UNIVERSIDADE BEIRA INTERIOR

Elite Performance in Futsal – towards an integrative approach of physical to individual tactical actions

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Tese para obtenção do Grau de Doutor em
Ciências do Desporto
(3º ciclo de estudos)

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CHAVE MÓVEL

Dedicatória

"If I have seen further, it is by standing on the shoulders of giants."

Isaac Newton

A todos os que através da COLABORAÇÃO tornaram possível a relização deste trabalho.

Agradecimentos

À Professora Doutora **Maria Paula Mota**, por me ter feito “ver” que devemos seguir aquilo que realmente gostamos de fazer e que temos os melhores ao nosso lado para nos ajudar!

Ao Professor Doutor **Bruno Travassos** por me deixar seguir o meu caminho, enquanto garantia que eu não me perdia. Por ter continuamente facultado um dos seus bens mais preciosos, o seu Tempo! Por me ter influenciado a sair da minha zona de conforto, e procurar melhorar as minhas lacunas! Por partilhar o entusiasmo de continuarmos a saber mais sobre o Futsal!
Obrigado por tudo!

Ao Professor Doutor **Jaime Sampaio** por estar sempre dísponivel em colaborar e a responder a todas as solicitações. Obrigado por toda a contribuição dada com críticas e sugestões aos trabalhos desenvolvidos, que muito moldaram e influenciaram esta tese.

Ao Professor Doutor **Micael Couceiro** por toda a disponibilidade e colaboração dada no desenvolvimento dos trabalhos da tese.

A todos os **co-autores** que participaram nos trabalhos e que muito valor lhe acrescentaram!

Ao **Farzad** e ao **António Ferrraz** por toda a partilha efetuada ao longo desta caminhada, pela motivação e inspiração que naturalmente me transmitiram! Por terem sempre uma palavra amiga! Obrigado por todas as tertúlias!

A todos os clubes, dirigentes, treinadores e jogadores de futsal que permitiram que fosse possivel recolher dados para realizar alguns dos trabalhos desta tese!

Ao meu coração, **Lara** por me ter facilitado a vida, por me ter incentivado, colaborado e dado todo o suporte nos momentos críticos em que precisava de tempo e espaço! Aos meus amores, **Noa**, **Mel**, **Caio** e **Mia** por representarem toda a força e motivação para concluir esta etapa da minha vida.

Á minha **familia**, em especial aos meus Pais e á minha irmã por todo o apoio e suporte dado durante esta caminhada!

Ao Mister **Jorge Braz** por ter enriquecido este trabalho com o seu prefácio, e por continuar a ser uma referência no Futsal, no âmbito profissional e pessoal!

Prefácio

É com grande prazer que escrevo este prefácio para a tese de doutoramento do João Nuno Ribeiro. Tive o prazer de conhecer o João há alguns anos, e desde então, tenho acompanhado o seu percurso com grande admiração. O João é um apaixonado pela modalidade, sempre na procura do conhecimento e inovação. A curiosidade e vontade de aprender que revela, são contagiantes e inspiradoras.

Ao longo da sua carreira, tem-se dedicado incansavelmente, à investigação na área da nossa modalidade, sempre preocupado em encontrar respostas para as questões mais desafiadoras e em identificar novas oportunidades para aprimorar as práticas existentes. A sua capacidade de análise e visão crítica são notáveis, assentes numa reflexão meticulosa acerca do que vai acontecendo em cada jogo e cada treino, conjuntamente, com o que surge em cada projeto de investigação. Por isso, a tese de doutoramento que o João apresenta é o resultado de anos de pesquisa e dedicação, entre a reflexão anteriormente mencionada, e o trabalho prático realizado nos pavilhões, com diferentes equipas.

O Futsal nos dias de hoje, é uma modalidade que exige atletas altamente preparados do ponto de vista físico, onde a monitorização e preparação física específica adequadas, são essenciais para maximizar o desempenho individual e coletivo da equipa. Deste modo, compreender as exigências físicas do jogo de Futsal, é determinante na definição de perfis de atividade e métricas, que nos ajudam não só a analisar e compreender o jogo, mas especialmente, a programar o treino com outro sentido.

Um dos aspetos mais relevantes deste trabalho, é a abordagem multidisciplinar adotada pelo João, que considerou a integração dos dados de carga externa com os diferentes contextos do jogo (análise física, tática e técnica). Essa abordagem inovadora é essencial para a otimização dos sistemas de monitorização física dos atletas, pois permite uma compreensão mais completa das exigências do jogo e dos fatores que influenciam o desempenho.

Em resumo, a pesquisa realizada fornece evidências concretas para a importância da monitorização física no Futsal, e destaca a necessidade de sistemas de monitorização precisos e personalizados para os jogadores e as equipas. Esses resultados têm implicações significativas para o treino e, para o desenvolvimento de jogadores, bem como para a gestão do desempenho individual e coletivo da equipa.

