were not analyzed. Some external load measures are extremely dependent on players' behaviors, which, in turn, are highly dependent on playing circumstances. To account for this, future studies should establish a link between physical demand variability and tactical behavior.

Despite its limitations, to the best of our knowledge, this research is the first examining the effects of ball touch limitations and the presence or absence of a goalkeeper on external load variability. Therefore, this work provides valuable new insights for coaches who regulate the design and application of SSGs.

As practical implications, we may highlight those higher noises observed in higher speed zones (e.g., high-speed running) in SSGs in the present study is likely associated to less occurrence of these activities compared to their lower speed zones during SSGs (Clemente et al., 2019). Sometimes practitioners target a specific neuromuscular external load GPS factor—such as high-speed running—to overload the hamstring muscles (Duhig et al., 2016) in a consistent and stable (i.e., less noisy) way. In these cases, we recommend implementing supplemental running-based interventions (e.g., running-based high-intensity interval training) alongside SSGs (Rabbani et al., 2019b). We also suggest prescribing higher number of intervals to impose players in performance decrements due to fatigue as our study showed that second interval is not enough fatiguing.

CONCLUSIONS

Our study showed that the variability of total distance is lower than that of other external load measures. Thus, higher movement speed zones were associated with increased noise across all SSGs, irrespective of the game format and regimen. For almost all SSGs, no meaningful external load performance changes were observed in the second interval, suggesting that a drop in performance occurs only after a higher number of intervals. Touch limitations and goalkeeper presence had no meaningful effect on variability either. Hence, further studies involving other task constraints are recommended to help us better understand this area of research.

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4.3 Paper 3: Relationships Between Aerobic Performance, Hemoglobin Levels, and Training Load During Small-Sided Games: A Study in Professional Soccer Players

Saeid Younesi[1*], Alireza Rabbani[2], Filipe Manuel Clemente[3,4], Rui Silva[2], Hugo Sarmento[1], António José Figueiredo[1]

[1]Research Unit for Sport and Physical Activity, Faculty of Sport Sciences and Physical Education, University of Coimbra, Coimbra, Portugal, [2]Department of Exercise Physiology, Faculty of Sport Sciences, University of Isfahan, Isfahan, Iran, [3]Escola Superior Desporto e Lazer, Instituto Politécnico de Viana do Castelo, Rua Escola Industrial e Comercial de Nun'Álvares, 4900-347, Viana do Castelo, Portugal, [4]Instituto de Telecomunicações, Delegação da Covilhã, Covilhã, Portugal

**Corresponding author: Saeid Younesi, saeidyounesi78@yahoo.com, Adress: Faculdade de Ciências do Desporto e Educação Física da Universidade de Coimbra, Avenida Conímbriga Pavilhão 3, 3040-248 Coimbra, Portugal*

The purposes of this study were (1) to analyze between-session variations of external and internal load measures during small-sided games (SSGs) and (2) to test the relationships between the maximum speed reached (V) during the last stage of the 30-15 Intermittent IFT Fitness Test, hemoglobin levels, and training load measures during SSG intervals among professional soccer players. Sixteen professional soccer players (mean ± SD; age 27.2 ± 3.4 years, height 174.2 ± 3.6 cm, body mass 69.1 ± 6.4 kg, and body fat 10.4 ± 4.1%) participated in this study. Hemoglobin and aerobic performance were first tested, and then a 3-week SSG program was applied using a 3 vs. 3 format. During those 3 weeks, internal and external load of entire sessions were also monitored for all training sessions. Trivial-to-small, standardized differences were observed between sessions for external and internal measures during SSGs. Total distance (TD) and mechanical work (MW) were the only variables that indicated small changes. Large-to-very-large relationships were found between VIFT and external loads: TD (*r* range: 0.69; 0.87), high-intensity running (HIR; *r* range: 0.66; 0.75), and MW (*r* range: 0.56; 0.68). Moderate-to-large negative relationships were found between hemoglobin levels and internal loads: Edwards' TRIMP (*r* range: −0.36; −0.63), %HRmax (*r* range: −0.50; −0.61), and red zone (*r* range: −0.50; −0.61). VIFT had unclear relationships with overall internal loads, while hemoglobin levels presented unclear relationships with overall external loads. In conclusion, no meaningful changes were found between sessions

considering the format of play used. Additionally, the detected relationships indicate that VIFT and hemoglobin levels are good indicators of the performance capacity and physiological profile of players during SSGs. Also, the use of SSGs protocols as a monitoring complement of the 30-15IFT is suggested.

Keywords: football (soccer), athletic performance, aerobic capacity, drill-based games, SSGs, motor skills

INTRODUCTION

The practical operationalization of soccer training in recent years has placed great emphasis on the inclusion of small-sided games (SSGs), which encompass the psychological, physical, technical, and tactical aspects of the game (Clemente et al., 2012). For coaches, the main objective of this training method is to mimic all those aspects of soccer that are required during competitions but on a smaller scale (Clemente et al., 2020; Clemente and Sarmento, 2020). Given SSGs' widespread use among coaches and practitioners, researchers have examined the external demands and internal responses of different SSG drills (Clemente et al., 2014; Arslan et al., 2017). Because of the SSG's beneficial and ecological use, there is a tendency to leave out the traditional running-based conditional exercises during a soccer training session (Moran et al., 2019). However, some research suggests that SSGs themselves may not be enough to promote the same patterns of the required physical demands during a soccer match, mainly due to the reduced frequency of high-intensity distance-based metrics of this training approach (Hammami et al., 2017; Lacome et al., 2017). Knowing the physical demands during SSGs is, for that reason, an important way to ensure a proper stimulus on the players.

The assessment and monitoring of a soccer player's current physiological and performance status assume an imperative role for better decision-making during the training process (Drew and Finch, 2016). Although there are several field testing methods used for assessing a player's performance capacity, these methods tend to be time-consuming, and coaches tend to reject these types of assessments given their maximal or sub-maximal nature (Turner et al., 2011). Researchers, however, have analyzed the relationships between traditional aerobic fitness tests with external and internal training load measures during SSGs, as well as the capacity of SSGs to assess the intermittent aerobic fitness of soccer players (Owen et al., 2020). In an interesting study (Owen et al.,

2020) using a 5v5 format, it was found a moderate-to-very large and large-to-very-large associations between external and internal measures, as well as with aerobic performance (in the Yo-Yo Intermittent Recovery test [YYIR], respectively. In that same study, the authors also found low coefficient of variation (CV%) values in external and internal measures, suggesting the potential use of the assessed 5v5 format protocol as an intermittent aerobic fitness assessment tool for soccer players. Furthermore, it seems that YYIR's strongest relationships are with total distance and high-intensity running metrics during soccer matches (Aquino et al., 2020). Considering SSGs, moderate-to-large correlations were observed when examining the relationships between external loads during 6v6 drills and YYIR performance (Stevens et al., 2016). Also, moderate-to-very large negative relationships were reported between heart rate measures, such as time spent above 80% HRmax (red zone), %HRmax, during SSGs and YYIR performance (Stevens et al., 2016; Owen et al., 2020).

Not only physical performance can be determinant for optimizing performance in SSGs, but also biological conditions. Examples as hematological parameters could be crucial for predicting optimum physical performance since hemoglobin and red blood cells play a fundamental role in transporting oxygen (Schumacher et al., 2002). In

this regard, it has been widely demonstrated that endurance training produces adaptations at the blood level. Such fact is characterized by an increase in blood volume explained by an expansion in the volume of plasma and an increase in the number of red blood cells (Sawka et al., 2000). The results of that study demonstrate that players residing at moderate altitudes have greater concentrations of hemoglobin (16.2 ± 0.2 g·dl−1) than players not living at sea-level locations (14.4 ± 0.7 g·dl−1). The mean VO2max value of the players residing at a moderate altitude (54.1 ml·kg−1·min−1) was also significantly greater than that of the players residing at low altitudes (49 ml·kg−1·min−1; Sawka et al., 2000). One review demonstrated that a higher hemoglobin concentration is related to an improvement in physical performance of between 5 and 10% (Wilber, 2002). The results of this review imply that soccer players residing at low altitudes should travel to the higher regions for a few days prior to the start of the pre-season period. This is because erythropoiesis begins the first day an individual is at a higher altitude. In approximately 4–7 days, this translates into an increase in hemoglobin concentration (Klausen et al., 1991). Recently, it has been suggested that assessments of the total mass of hemoglobin can be used as a predictor of VO2max in athletes, as it can help to identify talents in endurance sports (Eastwood et al., 2009).

However, to the best of our knowledge, there is no study addressing the relationships between the 30-15IFT, hemoglobin concentrations, and different external and internal load measures during SSG drills among professional players. The potential relationships between those variables can assist coaches and practitioners in using SSGs as a more ecological and time- efficient monitoring tool of player's physiological profile and performance capacity and might also serve as a complement to traditional running-based assessments. Additionally, several studies have analyzed between-session variations in the external and internal load measures of SSGs and suggested the use of standardized differences and small worthwhile change (SWC) to analyze the degree of changes/differences in performance between athletes instead of using percentages of changes (Buchheit and Rabbani, 2014; Clemente et al., 2019b; Younesi et al., 2021). Thus, it is important to understand how the load during SSGs may vary from session to session. Therefore, the purposes of the present study were (1) to analyze between-session variations of external and internal load measures during SSGs and (2) to analyze the relationships between VIFT, hemoglobin levels, and training loads measures during SSG intervals among professional soccer players. It is hypothesized that selected internal and external load measures will present no meaningful changes between sessions and that a possible relationship will be observed between training load in SSGs and the physical and hematological characteristics of the players.

MATERIALS AND METHODS

Study Design and Settings

This study followed an observational analytic cohort design. Players were assessed during the 1st week of data collection for hemoglobin levels and aerobic performance. After that, 3 weeks of training sessions were monitored, in which repeated-measures design was tested for specific SSGs (3v3), employed with the same conditions (same players and teams, with the same number of resting days in between). The data collection occurred in 2018/2019, in the first 4 weeks of the pre-season. However, training time (between 17:00 and 20:00) and environmental conditions (ambient temperature and relative humidity, ranging between 25 and 32°C and 54 and 76%, respectively) varied greatly over the data- collection phase. Data related to external load measures were obtained using global positioning systems during all SSG sessions, while internal load was monitored using heart rate monitors. All players involved in the study were professionals and were familiar with SSGs prior to the experimental period.

Participants

Sixteen professional soccer players (mean ± SD; age 27.2 ± 3.4 years, height 174.2 ± 3.6 cm, body mass 69.1 ± 6.4 kg, and body fat 10.4 ± 4.1%, 3.1 ± 1.5 years in the club), all members of a professional club competing in the 2018–2019 season of Qatar Star League (Qatar first division), participated in this study. The inclusion criteria were (i) participation in all the moments of assessment and games; (ii) absence of injuries, physical constraints, or illnesses exhibited during sessions occurred in the period and two weeks prior to the data collection; and (iii) absence of signals of fatigue on assessment days. Players were assigned to different teams (of three elements), and comparisons between teams revealed no meaningful changes in the main outcome (aerobic performance). The baseline fitness levels of players revealed an average VIFT of 17.9 ± 1.2 km/h. All players were informed of the experimental procedures and related risks and gave informed consent before commencing the study. The study protocol was approved by the University Research Ethics Committee. The study followed the ethical standards of the Declaration of Helsinki.

Small-Sided Games

The 3v3+Gk SSG format was used in the present study. This format was repeated over three trials of three *m*, with two sets of three minutes performed in each session. The conditions involved touch limitations (a maximum of three consecutive touches permitted to each player) in accordance with a previous study suggesting ball limitation as a way to increase the intensity (Dellal et al., 2011). Three working intervals were implemented for the 3v3 + GK format. Two minutes were allotted for recovery between intervals. Pitch dimensions were 20 × 27 m for 3v3, as the playing areas were standardized (~90 m2 per player, excluding the goalkeeper).

The coaching staff, which included one of the authors (a strength and conditioning coach), were directed to ensure the consistency of their supervision during all SSG sessions. Balls were kept near the SSG pitch so that coaches could restart the game immediately if a ball left the playing area. For each format, the teams were balanced based on their members' physical and technical abilities (as determined by the coach); this reduced the possibility of any strength or weakness bias.

Data Measurement and Quantitative Variables

Internal Load MeasurementHeart rate data were recorded during all SSG sessions using Bluetooth HR sensors (Polar H10, Polar-Electro, Kempele, Finland; recorded in 5-s intervals) that were synchronized to a validated portable 10-Hz VX Sport 350 GPS units (VX Sport, Wellington, New Zealand). Each unit was used for the same player across the study to reduce inter-unit variability. HR measures, including HRmax, Edwards'TRIMP, and time spent in the red zone (>80% of individual HRmax), were analyzed following each session. The HRmax of each individual was extracted from a maximal field-based test (i.e., the 30-15 Intermittent Fitness Test) conducted during the pre-season. To standardize Edwards' TRIMP and red zone measures so that fair comparisons, the corresponding data were divided by minutes played (Edwards'TRIMP.min−1 and Red zone.min−1).

External Load Measurement

External load measures were recorded during all sessions using portable 10-Hz VX Sport GPS units (VX Sport, Wellington, New Zealand), which are valid and reliable according to Buchheit et al. (2014). External load measures included total distance (TD), high-intensity running (HIR, distance > 14.4 km.h−1), and mechanical work (MW), for which the numbers of acceleration and deceleration efforts above and below 2.2 m. s2 thresholds were calculated the sum. The thresholds used for acceleration/deceleration efforts (2.2 m.s2) were selected based on practical experiences using the VX GPS system by the coaching staff. All external load measures were standardized by being divided by minutes played (e.g., TD.min−1) prior to the analysis so that they could be compared across different SSG formats.

Hemoglobin

A blood sample (15 ml) was collected from each participant between 8:00 and 10:00 a.m. The samples were collected with an overnight fast and after a minimum of 12 h of rest (without exercise). Blood samples were centrifuged at 2500 rpm for 10 min, and the serum of each sample was stored. Hemoglobin (g/dl) was determined using flow cytometry.

The 30-15 Intermittent Fitness Test

This test consisted of 30-s shuttles interspersed by 15-s periods of passive recovery. The velocity was set at 8 km.h−1 for the first run, and speed was increased by 0.5 km/h for each subsequent run. Players had to run back and forth between two lines positioned 40 m apart. Running pace was set by an automatic beeper to control the running speed when players entered a 3-m zone placed in the middle and at both extremities of the field. During the recovery period, players walked toward the closest line, either at the middle or one of the ends of the running area, depending on where they stopped in the last run. Players were told to complete as many stages as possible, and the test was ended when the players could not maintain the required running speed or could not reach the 3-m zone before the beep three consecutive times. The final velocity registered in the last stage determined the player's VIFT score (Buchheit et al., 2009; Grgic et al., 2020).

STATISTICAL ANALYSIS

Data are presented as mean and standard deviation (SD) or 90% of confidence limits (CL) where specified. Differences between sessions in terms of training load measures were analyzed using standardized differences or effect size (ES; Cohen, 2013). Qualitative thresholds for interpreting the ES were as follows: <0.2 = *trivial*, <0.60 = *small*, <1.2 = *moderate*, <2.0 = *large*, and ≥2.0 = *very large* (Hopkins et al., 2009). A magnitude-based inference approach using the smallest worthwhile difference or change (SWC, 0.2 × between-subject SD) was used to analyze the likelihood that the true changes were clear. Pearson's correlation coefficients were used to determine the relationships between VIFT and hemoglobin levels with internal and external load measures during SSG. Qualitative thresholds for correlations were categorized as follows: <0.1 = *trivial*, <0.3 = *small*, <0.5 = *moderate*, <0.7 = *large*, <0.9 = *very large*, and ≤1.0 = *near perfect* (Hopkins et al., 2009). If the 90% confidence intervals of the Pearson's correlation coefficients and standardized difference overlapped by small positive and negative values (±0.1 and ±0.2 for *r* and ES, respectively), the relationship was deemed *unclear*; otherwise, the obtained magnitude was deemed to be the observed magnitude (Hopkins et al., 2009). The statistical analysis was performed using a dedicated Excel spreadsheet built by Hopkins (2015).

RESULTS

The mean ± SD values of players' VIFT and hemoglobin were 18.0 ± 1.2 km.h−1 and 14.5 ±0.7 g.dl−1, respectively. The mean ± SD of external and internal load measures during different sessions/sets of SSGs are represented in Table 4.

Table 4. Mean ± SD of external and internal training load measures during small-sided games.

	Session 1		Session 2		Session 3	
Measure	Set 1	Set 2	Set 1	Set 2	Set 1	Set 2
TD (m)	355.6 ± 50.0	361.1 ± 44.2	352.7 ± 45.2	366.1 ± 44.4	375.3 ± 49.1	384.7 ± 63.2
HIR (m)	53.3 ± 25.9	54.1 ± 24.9	52.9 ± 24.5	54.9 ± 23.6	55.2 ± 27.0	56.9 ± 24.1
MW (n)	14.3 ± 4.9	15.0 ± 4.3	15.2 ± 4.6	15.1 ± 3.5	17.4 ± 6.8	17.1 ± 6.2
TRIMP (AU)	10.9 ± 1.0	10.8 ± 1.0	10.9 ± 1.0	10.9 ± 1.0	10.8 ± 1.0	11.2 ± 0.9
Red zone (min)	2.1 ± 0.5	2.0 ± 0.5	2.0 ± 0.5	2.0 ± 0.4	2.0 ± 0.4	2.1 ± 0.4
% of HR_{max}	80.8 ± 4.8	81.3 ± 4.7	81.1 ± 4.9	81.5 ± 4.6	81.6 ± 4.8	81.8 ± 4.9

Note. TD: total distance; HIR: high-intensity running (>14.4 km·h^{-1}); MW: mechanical work (the number of accelerations and decelerations > 2.2 m.s^2); TRIMP: Edwards' Training Impulse; AU: arbitrary units; Red zone: time spent in red zone (> 80% of maximal heart rate); HR_{max}: maximal heart rate; SD: standard deviation.

Between-Session Differences in External and Internal Load Measures

Trivial-to-*small* standardized differences were observed in TD (ES, 01; 0.43) and MW (ES, 0.15; 0.52) between sessions (**Figure 4.5**). *Trivial* (ES, 03; 0.10) changes were observed in HIR between sessions (**Figure 4.5**). *Trivial* changes were also observed in all internal load measures, including Edwards' TRIMP (ES, 0.01; 0.10), time spent in the red zone (ES, −0.02; 0.06), and average HR as % of HRmax (ES, 0.05; 0.12) between sessions (**Figure 4.5**).

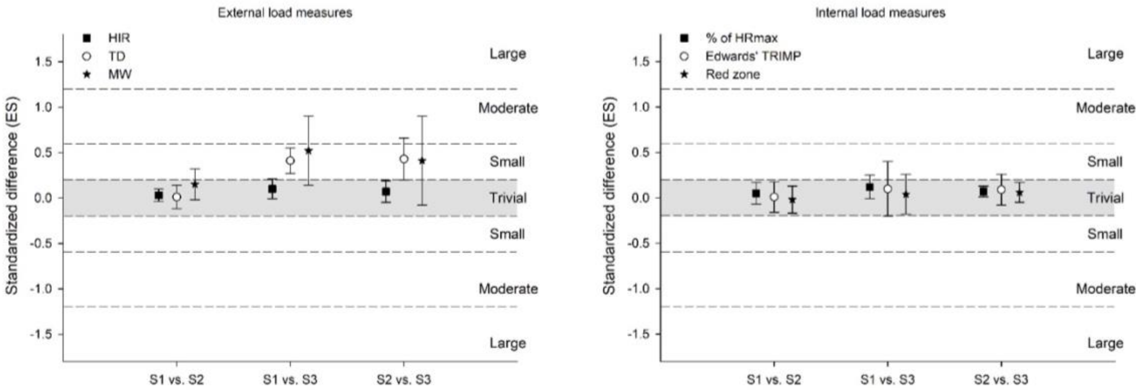

Figure 4.5. Standardized differences between sessions in external and internal load measures during small-sided games. *Note*. TD: total distance; HIR: high-intensity running (>14.4 $km \cdot h^{-1}$); MW: mechanical work (the number of accelerations and decelerations > 2.2 $m.s^{2}$); Edwards' TRIMP: Edwards' Training Impulse;; Red zone; time spent > 80% of maximal heart rate; HR_{max}: maximal heart rate; ES: effect size.

Relationship Between VIFT and Training Load Measures During SSGs

Large-to-very-large positive correlation coefficients were observed between VIFT with TD (r range: 0.69; 0.87) and HIR (r range: 0.66; 0.75) in different sessions (**Figure 4.6**). VIFT also showed large positive relationships (r range: 0.56; 0.68) with MW in different sessions (**Figure 4.6**). However, small negative to unclear positive associations were observed between VIFT and all internal load measures (r range: −0.25; 0.26).

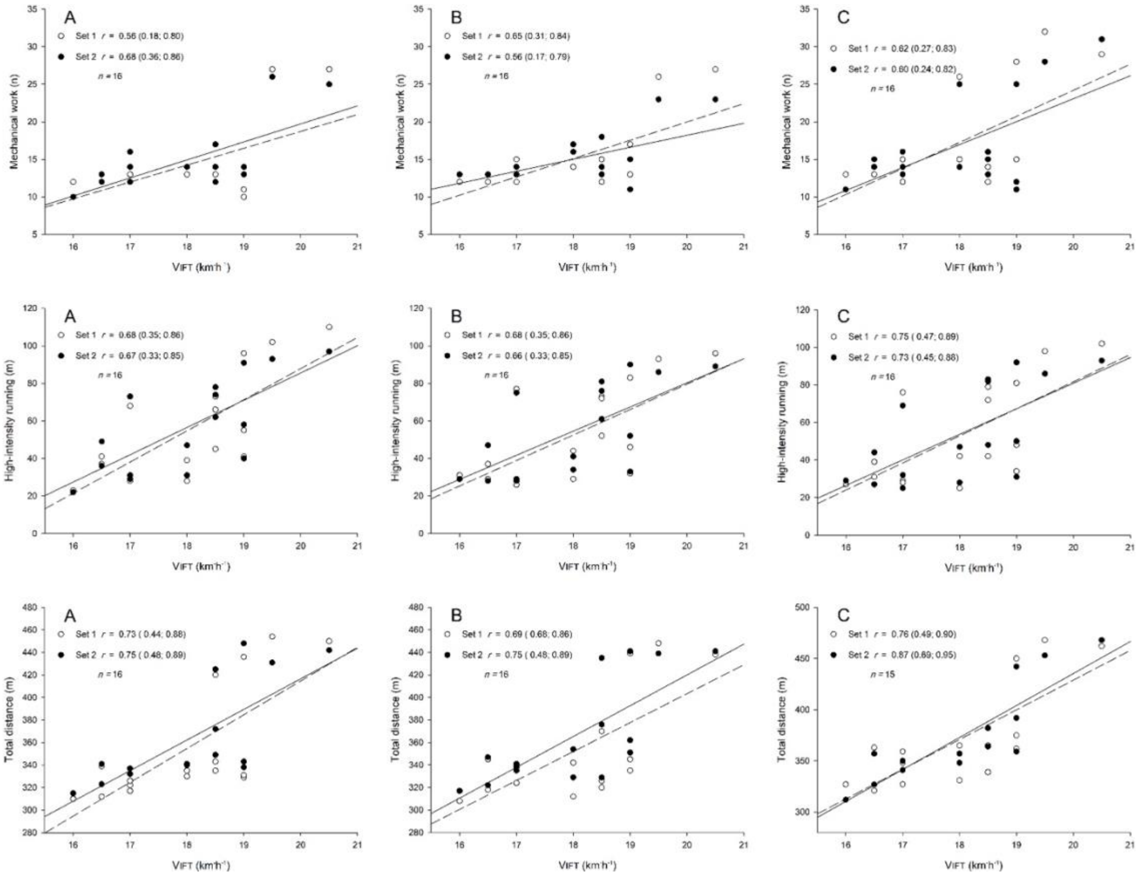

Figure 4.6. Relationships (correlation coefficient, *r*, 90% confidence limits) between the final speeds reached at the end of the 30-15 Intermittent Fitness Test (V_{IFT}) and external load measures during small-sided game intervals. *Note*. A: Session 1, B: Session 2; C; Session 3; High-intensity running: distance covered above14.4 $km{\cdot}h^{-1}$; Mechanical work: the number of accelerations and decelerations > 2.2 $m.s^2$.