Este trabalho representa uma contribuição significativa para a comunidade académica e profissional do Futsal, e certamente, será de grande interesse para aqueles que se dedicam ao estudo e à prática da modalidade.

O João, não só como treinador e investigador, mas especialmente, como pessoa, é uma fonte valiosa de inspiração para aqueles que se entusiasmam com o conhecimento e a inovação, particularmente, no Futsal.
Que enorme honra para mim, ter a oportunidade de conhecer o trabalho desenvolvido, e simultaneamente, poder recomendar a sua leitura e análise cuidada!

Muito obrigado, João!

Selecionador Nacional de Futsal

Jorge Braz

Resumo

Este trabalho teve como objetivo investigar as exigências físicas da modalidade de futsal, de forma a fornecer informação precisa para otimizar os sistemas de monitorização física dos atletas, tendo-se pretendido identificar, ao longo do seu desenvolvimento, os pressupostos metodológicos mais fiáveis para a recolha dos dados de carga externa, bem como a sua integração com os diferentes contextos (análise física, tática e técnica). Para tal, foram realizados seis estudos onde se procurou: a) identificar as diferentes variáveis de um sistema de monitorização física e a sua influência para a performance individual do jogador e da equipa; b) investigar as exigências físicas da modalidade de futsal, identificando os diferentes perfis de atividade e as melhores métricas para analisar o jogo; c) investigar a intra e inter variabilidade física dos jogadores ao longo de um período congestionado; d) investigar as atividades de alta intensidade nos diferentes perfis de atividade dos jogadores ao longo das rotações e explorar a influência do tempo de jogo e do tempo de descanso (work-rest ratio) na capacidade para realizar esforços de alta intensidade; e) investigar as atividades de alta intensidade nas suas diferentes propriedades ao longo das rotações no jogo, e nas diferentes posições que os jogadores ocupam em campo; e f) identificar as ações táticas individuais que os jogadores realizam nas atividades de alta intensidade (aceleração, desaceleração e corridas de alta intensidade) nas diferentes posições.

Os resultados desta tese realçaram a importância da operacionalização de um sistema de monitorização em atletas de futsal, sendo que, através do estudo 1, foi possivel identificar o CMJ-cv como uma variável chave a ser monitorizada, e que tem influência na performance individual e da equipa. Além disso, e segundo os resultados do estudo 2, observou-se que é possível adicionar a estes sistemas de monitorização dados de carga externa, que permitem identificar perfis de atividade dos jogadores através das variáveis que melhor representam as exigências do jogo: cinemáticas (distância percorrida por minuto e distância percorrida em diferentes limites), mecânicas (desaceleração) e metabólicas (*power* metabólico).

Ainda através do mesmo estudo, os jogadores de futsal de elite revelaram conseguir manter a sua performance física entre a primeira e a segunda parte do jogo. No estudo 3, os jogadores voltaram a comprovar a capacidade de manter a performance física em períodos congestionados (3 jogos em 4 dias), mas neste caso foi identificada a importância do tempo de jogo para melhor entender a variabilidade na performance individual dos jogadores. Estes resultados levaram-nos a investigar a performance física através das rotações que os jogadores realizavam em campo e percebemos, através do estudo 4, que o tempo de jogo não será o único fator importante a monitorizar, mas também o tempo de

descanso entre rotações. Neste seguimento, o estudo 5 demonstrou que a primeira rotação que os jogadores têm em campo é a físicamente mais exigente e que as atividades de alta intensidade devem ser monitorizadas não só em termos de frequência total (n), mas também através do tempo-frequência (tempo (s) entre a ocorrência de uma atividade de alta intensidade e outra) e do *work-rate* (distância percorrida nas atividades de alta intensidade por minuto de rotação (m/min)).

Na procura de contextualizar as atividades de alta intensidade do jogo de futsal, o estudo 6 demonstrou que as exigências físicas dos jogadores estão relacionadas com a função específica da posição em campo, sendo a a frequência e o tipo de ações táticas individuais as variáveis que revelaram distinguir os diferentes perfis de atividade nas diferentes posições. Este resultado está relacionado com o facto de as ações táticas individuais com bola (desaceleração e aceleração) e sem bola (aceleração e corrida de alta intensidade) requererem diferentes exigências físicas.

Em conclusão, os resultados sugerem que um correto sistema de monitorização física com os procedimentos metodológicos ajustados à especificidade da modalidade, e com a integração de diferentes fatores contextuais do jogo, permitem individualizar a monitorização dos jogadores em função do seu perfil de atividade ou posição, de forma a potenciar a performance individual e coletiva da equipa. Para além disso, pode fornecer ao staff técnico informação precisa para desenvolver exercicios de treino que melhor replicam o ambiente das exigências da competição.

Palavras-chave

Futsal; Monitorização; Carga Externa; Atividades de alta intensidade; Substituições; Performance

Abstract

This work aims to investigate the physical demands of the futsal match-play to provide precise information to optimize the athletes' physical monitoring systems, to identify, throughout its development, the most reliable methodological assumptions for the collection of external load data, as well as its integration with different contexts (physical, tactical and technical analysis). Six studies were conducted in this regard, with the goals of a) identifying the different variables of a physical monitoring system and their influence on the individual performance of the player and the team; b) investigating the physical demands of the futsal modality, identifying the different activity profiles and the best metrics to analyze the match; c) investigating the *intra* and *inter* physical variability of players over a congested period; and d) investigating the high physical variability of players; e) investigate high-intensity activities in their various properties throughout the match, as well as in the various positions that players occupy on the field; and f) identify individual tactical actions that players perform in high-intensity activities (acceleration, deceleration, and high-intensity running) in various positions.

The overall findings of this thesis highlight the significance of implementing a monitoring system in futsal athletes, and study 1 identified the CMJ-cv as a key variable to be monitored, which has an impact on individual performance and team collective performance. Furthermore, according to the findings of study 2, it was discovered that it is possible to add external load data to these monitoring systems, allowing us to individualize the work in the different activity profiles through the variables that best represent the game's demands, which can be divided into three dimensions: kinematic (distance covered per minute and distance covered at different thresholds), mechanical (deceleration), and metabolic (metabolic power). Similarly, elite futsal players were found to be able to maintain their physical performance between the first and second halves of the match in the same study. In study 3, players demonstrated their ability to maintain physical performance during congested periods (3 games in 4 days), but the importance of playing time was highlighted to better understand the variability in individual players' performance. These findings prompted us to investigate the physical performance through players' rotations that were performed on the field, and we discovered, through study 4, that game time is not the only important factor to monitor, but also the rest time between rotations. In this regard, study 5 shows that the first player rotation on the field is the most physically demanding and that high-intensity activities must be monitored not only in terms of total frequency (n) but also over time-frequency (time (s) between the

occurrence of one high-intensity activity and another) and work-rate (distance covered in high-intensity activities per minute of rotation (m/min).

In an attempt to contextualize the high-intensity activities of the futsal match, study 6 shows that the physical demands of the players are related to the specific function of their position on the field, with the frequency and type of individual tactical actions revealed as the variables that distinguish the different profiles of activity in the different positions. This result is related to the fact that individual tactical actions with and without the ball (acceleration and high-intensity running) necessarily require different physical demands.

In conclusion, the findings suggest that a proper physical monitoring system with methodological procedures tailored to the specificity of the modality, as well as the incorporation of various game contextual factors, allows for individual monitoring of players based on their activity profile or position, to improve individual and collective team performance. Furthermore, it can provide accurate information to technical staff to develop training exercises that best replicate the demanding competitive environment.

Keywords

Futsal; Monitoring Systems; External Load; High-intensity Activities; Substitutions; Performance

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List of Acronyms

ACC	Accelerations
AU	Urbitrary Units
ATP-CP	Adenosine triphosphate and phosphocreatine
CFI	Comparative Fit Index
CI	Confidence Intervals
CMJ	Countermovement Jump
CMJ-cv	Countermovement Jump variability
DEC	Decelerations
DF	Defenders
DSL	Dynamic Stress Load
EL	External Load
ES	Effect size
FIML	Full information maximum likelihood estimation
GPS	Global Positioning System
HIA	High-intensity activities
HMLD	High metabolic load distance
HR	Heart rate
HSR	High-speed running
ICC	Intraclass correlation coefficient
IL	Internal Load
IR	Interquartile range
LGC	Latent Growth Curve
LPS	Local Positioning System
Md	Median
MD	Match Day
ML	Maximum Likelihood
MP	Metabolic Power
PL	Player Load
PV	Pivot
RMSEA	Root mean square error of approximation
RPE	Rate of Perceived Exertion
S&C	Strength and Conditioning
SD	Standard Deviation
TDC	Total Distance Covered
TQR	Total Quality Recovery
TLI	Tucker Lewis Index
UWB	Ultra-wideband
VIF	Variance Inflation Factor
VO_{2max}	Maximal oxygen consumption
WBs	Well-being score
WG	Wingers

1. Introduction

In elite sports, where there is a strict line between success and failure, it is crucial to really understand what are the factors that can contribute to improve the readiness of players and teams for performance. Over the last years, the development of technological systems for data collection and analysis in training and competition allows the development of new metrics and variables that capture the performance of players in the performance environment. This condition is critical because player activity patterns are heavily influenced by contextual variables rather than the player's current fitness status, which may not be the most appropriate to analyze training loads without the real match-play environment (Lacome et al., 2018).

The increased prevalence of Local Position Systems (LPS) in indoor environments provide practitioners the opportunity to collect improved data to gain a more understanding of the performance demands (technical, tactical, and physical), of futsal players during competition settings. These advancements have resulted in an increase in the number of research studies surrounding futsal in recent years, allowing sport scientists to base their analyses on strong foundations. As a result, they could improve the implementation of more specific and effective training programs, as well as gain a better understanding of player fitness, readiness to perform, and fatigue, thereby improving the quality and efficiency of their support to coaching staff.