Relationship Between Hemoglobin Levels and Training Load Measures During SSGs

Inversed *moderate*-to-*large* associations were observed between hemoglobin levels and Edwards' TRIMP (*r* range: −0.36; −0.63; **Figure 4.7**). *Large* inverse relationships were observed between hemoglobin levels and average HR (as a % of HRmax), as well as time spent in the red zone (*r* range: −0.50; −0.61) in different sessions (**Figure 4.7**). The relationships between hemoglobin levels and external load measures were all *unclear*, as they included negative to positive *trivial*-to-*moderate* correlations (*r* range: −0.30; 0.29). The only *clear* associations observed between hemoglobin levels and external load measures were the *moderate* correlations observed when considering HIR in the second sets of the first and second sessions (*r* range: 0.38; 0.40).

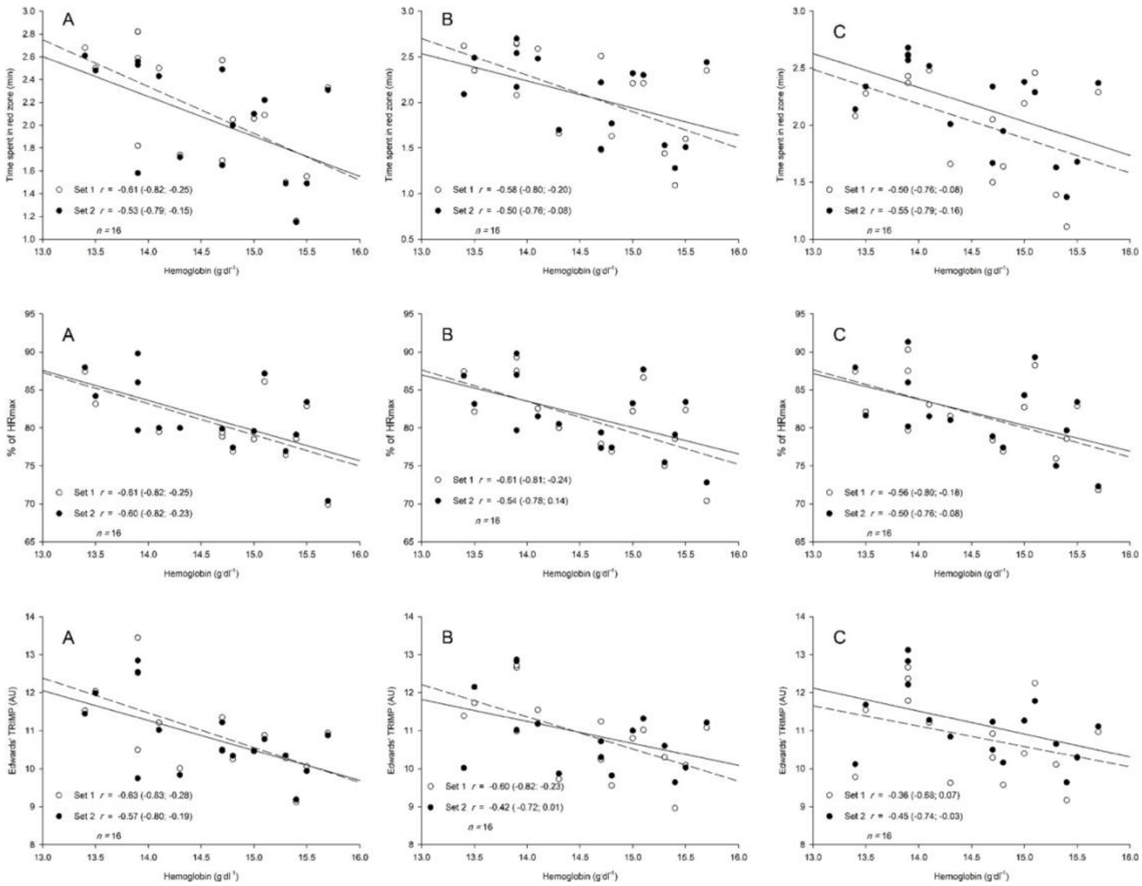

Figure 4.7. Relationships (correlation coefficient, *r*, 90% confidence limits) between players' hemoglobin levels (g·dl^{-1}) and internal load measures during small-sided game intervals. *Note*. A: Session 1, B: Session 2; C; Session 3; Edwards' TRIMP: Edwards' Training Impulse; AU: arbitrary units; Time spent in red zone; time spent > 80% of maximal heart rate; HR_{max}: maximal heart rate.

DISCUSSION

This study was designed to analyze between-session standardized differences of external and internal load measures and the relationships between VIFT and hemoglobin levels with training loads during SSGs intervals among professional soccer players. The main findings were that the external measures had trivial- to-small standardized differences, while all internal measures revealed trivial standardized differences between sessions. VIFT showed large-to-very-large positive relationships with TD, HIR, and MW, while hemoglobin levels showed moderate-to-large negative relationships with TRIMP, time spent in red zone, and %HRmax during different sessions. However, VIFT presented unclear relationships with all internal loads, while hemoglobin levels presented unclear relationships with overall external load.

Between-session standardized differences of SSGs were more pronounced only for TD and MW when comparing session 1 and 2 to 3, representing a small degree of change. Meanwhile, HIR presented trivial changes between all sessions. Using different approaches, other study have analyzed between-sets variations of SSGs and reported trivial-to-small standardized differences from the first set to the second set for TD when considering SSGs shorter and longer regimens (Clemente et al., 2019a). Also, the same pattern was reported for TD, HIR, and MW measures when considering different SSG formats (3v3, 4v4, and 6v6) with and without goalkeepers and with and without touch limitations (Younesi et al., 2021). Some explanations for the variations in external load demands are the variability of individual and collective dynamics related to tactical behavior (Clemente et al., 2020). However, in smaller formats, the individual participation is higher, thus possible variability may decrease. Interesting internal load measures remained consistent across sessions, which are of paramount importance for chronic adaptations to occur (Buchheit and Laursen, 2013). Similarly, Clemente et al. (2019a) found that the average HR measure presented trivial-to-small changes in both shorter and longer SSG regimens between three different sets, revealing HR consistency. However, that study was conducted on amateur soccer players, and the authors analyzed only HR average between-sets changes. The present study analyzed other HR measures and between-session changes, which makes the comparison with our results somewhat complex. From this, neither the external loads nor the internal loads seem to vary between-sessions during this type of SSGs formats.

The large-to-very-large relationships between VIFT and TD measures revealed in the present study are in line with other study that demonstrated a strong association between Yo-Yo IR scores and total distance covered and high-intensity running speeds during match play, suggesting a strong validity (Aquino et al., 2020). In fact, in a study conducted on 23 elite soccer players with the aim to analyze the relationships between a 5v5 SSG and the YYIR1 running performance, it was found that TD during the SSGs was very strongly associated with YYIR1 performance ($r = 0.88$; Owen et al., 2020). In our study, the final 30-15IFT score (VIFT) revealed similar associations with TD (r range: 0.69; 0.87) during SSG drills. Also, in the study of Stevens et al. (2016), the largest association was observed between YYIR2 and TD ($r = 0.59$) during 6v6 SSGs when considering only the elite population that was analyzed in their study. Considering the HIR measure, moderate-to- large ($r = 0.45$; 0.56) relationships were previously reported between YYIR2, YYIR1, and the time spent in HIR during a match (Rebelo et al., 2014). The present study revealed large-to-very-large associations between VIFT and HIR (r = 0.66; 0.75). In the same way, Stevens et al. (2016) reported large associations between HIR and YYIR2. This is of great interest, as it was previously demonstrated that HIR is one of the best variables to discriminate between won and lost matches (Aquino et al., 2018). In fact, despite differences between smaller formats (3vs.3) and larger formats as reported in previous studies (Owen et al., 2012), it seems that even in this case (3vs.3) physical fitness plays an important role since the magnitude of correlations.

Furthermore, the MW measures had large relationships with VIFT in the present study. These results contrast with a previous study that reported only a moderate relationship without statistical significance between acceleration measure and YYIR2 during 6v6 SSGs. However, there is a possible explanation for this difference. In fact, shorter formats of play are characterized by more changes of direction and accelerations/decelerations, thus being in line with something that 30-15IFT is also sensitive to (i.e., detecting the change-of-direction ability; Haydar et al., 2011). Our results also corroborate other work (Owen et al., 2020) that reported moderate-to-large associations between decelerations and accelerations and YYIR1. However, in that study, those metrics showed low R-squared values (R2 = 27 and 2% for accelerations and decelerations, respectively). This could mean that MW measures contain a higher factor of unexplainable variability – in fact, previous studies have reported a higher coefficient of variation for those metrics within SSGs (Ade et al., 2014; Aquino et al., 2019; Younesi et al., 2021). However, these comparisons must be carefully analyzed because our study considered MW measure, which encompasses both accelerations and decelerations, while other reported studies analyzed those metrics separately. Given the large-to-very-large associations between VIFT and the analyzed external measures considered during the SSGs in our study, it can be suggested that the VIFT is a good indicator of a player's performance during SSGs. Also, the examined SSGs may be used as a soccer-specific monitoring tool for the assessment of performance capacity.

Despite that, VIFT showed unclear associations with all internal measures. In fact, this is in contrast with other studies that examined the relationships between YYIR (levels 1 and 2) and HR measures during SSGs, which reported large-to-very-large inversed correlations (Stevens et al., 2016; Owen et al., 2020). Similar to our results are those from the study of Aquino et al. (2019), who reported unclear associations between average HR during SSGs and average HR during official matches. Notwithstanding the use of VIFT as a useful performance indicator, its capacity to assess internal loads remains unclear, assuming that internal loads do not necessarily indicate the running physical performance.

On the other hand, hemoglobin levels had moderate-to- large negative relationships with all internal loads during SSGs. However, unclear relationships with all external loads were found. To the best of our knowledge, there no study has reported possible relationships between hemoglobin levels and internal and external loads during SSGs, with only one study (Saidi et al., 2019) having examined (among other variables) the associations between hemoglobin levels and YYIR1 performance. According to our results, hemoglobin levels seem to decrease as the intensity of an SSG drill increases. In fact, increases in hemoglobin levels are related to a greater aerobic performance due to the better oxygen transport capacity (Otto et al., 2013). Several studies reported declines in hemoglobin levels in professional soccer players after periods of high-intensity activity (Silva et al., 2008; Bekris et al., 2015). Given that, monitoring hemoglobin levels can be useful for assessing SSGs intensity. Also, it may be a good indicator of players' fatigue, as their physical performance seems to decrease after congested weeks, resulting in a decrease of hematological parameters, including hemoglobin levels (Saidi et al., 2019). Furthermore, in the same study, which was conducted on 18 elite soccer players and analyzed the relationships between hemoglobin levels and YYIR1 performance, reported only small, insignificant correlations without statistical significance ($r = 0.21$; $p = 0.12$). These results are similar to our results with regard to the unclear associations between hemoglobin levels and the external loads during SSGs (Saidi et al., 2019).