Thus, a shift is emerging in the process of performance analysis, which should occur through the lens of specific team sport context and constraints (e.g., playing dimensions, player density, position characteristics, game rules, timing structure, physical demands, among others) which will how information can be applied (Torres-Ronda et al., 2022). The problem is not the data collection but the data analysis. Significant effort is required from performance stakeholders to transform the data into meaningful and reliable information for coaches and managers (*simple but powerful*) (Lacome et al., 2018). For that purpose, organizations should develop a "working fast-working slow" environment (Coutts, 2016) which allows that slow-thinking researchers work with their fast-moving practitioners in order to develop practice based research related with data and optimized communication between coaches and researchers (Buchheit, 2013). In effect, such innovations contribute to the development of the training monitoring processes and competition, thereby allowing coaches to make improved informed decisions in real-time.

Under this scope, the overall goal of this thesis was to investigate how to provide accurate information to optimize the athlete monitoring model. For that, some efforts were made to identify the most reliable metrics to evaluate the futsal requirements based on the environment, activity profiles, and playing positions. Furthermore, the integration of different contexts (physical, tactical, and technical analysis) and their influence on understanding futsal performance were explored using tracking data.

In the following sections some of the research questions that constitute the roadmap of our work are presented to sustain the definition of the goals of this thesis and the interconnection between the studies developed.

1.1 The athlete monitoring systems

Athlete monitoring systems have become commonplace in professional team sports.
Seeking to obtain a competitive advantage, organizations are investing in resources that can quantify training and competition characteristics in a valid and reliable manner. The main goal of training load monitoring is to provide an effective stimulus for improving physical performance during weekly training sessions (Impellizzeri et al., 2019). For positive adaptations to occur, a careful balance between training dose (the product of type, volume and intensity of training) and recovery status (individual athletes response to that dose) is required (Coutts et al., 2018; Gabbett, 2020). It is expected that such information can support decision-making process for the prescription and manipulation of training load (Vanrenterghem et al., 2017). Training load is the input variable in a training system that coaches and scientists most commonly manipulate to elicit the desired training response (Coutts et al., 2018). Furthermore, understanding the true effects of training load on players allows for the management of stimuli variation, the optimization of training individualization, a reduction in injury risk, the early detection of bad overreaching, and the reduction of the possibility of overtraining syndrome (Gabbett et al., 2017).
Traditionally, training load has been described as a measure of external load (workload the athlete performed; e.g., distance covered, number of accelerations or running speed) and internal load (athlete response to the workload; e.g., rate of perceived exertion [RPE], heart rate [HR]) (Impellizzeri et al., 2020). However in the athlete monitoring cycle proposed by Gabbett et al., (2017) the authors add more two dimensions: the perceptual well-being (whether the athlete is tolerating the workload; e.g., Hooper Index Questionnaire) and the readiness to train/compete (whether the athlete is physically and/or mentally prepared for exposure to another training stimulus; e.g., Countermovement Jump [CMJ], Total Quality Recovery Scale [TQR]).
In this regard, literature suggests the development of multifactorial athlete monitoring systems that combine external load, internal load, perceptual well-being, and readiness to train/compete because it provides more meaningful individual training prescriptions than interpreting data from any single athlete monitoring tool in isolation. According to a recent exploratory study, the most common method of recorder training load (either

internal or external) in Futsal was the RPE with 86.5%, followed by HR and Global Positioning System (GPS)/accelerometery systems with 40.5% and 37.8%, respectively (Spyrou, Freitas, Herrero Carrasco, et al., 2022). These results could be explained by the fact that indoor sports tracking systems are still relatively new and economically expensive, making them less accessible (Torres-Ronda et al., 2022). As a consequence, there is much to investigate in terms of methodology and procedures to develop a reliable proposal for performance monitoring in futsal.

Under this scope, it is warranted that the first step is to develop and update knowledge about futsal performance demands, understanding the game's complex constraints (e.g., playing dimensions, player density, position characteristics, game rules, timing structure, physical demands, among others) to enhance performance and reduce risk of injury.

In the future, the challenge is to incorporate physical and technical-tactical data into the monitoring process, which should provide practitioners with more context for physical efforts and training practices (Torres-Ronda et al., 2022).

Under this scope, the first overall goal of this thesis will be to investigate the following issue*: Is an athlete monitoring management system important for improving player match performance in elite futsal?*

1.2 Futsal demands characterization

Futsal is an indoor version of soccer that attracts the attention of more than 100 countries with more than 12 million athletes (Borges et al., 2022). Official futsal games are played indoors in a hard surface pitch measuring 40x20 m during two regressive stop-watched (clock stop for some events; i.e., ball out of the court, faults, corners, medical player assistance) ball periods of 20 min, interspersed by a 10 min interval. A match-play may last between 75 and 90 min (Barbero-Alvarez et al., 2008), and teams can request one timeout (1 min) in each half.

Furthermore, it is characterized by unlimited substitutions which can have a significant impact on player performance and must be properly managed by coaches.

Two teams play the futsal match, each consisting of five players: one goalkeeper, and four outfielders, commonly named defender, winger and pivot. Futsal involves several technical and physical abilities such as passing, shooting, making decisions, space and time domains, acceleration and slowdown actions, agility, change of direction, coordination, and body control (Caetano et al., 2015; de Oliveira Bueno et al., 2020). Regarding internal load, futsal players maintain their HR at levels higher than 80% of maximum HR for more than 83% of the match duration (Barbero-Alvarez et al., 2008). Due to its elevated HR mean (approximately 90%) futsal is considered one of the most demanding team sports (Barbero-Alvarez et al., 2008). The locomotor movements could change every 3-9 seconds, with a relatively short recovery period (20-30 seconds) between sprint bout series (3-4 bouts) (Castagna & Álvarez, 2010; Doğramacı et al., 2015). The combination of these previous findings allows futsal to be classified as a high-intensity sport with intense and intermittent energy demand that stimulates both aerobic and anaerobic metabolism (Castagna & Álvarez, 2010).

Studies that analysed the physical performance in futsal matches showed that high values of maximal oxygen consumption (VO_2max) are apparently essential for athletes at the professional level (Álvarez et al., 2009). Furthermore, in professional futsal players, the perception of effort is both correlated with the VO_2 max (59.6 ± 2.5 mL · Kg-1 · min-1) and with the overall training load accumulated over the total period (Milanez et al., 2011). Recreational players, compared to elite players, seem to require lower physiological demands and activity profiles during match play (Borges et al., 2022).

Regarding the blood lactate levels production, Castagna et al. (2009) showed that high-level futsal players had blood lactate levels of 5.3 mmol/L^{-1} when tested during highly competitive training games (4x10-mmin quarters). In turn, Dos-Santos et al. (2020) found that players who performed two interchange-rotations (substitutions) on average in each half had similar lactate concentration (8.4 vs. 8.2 mmolL^{-1}). Despite the fact that the lactate values presented in the two previous studies differ significantly, this data suggests that the activity profile of elite futsal players is dependent on both aerobic and anaerobic energy metabolism pathways, specifically the phosphagen system. In passive recovery, 50 percent of muscle adenosine triphosphate-phosphocreatine (ATP-CP) stores are restored within 20 seconds of rest and intramuscular reserves are restored after almost 3 minutes (Bogdanis et al., 1996; Ulupınar et al., 2021). In this context, knowing the metabolic fatigue (decreased ability to generate muscle exertion in response to physical exercise that has exceeded the ATP replacement rate) response to training/match is essential to maximize the players adaptation while minimizing the risk of injury and avoid any overload (Layzer, 1990).

Understanding the players' physiological responses to the demands of futsal requires linking this knowledge with the players' external load demands in order to improve the coaches' decision-making. This is necessary to comprehend the locomotor demands of a futsal match.

In this regard, it is critical to contribute with more information to investigate new methods for developing player tracking data, and provide an answer to the following question: *What will be the most accurate method to collect player tracking data, taking into account the futsal game constraints?*

1.3 Activity profile of elite futsal players

The physical demands of futsal require accurate measurement of the player's match activities. Identification of these critical performance factors is crucial because it may enhance training methods. Emerging fields for comprehending players' physical performance in competitive situations have opened new perspectives since FIFA approved the use of particular wearable sensors and microsensors in official futsal matches (Roell et al., 2018). Actually, with the ongoing development of microtechnology, player tracking has become one of the most important components of load monitoring in team sports (Akenhead & Nassis, 2016). The three main objectives of player tracking are: i) a better understanding of practice (provide an objective, a posteriori evaluation of external load and locomotor demands of any given session or match); ii) optimization of training load patterns at the team level, and decision making on individual players training programs to improve performance and iii) prevent injuries (e.g., top-up training vs unloading sequences, return to play progression) (Buchheit & Simpson, 2017).

External load could be classified into three main categories: (a) kinematics, which quantifies overall movement during exercise; (b) mechanical, which describes a player's overall load during exercise; and (c) metabolic, which quantifies overall movement energy expenditure during exercise (Rossi et al., 2018). These parameters can also be normalized or expressed in absolute (total match time) or relative (ball playing time) terms. This consideration is relevant because an analysis of the entire game that ignores match interruption may underestimate the real physical demands during the in-play phase (De Oliveira Bueno et al., 2014).