The present study is not without its limitations. For one, the small sample size makes it difficult to make any generalizations based on the results. However, the sample comprised professional players, who make up an interesting population for ensuring the quality of the results presented here. Other study limitation can be related with variation in environmental conditions occurred during the period of intervention. A final study limitation can be related to the temporal displacement between the analysis of aerobic performance and the last session of SSGs.

Regardless, as far as we know, the present study is the first to analyze the relationships between VIFT, hemoglobin levels, and training load measures among professional soccer players during SSG intervals. Therefore, since SSGs are highly specific and frequently used throughout the season, they could be a useful fitness indicator because (i) more players can be evaluated at the same time, (ii) SSGs involve technical and tactical demands, and (iii) players are performing soccer training during the test. As practical implications, this study suggests that the internal load and external load of SSGs (considering the outcomes used) are stable across the sessions, while training load is associated with the fitness and physiological status of the players. Based on that, coaches should consider adjusting the stimulus or drills to specific groups of players.

CONCLUSION

The present study revealed low between-sessions standardized differences for the overall internal and external measures of SSGs, with only TD and MW showing small changes. Thus, it is suggested that tactical behaviors might interfere with those metrics during SSGs. VIFT is a good indicator of performance capacity during SSGs, given the large-to- very-large relationships between and external measures. Also, hemoglobin levels seem to decrease at higher intensity drills, revealing associations with internal loads. Despite that, VIFT and hemoglobin levels revealed unclear relationships with internal and external measures, respectively. For those reasons, it is suggested that practitioners consider both internal and external loads. It is also suggested that they use SSGs to monitor soccer players' physiological and performance capacity to complement periodic assessment protocols such as the 30-15IFT.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by University of Coimbra. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

SY, AR, FC, and AF lead the project, collected the data, treated the data, wrote the statistical report, and revised the original manuscript. RS and HS wrote and revised the original manuscript. All authors contributed to the article and approved the submitted version.

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4.4 PAPER 3: DOSE-RESPONSE RELATIONSHIPS BETWEEN TRAINING LOAD MEASURES AND PHYSICAL FITNESS IN PROFESSIONAL SOCCER PLAYERS

Saeid Younesi[1], Alireza Rabbani[2], Filipe Manuel Clemente[3,4*], Rui Silva[3], Hugo Sarmento[1], António José Figueiredo[1]

[1]University of Coimbra, Research Unit for Sport and Physical Activity. Faculty of Sport Sciences and Physical Education, Coimbra, Portugal; saeidyounesi78@yahoo.com; hg.sarmento@gmail.com; afigueiredo@fcdef.uc.pt

[2]Department of Exercise Physiology, Faculty of Sport Sciences, University of Isfahan, Isfahan, Iran; alireza.rabbani@gmail.com

[3]Escola Superior Desporto e Lazer, Instituto Politécnico de Viana do Castelo, Rua Escola Industrial e Comercial de Nun'Álvares, 4900-347, Viana do Castelo, Portugal; filipe.clemente5@gmail.com; ruimiguelfps@hotmail.com

[4]Instituto de Telecomunicações, Delegação da Covilhã, Covilhã, Portugal

*Correspondence: FMC: filipe.clemente5@gmail.com

Abstract: The aim of this cohort study was two-fold: (i) to analyze within-group changes of final velocity in a 30-15 intermittent fitness test (VIFT), final velocity in a Vameval test (Vvameval), 20-m sprint and countermovement jump (CMJ); (ii) to explore the relationships between VIFT and Vvameval outcomes and their changes with internal and external loads. Twenty-two professional soccer players (mean ± SD; age 27.2 ± 3.4 years, height 174.2 ± 3.6 cm, body mass 69.1 ± 6.4 kg, and body fat 10.4 ± 4.1%, 3.1 ± 1.5 years in the club) participated in this study. External and internal loads were obtained using global positioning system, heart rate and rate of perceived effort (sRPE) after each training session. Players were assessed in CMJ, 20-m sprint, Vameval and 30-15 intermittent fitness test, before and after the observed period. Very large relationships were observed between VIFT and Vameval for pre- (r = 0.76), post (r = 0.80) and pooled-data (r = 0.81). Vvameval showed less sensitivity (−22.4%, [−45.0 to 9.4]), ES −0.45 [−1.05 to 0.16]) than VIFT. ΔVIFT had unclear associations with all sRPE, but had moderate correlations with objective internal and external measures, while, ΔVvameval varied between large and very large relationships with all sRPE, but had unclear associations with all other selected training loads. Objective internal and external loads may be used to track aerobic power related changes from VIFT.

Keywords: football; performance; athletic performance; sports training; internal load; external load

Introduction

In sports context, dose-response relationships are simply referred to the magnitude of an biological response, depending on the exposure to a given training stimulus after a certain time-period (Ian Lambert & Borresen, 2010). In that sense, it has been suggested that chronic exposures to training loads are associated with more resilient athletes that are capable of sustaining greater acute training loads, without higher injury risks (Gabbett, 2020; Lu et al., 2017). Despite that, the principles of training such as individualization, progression and overload, must be carefully followed for ensuring that athlete's dose-responses are adequate and have the desired effects on them (Kasper, 2019). Considering that in professional soccer teams, coaches typically follow a one-size-fits-all soccer practice, the above-mentioned training principles may not be adequately imposed (A. Los Arcos et al., 2017).

The dose-response relationship is highly dependent on different determinants of player's physical fitness levels, as the same stimuli might be perceived higher or lower for one athlete, and not for others. Given that, the response of a given dose is certainly different between athletes, resulting in within-team variations (Filipe Clemente, Nikolaidis, et al., 2019). Usually, training is quantified through different methods, depending on teams' different budgets. For instance, the external loads (imposed stimulus) are commonly quantified via Global Position Systems (GPS) in soccer (Carl Foster et al., 2017). The internal loads (response to a given imposed stimulus) can be quantified via objective measures such as heart rate (HR), and biochemical markers (Arcos et al., 2015; Fitzpatrick et al., 2018). On the other hand, internal loads can also be quantified via subjective measures, such as session-rate of perceived exertion (sRPE), and perceived level of exertion for respiratory and leg musculature efforts (E. Borg et al., 2010; Asier Los Arcos et al., 2014), and its associated indices (C. Foster, 1998). Both, internal and external load measures have been consistently researched for their meaningful associations, although providing different information for sports scientists and coaches (Arcos et al., 2015; Fitzpatrick et al., 2018).

The imposed training loads may be perceived differently between players and produce different adaptations. For those reasons, it is of paramount importance to establish associations between internal (objective and subjective) and external training load measures with the different determinants of player's physical fitness responses. In fact, considering the subjective measures of internal load quantification and its relationships with possible performance changes during intermittent-based field tests, such as the 30-15 intermittent fitness test (30-15IFT), it was previously revealed strong associations exist between sRPE and VIFT measure (Campos-Vazquez et al., 2017).

Moreover, negative associations between cumulative lower limb perceived load exertions and countermovement jump performance changes has been documented (Arcos et al., 2015). Considering the objective internal load measures such as HR variables, contradictory evidence has been documented (Campos-Vazquez et al., 2017; Manzi et al., 2013). Despite that, strong associations between HR measures (training impulse, TRIMP) and aerobic performance, as well as field tests performance improvements has been revealed (Manzi et al., 2013). Also, considering the different commonly used TRIMP methods, it was revealed that despite the Bannister's TRIMP method significantly correlated with sRPE, it was not associated to aerobic fitness adaptations (Akubat et al., 2012).

Furthermore, quantifying training and match activity is now facilitated by the use of GPS systems that enables coaches to extract information about weekly distance- and accelerometry-based measures (Filipe Manuel Clemente, Silva, Castillo, et al., 2020; Filipe Manuel Clemente, Silva, Ramirez-Campillo, et al., 2020). Given that, using these metrics to analyze their dose-relationships with physical fitness of soccer players is a topic of interest. However, there is a lack of studies supporting these associations (Akubat et al., 2018; Fitzpatrick et al., 2018; Rabbani, Kargarfard, et al., 2019).

In fact, one of the few studies that analyzed external load dose-response relationships, found large associations between the weekly time spent above maximal aerobic speed (MAS) and adaptations in aerobic fitness (Fitzpatrick et al., 2018). However, unclear correlations were found between different high-intensity running thresholds and MAS (Fitzpatrick et al., 2018). Similarly, a study conducted on eleven professional soccer players, revealed unclear relationships between very high-intensity running, total distance and changes in V_{IFT} (Rabbani, Kargarfard, et al., 2019). Interestingly, the same study (Rabbani, Kargarfard, et al., 2019), revealed large relationships between accumulated new body load (NBL) and aerobic changes. Also, a similar accelerometry metric (player load), had demonstrated associations with variations in different fitness determinants (Akubat et al., 2018).

As mentioned earlier, there are conflicting evidence surrounding the dose-response relationships between internal loads and physical fitness changes, and there are still a lack of studies analyzing dose-response relationships using different external load measures in adult professional soccer players. For instance, one of the studies that analyzed external loads dose-response relationships used a sample of amateur soccer players (Akubat et al., 2018), while another study used a sample of youth soccer players (Fitzpatrick et al., 2018). Moreover, only one study, to the best of our knowledge, was conducted on professional adult soccer players (Rabbani, Kargarfard, et al., 2019), but only testing the effects on 30-15 Intermittent Fitness Test and not in other determinants of performance as sprinting or vertical jump.

As the training process may be reflected by a highly within- and between-players variation in terms of responses to the imposed loads, it is of interest to understand the relationships between both internal (objective and subjective) loads and external (distance-based and accelerometry-based) loads with possible changes in different levels of fitness parameters. Despite some studies testing the effects of specific load parameters in fitness changes, no study has been included both internal and external load demands, and also analyzed relationships with different fitness tests that are tested for their relationship (e.g., 30-IFT and Vameval). This can be interesting, namely to identify how tests can be related in their changes, and how load can be associated with that. For those reasons, the purposes of the present study were: i) to analyze the within-group changes of V_{IFT}, $V_{vam\text{-}eval}$, 20-meter sprint and CMJ; and ii) to explore the relationships between V_{IFT} and $V_{vam\text{-}eval}$ tests as well as their changes (i.e., ΔV_{IFT} and $\Delta V_{vam\text{-}eval}$) with accumulated training load indices. We hypothesize that beneficial changes will occur after the cohort in the fitness performance, while sRPE will be the measure with a better dose-response relationship since represents both dimensions of load (internal and external).

Materials and Methods

Experimental Approach to the Problem

An observational analytic cohort design was implemented in this study. First fitness assessments of the players were conducted one week prior to the beginning of 2018/2019 pre-season, between 24th June and 1st July and second test was performed immediately after preparation phase between 19 and 26 August. All the materials were the same and the environmental conditions were almost similar during fitness assessments (indoor track, ambient temperature and relative humidity, ranging between 22 and 26 ◦C and 45 and 52% respectively). For each assessment, temperature and relative humidity were collected two times, and the mean value was registered. However ambient temperature and relative humidity varied greatly over the training data collection phase, ranging between 25 and 32 ◦C and 55 and 76%, respectively). For each training, temperature and relative humidity were collected two times, and the mean value was registered. Training intervention was implemented from 2 July to 18 August. Training time in the morning and afternoon were between 10:00–12:00 and 17:00–20:00, respectively. During training intervention phase, which lasted 47 days, the external and internal loads were obtained using global positioning and HR monitoring systems, respectively. The sRPE was also collected after each training session. All players involved in the study were professional and were familiar with the GPS system and sRPE methods.