In the past, time-motion analysis (using video and computer-based tracking systems) was used to collect the majority of scientific knowledge about external load and activity profiles (Spyrou et al., 2020). Using this technology, it was possible to determine that the average distance covered by futsal players is between 3-5 km (Makaje et al., 2012). However, in sports with unlimited substitutions, the total distance covered cannot be used to predict performance; instead, the distance covered per minute (relative distance) is a better indicator of the overall intensity of the exercise (Barbero-Alvarez et al., 2008). Previous studies have shown that futsal players also perform a sprint every 79 seconds during regular matches and usually cover 121 (105-137) $m \cdot min^{-1}$ and spend 5% and 12% of total playing time sprinting and high-intensity running respectively (Barbero-Alvarez et al., 2008; Castagna et al., 2009). Moreover, players perform a low-intensity effort every 14 seconds, a medium-intensity effort every 37 seconds, a high-intensity effort every 43 seconds, a maximum-intensity effort every 56 seconds. Besides this, players engage 8.6 activities per minute of match play and change locomotor activities every 3.3 seconds (Dogramaci et al., 2011; Naser et al., 2017).

This previous data only measures kinematic variables of match demands and has no knowledge of mechanical or other components of player activity profile. In this regard, the following issue emerges: *Do the players have the same activity profile?*

Under this scope, and with the LPS availability the inclusion of mechanical and metabolic data is now warranted, providing researchers and practitioners with a more comprehensive understanding of the physical demands that futsal players are exposed to. Furthermore, with the great amount of data available to measure physical load, the challenge is to understand the most reliable and relevant variables that should be collected to characterizes activity profiles of players during training sessions and matches (Buchheit & Simpson, 2017). From this perspective, more research is required to accurately inform about the physical load experienced by players. This combination of findings could provide valuable support for training prescription, especially when attending to individualized training and rehabilitation programs, as well as return-to-play protocols after injury.

Following this line of thought, we intend to provide more knowledge exploring this issue in this chapter: *What are the most effective metrics for measuring physical performance in futsal?*

1.3.1 Physical performance during elite futsal match-play

One of the most researched hot topics in team sports is the player tracking fatigue, which investigates the impairment of performance by transiently reducing the intensity of the match after the most intense periods and/or during the second half.

Unlike the numerous studies that have quantified the physical demands of different sports (particularly football), there have been few studies that have examined official futsal matches. It is well accepted that competitiveness can influence motion characteristics (Dogramaci et al., 2011) and possibly induce bias in the interpretation of the physical demands of non-official or friendly matches.

The high demand of futsal match-play could indicate that the players may have difficulty to maintain the intensity of effort in the second half. However, this statement is not widely accepted in the literature. Professional futsal players had lower mean HR in the second half compared to the first half, 88,1 vs 91,1 % of HR_{max} respectively, and percentage of time spent in high intensity HR zone (Barbero-Alvarez et al., 2008). Distance covered in high-intensity running also decays in the second half in official matches (Barbero-Alvarez et al., 2008; De Oliveira Bueno et al., 2014). In contrast, in a simulated match the HR did not differ among the four 10-min periods (Castagna et al., 2009), as well as parameters relationship to the players sprint did not differ between halves in official matches of professional players (Barbero-Alvarez et al., 2008; De Oliveira Bueno et al., 2014), and in the simulated match (Milioni et al., 2016).

Regarding blood lactate, the same controversy results, a reduction in lactate concentration was found after the second half in university-friendly match (Tessitore et al., 2008), and in contrast, the blood lactate concentration remained unchanged in a simulation game with four 10-minute periods (Castagna et al., 2009) and in a friendly match (Dos-Santos et al., 2020).

Considering all of the previously reported evidence and inconsistencies, the development of new studies is justified in order to better understand the constraints of physical performance throughout the match, which we will attempt to answer in the following question: *Physical abilities of elite futsal players remain constant during matches, or have they changed?*

Also, it should be emphasized that physical performance on the court could be affected by many different contextual factors: playing position, congested fixtures, unlimited substitutions, tactical disposition, characteristics of match, among others (Novak et al., 2021).

1.3.2 Player's physical performance during congested periods

Following the previous chapters, and with the purpose of increasing knowledge about player tracking demands in different contextual factors, it is critical to investigate match congested fixtures (two or three competitive matches per week) because it is one of the topics that generates the most concern among stakeholders from high level competitions and teams (Gouttebarge et al., 2019; Julian et al., 2021; Pillay et al., 2022). This concerns derives from the fact that the majority of international competitions and playoffs of the world's major leagues are played in congested periods schedules, with matches played with very short recovery times (Howle et al., 2020).