Participants

Twenty-two professional soccer players (mean ± SD; age 27.2 ± 3.4 years, height 174.2 ± 3.6 cm, body mass 69.1 ± 6.4 kg, and body fat 10.4 ± 4.1%, 3.1 ± 1.5 years in the club), all members of a professional club competing in the 2018/2019 season of Qatar Stars League (Qatar First Division), participated in this study. Sample was chosen in convenience, as well as the sample size. The inclusion criteria were (i) participation in all assessments and training sessions, (ii) absence of injuries, physical constrains, or illnesses exhibited during sessions occurred in the period and two weeks prior to the data collections; and (iii) absence of signals of fatigue on assessment days. Players were daily monitored for the training load parameters; thus, the follow-up was ensured by daily collecting information from the players. None of the included players had an illness or chronic clinical conditions, all of them were professional and fully dedicated to the team. All players were informed of the experimental procedures and related risks and gave informed consent before commencing the study. The study protocol was approved by the Scientific Committee of School of Sport and Leisure (Melgaço, Portugal) with the code number CTC-ESDL-CE00118. The study followed the ethical standards of the Declaration of Helsinki.

Fitness Assessment

Assessments included anthropometric assessments conducted on the first day. On the following day, the players were evaluated in countermovement jump, 20-m sprinting test, followed by Vameval test. The 30-15IFT was performed three days after. Training inter- vention included 47 days (morning or evening sessions) including five friendly matches, six days off and six recovery sessions. To avoid bias in data collection, the players were familiarized with the testing protocols and the instruments of load monitoring were in dividualized. Additionally, the observers during fitness assessment were blind to the study protocol to minimize the risk of bias. Aiming to minimize the effects of confounders variables, before assessment periods the players had rest for 48-h and had similar patterns of dietary and supplementation and sleep routines.

The 30–15 Intermittent Fitness Test

The 30-15IFT consisted of 30 s of running interspersed by 15 s of walking for recovery. Players were required to run between two lines positioned 40-m apart and return. The test started at 8 km·h−1 followed by 0.5 k/h increments every 30 s. At every 30 s, a beep sounded to signal the start of the 15 s of recovery. During the 15 s of recovery the athletes had to stay within the 3-m limits outlined between each line of cones and wait for a new beep to start the next 30 s run. Players were told to complete as many stages as possible, and the test was ended when the players could not maintain the required running speed or could not reach the 3-m zone before the beep on three consecutive times. The test final outcomes were HRmax (bpm) and the VIFT (km·h−1) score, which was determined by the final velocity reached in the last running lap (Buchheit et al., 2009).

Vameval Test

The Vameval is a cardiorespiratory fitness test that consists in a progressive incre- mental running until exhaustion. The athletes were required to run in a circular setup with 31.85-m radius with cones placed every 20-m. The test started at 8 km·h−1 followed by 0.5 km·h−1 increments every minute. After the start, the athletes had to maintain the correct running pace as indicated by the audio recording, so that they were in line with each of the placed cones when the beep sounded. If athletes were 1-m behind a cone when a beep sounded, they were given one fault. At the second warning the test stopped. The test final outcomes were the total time in minutes and seconds to complete the test, and MAS (km·h−1). To calculate MAS, firstly an VO2max estimate was calculated (3.5 × velocity of the last lap). Then MAS was calculated as the estimated VO2max divided by 3.5 (Carminatti et al., 2013). The Vvameval (km·h−1) was determined by the final velocity reached in the last running lap.

The Sprinting Tests

To measure sprint performance, the 20-m sprint test, including the 5-m, 10-m and 15-m split times, was conducted. To assess sprinting times and split times, two pairs of timing gates (Smart Speed, Fusion Sport, Queensland, Australia) were used. Before the test started, a standardized sprint specific warm up was completed. A 20-m straight line was marked by a cone at the beginning (0-m) and at the end (20-m) of the space outlined for the test. The athletes started from a static position with one foot in front of the other, with the front foot behind the starting line. The athletes were instructed to start the test after a “3,2,1, go” verbal signal was made. After the signal was made, the athletes had to maximally accelerate and reach the ending line as fast as possible. Each athlete completed three 20-m sprint trials interspersed with 3 min of rest. The total time in seconds to complete each 20-m sprint was recorded.

Countermovement Jump

For the CMJ free arms was used allowing them to do arm swings (Markovic et al., 2004b). The CMJ tests were performed on a force plate (Force Decks v1.2.6109, Vald Performance, Albion, Australia). Players were told to start from a standing position and were allowed to do a knee flexion at their comfortable depth before the jump take off. During the flight phase, the athletes had to maintain hip, knee and ankle extension and jump as high as possible. Also, players were instructed to try to land with the tip toes in the same place they took off. Three maximal trials were made and the jump heights (cm) were registered for further analysis.

Training Load Monitoring

Internal Load

For the internal load objective measures, HR data were recorded using Bluetooth HR sensors (Polar H10, Polar-Electro, Kempele, Finland, recorded in 5-second intervals) synchronized to a portable 10-Hz VX Sport 350 GPS units (VX Sport, Wellington, New Zealand). HR measures including HRavg, Edwards'TRIMP, and Bannister'TRIMP were analyzed following each session. The HRmax of each individual was extracted from maximal field-based test 30–15 Intermittent Fitness Test. The test seems to be valid for extracting the HRmax (Čović et al., 2016). For internal load subjective measures, approximately 30 min after each training session the Foster's 10-point scale of the rate of perceived exertion (RPE) was applied (C. Foster et al., 2001). The athletes were asked about how hard the training session was, and they had to score from 1 to 10, were 1 corresponds to "very light activity" and 10 corresponds to "maximal exertion". The athletes scored the RPE individually without the presence of other athletes. Moreover, the athletes rated their perceived level of exertion separately for respiratory (sRPE[R]) and leg musculature (sRPE[M]) efforts, as previously detailed (E. Borg et al., 2010; Asier Los Arcos et al., 2014). Also, they were allowed to score the RPE in decimals (e.g., 1.5). The subjective internal load was then obtained by multiplying each athlete's RPE score by the total duration of the soccer training session in minutes to determine the session-RPE (sRPE), expressed in arbitrary units (A.U.) (Haddad et al., 2017).

External Load

External load measures were recorded during all sessions using portable 10-Hz VX Sport GPS units (VX Sport, Wellington, New Zealand), which was previously considered a valid and reliable GPS device (Buchheit et al., 2014). The external load measures included in this study were total distance (TD), high-speed running (HSR, distance > 19.8 $km.h^{-1}$), sprint distance (SD, ≥ 25.2 $km.h^{-1}$) and mechanical work (MW) that summed the numbers of acceleration and deceleration efforts above and below 2.2 $m.s^2$ thresholds.

Statistical Analysis

The results are presented in text, table and figures as Mean±SD or 90% confidence intervals (CI) where specified. Normality of the sample and homogeneity was preliminary tested and confirmed in the Kolmogorov-Smirnov and Leven's test, respectively (p >

0.05). Within-group changes in changes of V_{IFT}, $V_{vam-eval}$, 20-meter sprint and CMJ were expressed as percentage changes and standardized differences as Cohen's d (effect size, ES, 90% CI) (Cohen, 1988a). No missing data occur in within group analysis. Between-group differences in changes of V_{IFT}, $V_{vam-eval}$ tests was also expressed based on Cohen's d (effect size, ES, 90% CI) (Cohen, 1988a). Magnitude-based inference approach was used for interpreting data (Batterham & Hopkins, 2006a). Threshold values for ES were <0.2: trivial; 0.20-0.59: small; 0.60-1.19: moderate; >1.2: large (Batterham & Hopkins, 2006a). Probabilities were calculated to indicate whether the true change was lower than, similar to, or higher than the smallest worthwhile change (SWC) (William Hopkins et al., 2009). The scale of probabilities was as follows: 25–75%: *possible*; 75–95%: *likely*; 95–99%: *very likely*; >99%: *almost certain* (William Hopkins et al., 2009). The probabilities were used to make a qualitative probabilistic mechanistic inference about the true effect: if the probabilities of the effect being substantially positive and negative were both >5%, the effect was reported as unclear; the effect was otherwise clear and reported as the magnitude of the observed value. Person correlation coefficient was also used to measure the association between V_{IFT} and $V_{vam-eval}$ tests as well as their changes (i.e., ΔV_{IFT} and $\Delta V_{vam-eval}$) with accumulated training load indices. The correlation coefficient (r, 90% confidence limits, CL) was ranked as trivial (<0.1), small (0.1-0.29), moderate (0.3-0.49), large (0.5-0.69), very large (0.7-0.89) and nearly perfect (0.9-0.99) (Hopkins, et al., 2009). The statistical procedures were conducted in propre-designed Excel spreadsheets (W. Hopkins, 2015).

Results

The results showed almost certainly moderate changes in VIFT, VVameval, and CMJ following training intervention (Table 1). An almost certain large improvement was also observed in 20-m sprint in players (Table 5).

Table 5. Within-group changes in physical fitness tests

Group	Pre	Post	% difference (90% CL)	Standardized difference (90% CL) rating	% greater/similar/lower (90% CL) probability

V_{IFT} (km·h⁻¹)	17.8 (1.4)	19.0 (1.4)	6.8 (5.4; 8.2)	0.8 (0.64; 0.96) Moderate	100/0/0 Almost certain
$V_{Vam\text{-}eval}$ (km·h⁻¹)	16.5 (1.5)	17.5 (1.5)	5.7 (4.2; 7.2)	0.6 (0.4; 0.7) Moderate	100/0/0 Almost certain
20-meter sprint (s)	3.0 (0.0)	2.9 (0.0)	-2.8 (-3.9; -1.6)	-1.1 (-0.6; -0.6) Large	0/0/100 Almost certain
CMJ (cm)	46.7 (3.3)	49.7 (3.9)	5.5 (3.9; 7.2)	0.7 (0.5; 0.9) Moderate	100/0/0 Almost certain

V_{IFT}: The maximal speed reached at the end of 30-15 Intermittent Fitness Test, $V_{Vam\text{-}eval}$: The maximal speed reached at the end of Vam-eval test, CMJ: Countermovement jump, CL: Confidence limits.

Very large relationships were observed between changes VIFT and VVameval for pre-, post- and pooled-data (Figure 4.8).

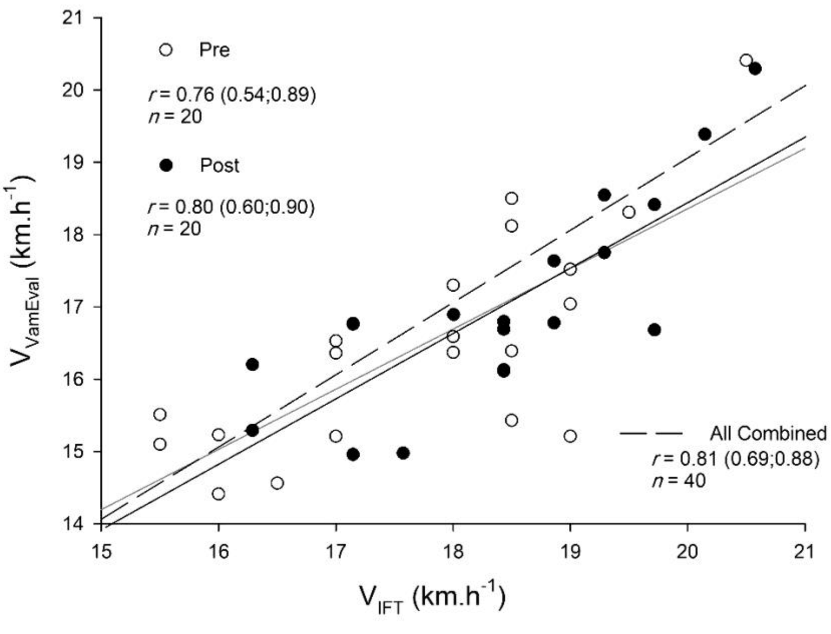

Figure 4.8. Relationships between V_{IFT} and $V_{vam\text{-}eval}$ tests for pre-, post- and pooled-data.