It is well established that playing two or three competitive matches per week reduces a player's ability to sprint, jump, and perform repeated intensive activities when compared to playing one match per week (Rollo et al., 2014). In concordance, previous research has observed that some players, although potentially dependent on playing standard, may still not be 100% recovered in the 72h following a competitive match (Nédélec et al., 2013). These findings may be related to lower performance and muscle function as a result of increased inflammation and muscle damage (Moreira et al., 2016; Mujika et al., 2018). For example, thigh muscular isokinetic torque (Ispirlidis et al., 2008) and biochemical markers, such as creatine kinase and uric acid (Magalhães et al., 2010), remain

significantly impaired when compared to baseline levels at≥ 72h post-match. In addition, players perception of fatigue persisted 72 h post-match play (Brownstein et al., 2017).
In this regard, current knowledge about the demands of congested fixtures in team sports has increased the interest of medical and technical staff in developing strategies to improve performance and reduce the likelihood of injuries (Doeven et al., 2021; Nassis & Gabbett, 2017). In football, such views were presented in a survey at the 2014 World Cup, whereby national team practitioners ranked reduced recovery periods, accumulated fatigue, and congested match schedules among the most important risk factors for non-contact injury (McCall et al., 2015). Similarly, national team practitioners ranked monitoring tools that quantify match exposure and subjective markers of fatigue and recovery status as commonly used (McCall et al., 2015). Additional factors, such as the number of travels and squad rotations, can exacerbate or reduced the physical and mental demands of these matches (Julian et al., 2021).
Despite physiological evidence suggesting a decrease in player`s physical performance, a recent systematic review in football found no negative effects in terms of total distance covered when competing during congested periods (Julian et al., 2021). Some studies, however, have found a negative effect on some external load variables, such as the distance covered at low and moderate intensity, which may indicate that athletes use pacing strategies to maintain high-intensity actions throughout this period.
Furthermore, while player monitoring practices are common in professional football, with a large scientific production on literature (Gualtieri et al., 2020; Julian et al., 2021; Noor et al., 2021), research available on the impact of futsal match play in short congested periods is very scarce and remains unclear.
In elite futsal, players are subject to the correct balance between load and recovery during in-season intensified competition periods, participating in both national and international competitions. This leads to a high match frequency and subsequently to a high physical and psychosocial load (Doeven et al., 2017; Rollo et al., 2014). To the best of our knowledge, only two studies have investigated the physical performance of futsal players during congested match periods. Charlot et al (2016) analysed the intensity of matches on a 4-day FIFA futsal tournament and reported no differences in heart rate, recovery kinetics, and well-being, but a small decrease in sprinting activity between matches. In turn, a second study revealed a general small decrease in sprinting and an increase in walking activity of players after a multiday futsal tournament (Dogramaci et al., 2012). However, none of these studies were developed in competitive environments, and further information is warranted to understand the impact of congested fixture periods on the physical performance of elite futsal players.

In addition, in the studies developed to understand the effect of matches in a congested period used central tendency measures without considering intraindividual variability between players. Considering that the response of each player could be different according to individual capabilities, playing time variations caused by coaching decisions, or other individual or contextual factors (Carling et al., 2016; Mujika et al., 2018), it is necessary to consider the nonlinear responses of each player during match play (Illa et al., 2021).
In this regard, the following question will be explored in this chapter:
Is it possible for players to maintain physical performance during a congested period? - What about individual variation?

1.4 Player interchange rotation in Futsal

In futsal, it is expected that over the entire match players being able to perform fast straight movement speeds by developing power, strength, and agility, which should result in a greater ability to sprint, brake, or change direction (Spyrou et al., 2020). However, more than individual, such capacity to produce high intense actions over the entire match could be a result of a good use of the rule of unlimited substitutions.
Thus, the analysis of interchange rotations of players seems to be crucial to further understand physical performance of futsal players. In fact, the literature lacks an understanding of the physical demands of team sports with unlimited substitutions (player interchange rotations).
Following this, it is critical to understand the impact of player interchange-rotation management on physical performance, which is used during futsal matches for a variety of reasons; however, given the high-intensity nature of the match, interchanges are arguably most commonly used to delay the onset of fatigue (Dos-Santos et al., 2020; Montgomery & Wisbey, 2016). Furthermore, another factor that could have a significant impact on player interchange rotation management is the time spent on the court versus the time spent on the bench, which could be represented by a work-rest ratio and could help to explain some performance results (Dos-Santos et al., 2020). For example, in football it is well established that the HR and the blood lactate concentration are reduced in the second half (Dellal et al., 2012). However, substitutes entering the second half covered a greater distance at higher intensity compared to the players who started playing (Bradley et al., 2014). Similar results can be found in an Australian football review, where the authors discovered that a well-design interchange rotation strategy can positively affect match running performance (e.g., the total distance covered by a player during match-play) (Wing et al., 2021). In the futsal literature, a recent investigation found that players performed two interchange rotations on average in each half, had similar lactate

concentrations and HR values in the first and second halves, and these findings support the idea that a balanced player rotation is important (Dos-Santos et al., 2020).
From a strategic standpoint, managing the number and length of player interchanges is critical in futsal in order to anticipate substitutions caused by fatigue, foul trouble, poor performance, tactical changes, or other team strategic factors, and thus achieve positive effects on match outcome (Clay & Clay, 2014; Gómez et al., 2017).
Despite the perceived benefits of such practices, futsal research provides little evidence to support such assumptions. Furthermore, to the best of our knowledge, there is no information available about the player`s external load variation during match interchange-rotations. Nonetheless, it is assumed that a variety of situational factors can influence the magnitude of high-intensity activities (HIA) during the match. For instance, the current time of occurrence within the match, half or period, the number of players interchanges, the minutes played by the player, the accumulated load in the period immediately preceding the HIA, the strength of the opposition or the current score, among others things (Novak et al., 2021).
In this regard, it is warranted to answer the following questions: *What is the variation in player physical performance across interchange-rotations? How the characteristics of inter-change rotations affect futsal players' performance?*