VVameval showed likely smaller changes (i.e., sensitivity) (−22.4%, [−45.0 to 9.4]), ES −0.45 [−1.05 to 0.16]) compared to VIFT following training intervention (Figure 4.9).

When analyzing dose-response relationships between ΔVIFT and ΔVVameval and training load indices, ΔVIFT revealed trivial unclear associations with sRPE and its differential versions (i.e., respiratory and muscular sRPE) but showed moderate correlations with all other selected measures (Figure 4.10). In contrast, VVameval showed large to very large relationships with sRPE and its differential versions but revealed unclear trivial-to-small associations with all other selected training load measures (Figure 4.10).

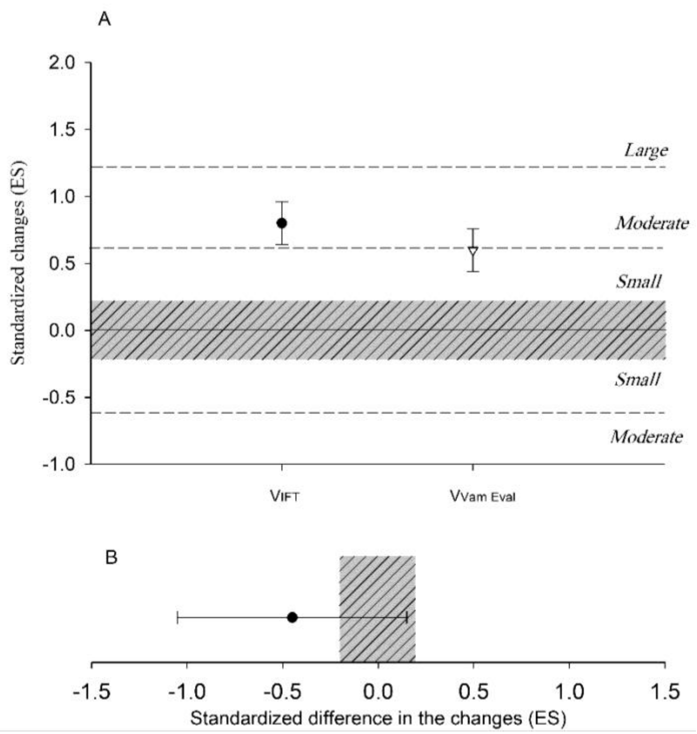

Figure 4.9. Relationships and sensitivities of V_{IFT} and $V_{vam\text{-}eval}$ to training. A) Within-group changes and B) between-group changes in V_{IFT} and $V_{vam\text{-}eval}$.

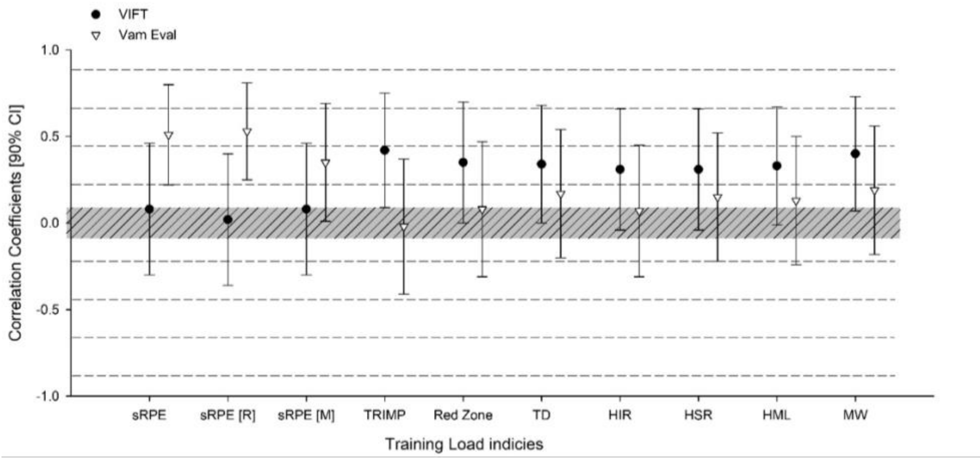

Figure 4.10. Dose-response relationships between V_{IFT} and $V_{vam\text{-}eval.}$ with selected training load measures. *Note*. sRPE; session-ratings of perceived exertion, sRPE (R); respiratory session-ratings of perceived exertion, sRPE (M); muscular session-ratings of perceived exertion, TRIMP; training impulse, Red Zone; time spent>85% of HR_{max}, TD; total distance, HIR; high-intensity running, HSR; high-speed running, HML; high-metabolic load, MW; mechanical work (number of accelerations and decelerations > 3 m.s^2).

Discussion

The aims of the present study were to analyze the within-group changes of V_{IFT}, $V_{vam\text{-}eval}$, 20-m sprint and CMJ after training intervention, and to explore the relationships between V_{IFT} and $V_{vam\text{-}eval}$ tests, and their changes, with accumulated training load indices. The main findings revealed that although there were very large relationships between changes of V_{IFT} and $V_{vam\text{-}eval}$ measures, the V_{IFT} was the most sensitive to track small changes. While V_{IFT} showed unclear associations with both sRPE measures, it showed moderate relationships with all external and objective internal loads. On the other hand, $V_{vam\text{-}eval}$ showed large-to-very large associations with both sRPE measures, but not with any external and objective internal loads.

Within-group changes (pre-post) of V_{IFT}, $V_{vam\text{-}eval}$, and CMJ showed almost certain moderate improvements, and almost certainly large improvements for the 20-m sprint test were revealed after training intervention. This finding may be related to the fact that the analyzed training intervention period was from the beginning until the end of the preparation phase where greater training volumes usually ensured. In fact, some studies suggest that the overall physical fitness parameters tend to increase after the pre-season period (Caldwell & Peters, 2009; Metaxas et al., 2006). However, some caution should be given to this, as some controversies has been documented regarding this topic. For instance, in contrast with our findings, no significant changes for sprint performance were found after the pre-season period (Meckel et al., 2018). Indeed, other study conducted on 19 professional Spanish soccer players revealed no significant differences for CMJ performance from the beginning of pre-season to 4-weeks after the beginning of in-season (Arcos et al., 2015). However, that study revealed significant sprint time improvements, similar to our results (Arcos et al., 2015). These setbacks may be related to the different methodologies used, considering the type of population, observational periods and the testing protocols used.

The V_{IFT} and $V_{vam\text{-}eval}$ measures showed very large associations between them, with V_{IFT} being the most sensitive measure. Previous research have documented similar associations between the 30-15IFT test and the Yo-Yo Intermittent Recovery test (YYIRT), with similar sensitivity (Buchheit & Rabbani, 2014). The greater sensitivity of V_{IFT} to track small changes may be due to the fact that the 30-15IFT is more dependent to aerobic power, while the Vameval test is more related to aerobic endurance. Also, the Vameval test is done in a circular fashion, while the 30-15IFT characteristics and the test final outcome (V_{IFT}) are more soccer specific (Thomas et al., 2016). For those reasons, using the 30-15IFT and V_{IFT}, seem to be more useful for tracking even the smallest but worthwhile changes in performance than the Vameval test and its related $V_{vam\text{-}eval}$.

Surprisingly, the dose-response relationships between V_{IFT} and $V_{vam\text{-}eval}$ changes and internal and external loads revealed to be somewhat complex. Although meaningful correlations between 30-15IFT and Vameval tests, it seems that they might have different dose-response relationships with training loads. In the present study, only $V_{vam\text{-}eval}$ presented strong associations with all sRPE measures, while V_{IFT} showed no relationships with any of the internal subjective measures. In contrast, a study conducted on twelve professional soccer players, revealed that soccer practice volume and the accumulated subjective measures of training loads had strong associations with increases in higher velocities completed during the 30-15IFT (Campos-Vazquez et al., 2017). Interestingly, it was previously revealed no relationships between sRPE, sRPE [R] and sRPE [M] with changes in aerobic fitness (Arcos et al., 2015).

As mentioned before, contradictory evidence has been documented regarding the relationships between objective internal load measures and changes in field tests performances (Campos-Vazquez et al., 2017; Manzi et al., 2013). In fact, no relationships were found between HR measures and changes in 30-15IFT test performance, which is in contrast with our findings (Campos-Vazquez et al., 2017). Conversely, other study conducted on eighteen professional soccer players, revealed large-to-very large associations between TRIMP and the yo-yo intermittent recovery 1 test performance (Manzi et al., 2013). Similarly to our results, Rabbani et al. (2019). revealed that both Bannister's and Edward's TRIMP showed large relationships with changes at the final speed reached on 30-15IFT. However, methodological differences between the above-mentioned studies must be highlighted, as some used field tests and others used laboratory tests.

Moreover, our study demonstrated moderate relationships between V_{IFT} and all external loads, while $V_{vam\text{-}eval}$ did not show any associations. Similar to our results, a recent study conducted on 11 professional soccer players, revealed large dose-response relationships between NBL and changes in high-intensity intermittent running capacity assessed via 30-15IFT and its related V_{IFT} (Rabbani et al., 2019). Although that same study (Rabbani et al., 2019), revealed no associations between TD and high-intensity running (HIR), and very high-intensity running (VHIR) metrics with changes in V_{IFT}, which is in contrast with our results. Also, other study (Fitzpatrick et al., 2018) revealed a lack of relationships between the overall external metrics and changes in aerobic fitness performance.

These differences might be related to the fact that the two above-mentioned studies (Fitzpatrick et al., 2018; Rabbani et al., 2019), analyzed the dose-relationships during in-season period, while in the present study our observations were from pre-season period to only 4 weeks of the beginning of the season. However, it should be noted that only moderate relationships were found between V_{IFT} and all external loads. Also, MW was the metric the strongest associations compared to all other external loads, reinforcing the statement regarding the usefulness of HR-based and MW-based metrics for tracking changes in high-intensity intermittent running performance in professional soccer players (Rabbani et al., 2019).

The present study had its limitations. One of the main limitations is related to the small sample size, which makes generalizations based on the results difficult. However, considering that the sample is from professional players, is almost impossible to have larger samples. Other study limitation can be related with variation in environmental conditions occurred during the period of intervention. Another limitation is the fact that only a brief period during the initial phase of the season was analyzed. These limitations may influence the results, since no dose-response relationship was analyzed in the later stage of the season, and possibly different results can be found. Future studies should analyze a more longitudinal period to make better generalizations.

Considering the lack of studies and the conflicting evidence surrounding the dose-relationships between internal and external loads with physical fitness changes, the present study revealed some interesting findings. As practical implications, this study suggests that despite field tests may show relationships between them, it does not mean that they present similar dose-response relationships with internal and external training loads. Therefore, different dimensions of load may produce different impact in fitness of players. However, conclusions should be interpreted carefully, since the limitations and small sample may affect the generalizability of the findings.

Conclusions

The present study revealed significant improvements of VIFT, VVameval, CMJ and 20-m sprint tests after the training intervention. Despite very large relationships between VIFT and VVameval, the VIFT showed great sensitivity to track small changes. Also, these two measures revealed dose-response relationships with different dimensions of training load quantification. Objective internal and external load measures seem to be better suited for tracking VIFT changes. While subjective internal loads are better suited to track changes in aerobic endurance from VVameval, at least during the initial phases of the season. For those reasons, coaches and practitioners should use objective internal and external loads to track aerobic power related changes from VIFT.

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CHAPTER 5: DISCUSSION

5 DISCUSSION

The primary purpose of the present thesis was to investigate four articles with four general aims: (i) to analyze between-session variations in external and internal load measures during SSGs; (ii) to analyze the relationships between VIFT, hemoglobin levels, and training load measures during SSGs; (iii) to analyze the within-group changes of VIFT, VAMEVAL, 20-m sprint, and CMJ performance; and (iv) to test the relationships between VIFT and VAMEVAL tests and their changes with accumulated training load indices. For ensuring a clear interpretation of the general discussion of the above-mentioned study purposes, this discussion section is organized based on the four aims described above.

5.1 BETWEEN- AND WITHIN-SESSION VARIATIONS IN INTERNAL LOAD MEASURES DURING SSGS

Regarding the between- and within-session variations of internal and external loads during SSGs, Paper 1 explored the between- and within-session variations of different internal load measures.

Considering the within-session (between intervals) variations of internal load measures across different SSGs, results revealed trivial differences between intervals using 3v3, 4v4, and 6v6 SSG formats for the overall internal load measures. In concordance with these findings, a study conducted on twelve adolescents analyzing the differences between-interval and between-session variability using SSGs found that between-interval variability (1.94-3.16% of CV%) was lower than between-session variability (3.26-4.62% of CV%) for HR measures (Ngo et al., 2012). However, the study used a sample of adolescents and involved only four hours of soccer training per week. Therefore, despite the similarities of the study with the findings of Paper 1 of this thesis, it must be highlighted that this pattern may not be so straightforward as in Paper 1, which included a sample comprised of elite soccer players from Qatar’s first league. In fact, another study conducted on U15 soccer players with three weekly training sessions revealed significant increases in HR measures between intervals during SSGs (Silva et al., 2011). However, differences in the samples, competitive levels, and other contextual factors in both mentioned studies must be considered when being compared with an elite soccer setting, as the frequency and level of training intensity can be substantially different (Hill-Haas, Coutts, et al., 2008). Further studies must be conducted on elite soccer players to confirm the findings of Paper 1 of the present thesis.

On the other hand, when analyzing between-session variations, it was shown that the variability of internal loads during SSGs depends on different measures. In fact, HR average (HRavg) showed lower variability (0.9% to 1.7% of CV%) than Edwards' TRIMP and Red Zone HR measures (2% to 9.7% of CV%). Although HRavg revealed low CV% values in the present work, overall, the available literature on SSGs has reported higher CV% values (Hill-Haas, Coutts, et al., 2008; Little & Williams, 2006; Ngo et al., 2012). Indeed, a recent study reported CV% values between 2.6% and 6.0% for all HR measures, with HRavg showing the greatest CV% values (Milanović et al., 2020). Also, Aquino et al. (2019) conducted a study on 51 youth soccer players to test the reliability of 6v6 SSG interventions, revealing CV% values of 4.1% for HR avg between the two trials conducted. Moreover, a study conducted on both professional and amateur soccer players revealed HRavg CV% values of 2.2%, which, compared to other studies' findings, are more similar to those found in Paper 1 of the present thesis (Stevens et al., 2016).

During the data collection for producing the present thesis, a well-controlled design was ensured (e.g., similar players for each team in each condition), and three trials were implemented for each SSG to reduce the risk of increasing the noise in the analyzed variables, according to previous recommendations (Hopkins, 2004). The lower CV% values found in Paper 1 (when compared to the available research on this topic) might be due to the latter factors, as the overall literature implemented only two trials for each SSG condition. Also, the previous studies were conducted on youth soccer contexts, while all four studies examined in the present thesis were conducted on elite adult soccer players.

Furthermore, standardized typical errors of internal load measures tend to decrease when using touch limitations or goalkeepers in 3v3 and 6v6 SSGs but not 4v4 SSGs. Indeed, it was previously reported that SSGs with touch limitations and goalkeepers increased the intensity of SSGs while decreasing their variability, as the increased exercise intensities seemed to decrease the related noise (Aguiar et al., 2012; Ngo et al., 2012). Thus, manipulating factors that affect internal load measures during SSGs and increase their intensity may reduce the noise associated with these drills. However, this is possible only if soccer players are consistently exposed to more stable chronic internal loads during SSGs, which may not be feasible given the natural variability of SSGs (Clemente et al., 2020). As mentioned earlier in this thesis, traditional running-based drills produce less noise (0.9% of CV%) than overall SSGs drills (1.3% of CV%) (Ade et al., 2014). Therefore, using traditional running-based drills in combination with SSGs may be better for ensuring that soccer players are exposed to more consistent high-intensity (near to maximal oxygen uptake) stimuli (Rabbani, Clemente, et al., 2019a).

5.2 Between- and within-session variations of External load measures during SSGs

Regarding the within-session variations of external load measures across different SSGs, results revealed trivial differences between intervals (within-session) in TD.min^{-1} and HIR.min^{-1} for all SSGs, as well as in HSR.min^{-1} and MW.min^{-1} for all SSGs formats overall. Indeed, a study conducted on 20 international soccer players from a national team revealed only trivial changes between the first two intervals for all high-to-high-intensity external measures, which is similar to the findings of Paper 2 of the present study (Dellal et al., 2012). However, the above-mentioned study analyzed four intervals of different SSG formats, revealing greater decreases in the overall external load measures from the second to the fourth interval. Thus, the external load measures seem to remain relatively consistent between the first two intervals, as observed in Paper 2, and then tend to decrease after the second interval (Dellal et al., 2012).

Indeed, other studies documented small-to-trivial changes between the first and second intervals (Clemente et al., 2019, 2020). However, the possible external load variations that might occur during SSG intervals, mainly after the second interval, might be due to the training regimen used, as longer intervals revealed greater decreases in TD, ACC, and DEC (Clemente et al., 2020). For these reasons, coaches should be aware that reductions in external load measures during SSG drills can be influenced more strongly by the duration of each drill than the number of sets.

On the other hand, when considering the between-session external load variations of SSGs, small-to-large standardized typical errors were revealed for the session-to-session variations of all external load measures across the different SSGs used. While TD had lower variability (2.2 to 4.6% of CV%), the overall analyzed high-intensity external load measures had higher variability values (ranging between 7.2% and 29.4% of CV%).

In fact, the range of CV% values found for the TD measure in Paper 2 is in concordance with a recent study revealing that TD had a CV% of 4.4%. Indeed, Stevens et al. (2016) also reported very similar TD CV% values with those found in the present thesis, ranging between 3.0-4.1%. However, in contrast to the findings of Paper 2, higher TD CV% values (ranging between 6-8%) were previously reported in the literature (Ade et al., 2014; Hůlka et al., 2015). The type of SSG format used, the different GPS tracking systems, and the competitive level of the players, among other contextual factors, may have led to the slightly higher CV% values reported in the above-mentioned studies (Ade et al., 2014; Hůlka et al., 2015). Although higher TD CV% values were reported, it is known that CV% values close to 10% are still considered acceptable (Atkinson & Nevill, 1998).

Considering the CV% values for high-intensity measures (HIR, HSR, and MW), Paper 2 of this thesis revealed that external load measures of higher intensities produce greater CV% values. In fact, other studies have reported HIR CV% values ranging between 8.1 and 16.6%, which are similar to the findings of this thesis (HIR CV% values of 7.2-16.4%) (Aquino et al., 2019; Stevens et al., 2016). The HSR was the external load showing the greatest CV% values in Paper 2 of the present thesis (12.2 to 29.4%). However, some contradictory evidence has been reported regarding this external load measure. In fact, some researchers revealed CV% values ranging between 30 and 60% (Ade et al., 2014; Hill-Haas, Rowsell, et al., 2008). Meanwhile, other research reported HSR CV% values even lower than those reported in Paper 2 (approximately 8%) during SSGs (Aquino et al., 2019). The mentioned contradictions may be due to the fact that in Paper 2, the HSR measure was relativized per minute, while the above-mentioned studies used absolute HSR values in their analysis. Moreover, for the MW measure, CV% values ranging between 9.4 and 22.5% during SSGs were reported in this thesis. As the MW measure used in this thesis is the sum of the number of ACC and DEC and given that the overall studies analyzing the external load variations of SSGs used ACC and DEC in isolation, it is not possible to make useful comparisons. Further research should be conducted to confirm whether these MW CV% values are maintained during SSGs.

In contrast to the findings of internal load measures in Paper 1 of this thesis, neither decreases nor increases in variability were found in Paper 2 for external load measures when implementing touch limitations or using goalkeepers. Despite that, low ICC values were found in SSGs without goalkeepers, suggesting that the use of goalkeepers may increase the reliability of external load measures (Milanović et al., 2020). This finding can be useful for coaches if the aim is to keep external load exposure consistent during a soccer training week.

5.3 Relationships between VIFT, hemoglobin levels, and training load measures during SSGs

The relationships between VIFT performance, hemoglobin levels, and internal and external load measures during SSGs were tested. Results revealed relationships with both internal and external load measures.

Large-to-very-large positive relationships between VIFT and TD, HIR, and MW were found in the present thesis. On the other hand, VIFT showed unclear relationships with all internal load measures. To the best of our knowledge, no study has tested the relationships between the final velocity of the 30-15IFT and training load measures during SSGs. However, some research has tested these relationships using the YYIR test (Aquino et al., 2020). In fact, TD showed the greatest relationships with VIFT, ranging between r = 0.69; 0.87 in Paper 3, which is in concordance with a previous study that reported a relationship between YYIR2 test scores and TD (r = 0.59) during a 6v6 SSG, similar to the lowest value reported in Paper 3 (Stevens et al., 2016). Also, the study of Owen et al. (2020) revealed a relationship between YYIR1 test outcomes and TD (r = 0.88) during a 5v5 SSG, similar to the highest value reported in Paper 3.

Furthermore, considering the high-intensity measures (HIR and MW), the findings of Paper 3 revealed large-to-very-large associations between VIFT and HIR (r = 0.66; 0.75) and large associations with MW (r = 0.56;0.68). Similarly, a study conducted on 31 soccer players from a Portuguese U17 team revealed moderate-to-large relationships (*r* = 0.45; 0.56) between YYIR1 and YYIR 2 test scores and HIR during SSGs (Rebelo et al., 2014). Also, in line with this thesis, a recent study showed that YYIR 1 test performance had moderate-to-large associations with both ACC and DEC during SSGs (Owen et al., 2020). Although there are flagrant methodology differences between the above-mentioned study (use of YYIR test) and the present thesis (use of 30-15IFT), it seems that the VIFT measure from the 30-15IFT is a good indicator of physical performance during SSGs in terms of external load measures. Also, using a 3v3+GK SSG format may be useful as an integrated soccer-specific tool for monitoring physical performance.

Moreover, hemoglobin levels had moderate-to-large negative relationships with Edwards' TRIMP, %HRmax, and Red Zone. However, hemoglobin levels revealed unclear relationships with the overall external load measures. Comparisons between the findings of this thesis and other research are not possible, as no study has compared the relationships between hemoglobin levels and training load measures during SSGs. However, similar to the findings presented in this thesis, a study conducted on 18 adult soccer players aiming to analyze the relationships between hemoglobin levels and YYIR1 performance revealed small correlations without statistical significance (Saidi et al., 2019). Despite the lack of studies on this topic, the findings of the present thesis suggest that monitoring hemoglobin levels can be useful for assessing the intensity of SSGs. However, this might not be feasible for many contexts, given the logistics of such assessments.

5.4 WITHIN- GROUP CHANGES IN VIFT, VAMEVAL, 20-M SPRINT, AND CMJ PERFORMANCE

Following previous studies conducted in this thesis (Papers 1, 2, and 3), it became logical to also analyze the within-group changes of physical performance of elite soccer players during a pre-determined season period. Specifically, the within-group changes (pre-post pre-season period) of VIFT, VAMEVAL, and CMJ were assessed, and results revealed almost certain moderate improvements for VIFT, VAMEVAL, and CMJ and almost certain large improvements for 20-m sprint test performance after the training intervention. It is also important to highlight the fact that this study was conducted on the same team from the Qatar Stars League (Qatar First Division), as in the other papers from this thesis. As such, the SSG training methodology was also part of weekly training sessions in this study.

Although some interesting changes were observed after the pre-season training intervention, it is of paramount importance to consider the fact that these changes may not be fully related to the soccer training intervention itself, as they can be influenced by other contextual factors (Guerrero-Calderón et al., 2021). Also, the fact that significant changes in fitness and neuromuscular performance were found after the pre-season period may be related to the greater weekly training volumes typical of this season period (Caldwell & Peters, 2009). However, some incongruences were reported in recent research (Meckel et al., 2018). In fact, no significant changes after the pre-season period were reported for sprinting and neuromuscular test performance (Arcos et al., 2015; Meckel et al., 2018). Although this finding highlights the fact that using SSGs as a training methodology may improve chronic physical adaptations, the different methodologies used in the above-mentioned studies, among other contextual factors, make generalizations difficult.

5.5 Dose-response relationships between VIFT and VAMEVAL tests and accumulated training load indices

The relationships between VIFT and VAMEVAL performance and internal and external load measures were tested in Paper 4. Very large associations between VIFT and VAMEVAL were found. However, the VIFT showed the greatest sensitivity to track small changes in performance. Interestingly, the relationships between the 30-15IFT and VAMEVAL test outcomes and the related final outcomes (VIFT and VAMEVAL) were previously reported and revealed similar associations as those found in Paper 4 of the present thesis (Buchheit & Rabbani, 2014). Although these two tests assess aerobic capacity, the 30-15IFT is related to the assessment of aerobic power, while the VAMEVAL test is related to aerobic endurance capacity. Given the specificity of soccer and the high sensitivity of the 30-15IFT and its related VIFT, the present thesis recommends the use of the latter test to assess the aerobic capacity of soccer players to complement SSGs to monitor players' physical performance during training, as mentioned in Paper 3.

The dose-response relationships between VIFT and VAMEVAL and internal and external loads were inconsistent. Notwithstanding the meaningful associations between 30-15IFT and VAMEVAL tests, both tests showed different dose-response relationships with training loads. In fact, Paper 4 of the present thesis revealed that the VAMEVAL presented large-to-very large associations with all sRPE measures (sRPE, sRPE[M], and sRPE[R]), while no relationships were found for any objective internal and external load measures. In contrast with the findings of Paper 4, no previous relationships between VAMEVAL test outcomes and aerobic improvements were reported (Arcos et al., 2015).

Meanwhile, VIFT showed no relationships with any of the internal subjective measures, though moderate relationships were found with all external loads (TD, HIR, HSR, HML, and MW) and objective internal loads (TRIMP and Red Zone). Similar to these findings, a study conducted on 11 soccer players revealed that TRIMP measures had large relationships with changes in the final speed reached during the 30-15IFT (Rabbani, Kargarfard, et al., 2019). However, in contrast with the results of Paper 4 of the present thesis, a recent study revealed that the sRPE measures demonstrated strong relationships with changes in the 30-15IFT performance of professional adult soccer players (Campos-Vazquez et al., 2017).

These incongruencies may be due to the fact that some studies used laboratory-based tests, while the papers in this thesis involved only field-based tests for assessing aerobic performance. Also, analyzing the dose relationships during the in-season period (or in any other season period) may influence such relationships. Furthermore, MW was the external load metric with the strongest associations. Given the importance of such high-intensity measures in team sports, this thesis suggests the usefulness of monitoring HR and MW measures to track even minute changes in high-intensity intermittent running performance in professional soccer players. However, future studies should analyze a longer period to make better generalizations.

5.6 STUDY LIMITATIONS

All four papers conducted to produce the present thesis had some limitations. One of the main limitations was the small sample size used for all papers. However, this is a very common research issue for studies conducted in elite team settings. The papers of this thesis were conducted in different season periods (pre-season and in-season), and so it is possible that the consistency seen during the in-season period may not be found in other periods of the season (e.g., pre-season) due to the greater heterogeneity of fitness levels. Interactions between session-to-session variations and readiness to train, as well as tactical behaviors, were not tested. Another study limitation is related to the fact that during data collection, variations in environmental conditions occurred and it was not possible to maintain consistent temperature conditions, which may have influenced some results. Also, one of the studies considered a short period of the season—different results might be found if a longitudinal approach was conducted.

5.7 FUTURE RESEARCH

Given the small sample size used in all the papers in this thesis, further research should be conducted on different clubs to generalize the findings of the present thesis. Using smaller SSGs (e.g., 3v3) or larger ones (e.g., >6v6) and applying other SSG manipulations would be interesting for future studies to give coaches better insights regarding all patterns found in each SSG condition. Future studies should analyze the interactions between interval duration variations and fitness levels. Also, the relationships between readiness status and physical demand variations in SSGs should be analyzed in future research. Along the same line, associations between physical demand changes and tactical behaviors should be investigated, as external load measures seem to be highly dependent on tactical behaviors and other contextual factors.

5.8 PRACTICAL IMPLICATIONS

Notwithstanding all the above-mentioned limitations among the four papers conducted in the present thesis, some interesting practical implications can be highlighted. Considering the between-sessions internal load variability during SSGs, using different SSGs formats (which show higher internal load variability) concomitant with traditional running-based (less variability) drills is well-suited to controlling the consistency of high-intensity stimulus during a training week. Manipulating touch limitations and using goalkeepers increase an SSG’s intensity while producing smaller session-to-session internal load variations, which ensures greater chronic training adaptations.

On the other hand, regarding the between-session external load variations during SSGs, high-intensity external load measures produce more noise than lower-intensity measures. However, these variations seem to be related to the lower exposures to high-intensity measures using SSGs, which corroborates the need to use traditional running-based drills to complement SSGs to ensure progressive exposure to determinant external load measures such as HSR to prevent common neuromuscular injuries, mainly in the posterior chain. Also, two sets of SSGs might not impose sufficient fatigue. If the aim is to produce fatigue on players, more than two sets are needed.

Considering the relationships between VIFT, hemoglobin levels, and training load measures during SSGs, internal and external load measures observed during SSGs are associated with the fitness and physiological status of players. VIFT seems to be a good indicator of performance capacity during SSGs. Also, the use of SSGs to monitor soccer players' physiological and performance capabilities can be used as a complement of the 30-15IFT. This is of great use, as more players can be assessed simultaneously during a training session while being exposed to technical and tactical demands. Furthermore, regarding the dose-response relationships between training load measures and physical fitness, it must be highlighted that even when two similar tests present a strong relationship, this does not necessarily mean that they would present similar dose-response relationships in terms of internal and external load measures. Nevertheless, the use of training load measures to track aerobic power changes from VIFT values can be implemented in professional soccer settings.

CHAPTER 6: GENERAL CONCLUSIONS

6 CONCLUSION

Considering that modern professional soccer settings are characterized by short schedules with time-related constraints during a training week, the use of SSGs as a training methodology has become common in most soccer clubs, especially in Europe. Understanding the possible within- and between-session variations of training load measures during SSGs and investigating the usefulness of such a training methodology as an integrated tool to assess players' physical fitness were the main purposes of the present thesis.

One of the main problems of using SSGs alone is the fact that some external load measures such as HSR and maximal speed might not be fully imposed on athletes during training. Given that, consistent high-intensity stimulus is not possible using SSGs due to its high variability. Therefore, planning weekly training sessions based on SSGs concomitant with traditional running-based drills could ensure that determinant external load measures are sufficiently imposed on athletes on a weekly basis and that more stable high-intensity exposure is provided to facilitate chronic adaptions to training interventions. Also, from a logistic and time-efficiency perspective, coaches, practitioners, and players themselves would benefit from using the training process itself as a method of monitoring players' status.

For all the above-mentioned reasons, the present study highlighted interesting findings that could assist coaches and practitioners to improve their weekly training plans and continuously assess their teams in a time-efficient fashion. The main findings of the present thesis are as follows:

i. Between-interval trivial differences were found for all internal load measures during the all analyzed SSGs formats overall.
ii. Session-to-session variations in internal load measures were variable dependent, with HRavg showing less variability than Edwards' TRIMP and Red Zone measures.
iii. Lower noise was observed when implementing touch limitations and using goalkeepers.
iv. TD produced lower between-session variability than all other high-intensity external load measures.

v. The high-intensity external load measures produced high variability regardless of the SSG format and regimen.
vi. External load measures do not produce significant performance reductions between only two sets (more sets are needed to produce significant changes).
vii. Touch limitations and the inclusion of goalkeepers produced no meaningful effects on SSG external load variability.
viii. VIFT and hemoglobin levels were good indicators of the performance capacity and physiological status of soccer players during SSGs.
ix. The use of SSGs as a monitoring complement of aerobic tests such as the 30-15IFT is recommended.
x. Objective internal and external load measures can be used to track aerobic power changes based on the VIFT measure.
xi. VIFT and VAMEVAL tests presented very large relationships.
xii. VIFT was more sensitive to tracking small changes in performance than VAMEVAL.
xiii. Despite the relationships between the two tests, they produced different dose-response relationships.
xiv. Objective internal and external load measures seemed to be suitable for tracking VIFT changes.
xv. Subjective internal loads were suitable for tracking changes in aerobic endurance based on VAMEVAL.

Given the above-mentioned findings of the four papers of the present thesis, coaches and practitioners should adjust the training process and weekly training plans accordingly. If coaches intend to produce greater chronic internal load adaptations, there is a need to bridge the gap between the high levels of internal load variability of SSGs and the intensity stabilization characteristics of traditional running-based training. For these reasons, incorporating more traditional running-based drills concurrent with SSGs is of paramount importance to ensure chronic training adaptation in professional soccer players. Also, during SSGs interventions, coaches must plan drills with touch limitations and goalkeepers to ensure even lower variability in internal load measures.

On the other hand, if coaches intend to control the demands imposed in terms of external load measures, using touch limitations and goalkeepers will not produce any difference. Therefore, coaches have more freedom to implement other task constraints or even use constraint-free drills. However, further research is needed to investigate the effects of constraint-free drills and other task constraints besides touch limitations and goalkeepers. If the aim is to ensure team recovery during a given training session, coaches must plan only two sets of any given SSG, as two sets did not produce physical performance reductions. In contrast, if the aim is to produce fatigue during SSGs, then planning SSGs drills consisting of more than two sets is recommended. Furthermore, coaches and practitioners must acknowledge the fact that high-intensity measures produce high levels of variability in different SSG formats and regimens. This reinforces the suggestion to use traditional running-based drills to ensure that determinant external load measures such as HSR and MW are progressively imposed on athletes on a weekly basis.

Moreover, the use of VIFT outcomes from the 30-15IFT is recommended to assess the players' performance capacity (in terms of external loads), as is using hemoglobin levels to assess their physiological responses during SSGs. The SSG training methodology seems promising for use as an integrated method of assessing players' fitness levels. However, they must be used concurrently with the implementation of more traditional field tests such as the 30-15IFT. Also, objective internal load and external load measures can be used to track changes in aerobic power performance through the 30-15IFT's main final outcome (VIFT). When choosing an aerobic fitness field test to implement in an elite soccer team, coaches must consider the fact that even when some aerobic tests may show strong associations, it does not necessarily mean that they produce similar dose-response relationships. Coaches would benefit from using the VIFT measure to track even the smallest worthwhile changes in performance instead of using the VAMEVAL, given the high sensitivity of VIFT to tracking changes over time, as revealed in the present thesis.

Although the findings of the four papers included in the present thesis present important practical implications, given the actual logistic and time-constraints characteristics of modern professional soccer, further research is needed to corroborate these findings. Shifting the isolated use of only traditional or relatively ecological methods of soccer training into an integrated method englobing both methods may be of great usefulness. The same holds for the periodic and continuous assessment of players' physical and physiological responses to training interventions.

CHAPTER 7: GENERAL REFERENCES

7 REFERENCES

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ATTACHMENTS