1.5 Physical load of individual tactical actions

To improve the transfer from training to competition, practice tasks should replicate the frequency, duration and the context of repeated HIA bouts. Superimposed on this HIA are individual tactical actions (with and without the ball) that are directly related to involvement in the match.
Over the years, most of the research has characterized futsal efforts by neglecting the relationship between physical outcomes and individual tactical actions (contextual information) of the game (Arjol-Serrano et al., 2021; Bradley & Ade, 2018; Pino-Ortega & Rico-González, 2021). Understanding the frequency of HIA is just as important as understanding context during which HIA occur (Ju, Lewis, et al., 2022). More than a blind quantification of efforts, HIA should be contextualized and associated with specific match events (Nosek et al., 2021). In fact, there is a need to understand the relationship between high intensity efforts, such as changes of direction, as well as increasing and decreasing velocity (Ribeiro et al., 2022b; Spyrou et al., 2020), with offensive and defensive individual tactical actions (Bradley & Ade, 2018). Thus, the contextualization of HIA is critical for the analysis and development of individual athletic performance and team-based training (Santos et al., 2020).

For example, the passes, dribbles, marking actions or defensive returns, correspond to the specific tactical actions that players perform individually to contribute to the collective success of the team. From an ecological dynamics perspective, such individual tactical actions emerges from the relationship between the players' capabilities to play (perceptive, physical, coordinative, technical, among others) and variations in game environments during two specific phases of the game: (a) with ball possession and (b) without ball possession (Corrêa et al., 2012).

The value of combining these performance dimensions could be consulted in some futsal studies where team success is dependent of high-intensity efforts which are related to some activities such as the rate of shots on target, number of goals, key pass accuracy, ball recoveries, higher rate of challenges won and success rate of set pieces (Méndez et al., 2019; Santos et al., 2020).

Variations in individual tactical actions and physical efforts of players are now recognized to be associated with variations in playing positions or individual specificities of each player's actions during match play (Serrano et al., 2020). Such findings contradict the "one-size-fits-all" approach and highlight the importance of contextualizing players' activities for bespoke player training and monitoring processes.

To design representative learning environments, a practice task needs to guide players through the information sources that shape actions and behaviours within competition. Thus, informational constraints could be sampled from a competitive to allow them to be designed into a practice activity which simulates the competitive performance and environment (Woods et al., 2020).

As a result, one of the major challenges of team sports analysis is to integrate and contextualize physical data with individual tactical actions (Torres-Ronda et al., 2022). The best training results are achieved when the training stimulus replicates the physiological demands and movement patterns of the sport (Gabbett, 2010). Based on this premise, coaches and strength and conditioning professionals should be aware of specific match contexts and activities when designing training drills as a means of improving the behaviours and physical performance levels of team sports athletes' (Gabbett et al., 2009).

To the best of the author`s knowledge, no previous research has focused on investigating the relationship between physical and individual tactical data in futsal to provide coaches with concise information to better prepare training sessions.

In this sense, and in this final chapter, we intend to address the following challenge issue:

What are the physical requirements of each individual tactical actions performed by a futsal player, depending on playing position?

2. Objectives

Considering previous ideas, to improve performance and reduce the risk of injury of futsal players, practitioners should continuously look for the information that could support their intervention. In this regard, the overall goal of this thesis was to provide accurate data that will help sport scientists developing an athlete monitoring model of Elite Futsal, based on match-play constraints. It will provide coaching staff with accurate information to develop training session exercises that better replicate the competition environment and demands.

Based on the above, the objectives of this investigation were:

- To investigate how weekly training load constraints players and team`s match performance using an athletic monitoring system.

- To describe the external load of elite futsal match-play and compare physical performance between first and second half, as well as to identify the external load metrics that distinguish different futsal player profiles, and the collinearity between them.

- To investigate the match-to-match variation of physical performance (i.e., external load and internal load) of elite male futsal players over short-congested period during two 4-day FIFA futsal world cup qualifiers, encompassing two periods of three matches in four days.

- To quantify the HIA between player interchange-rotations in the match, and to identify the effect of match time and work-rest ratio along the interchange-rotations on the high-intensity activity profile of elite futsal players.

- To investigate the rate of change in performance work-rate across player interchange-rotations for each playing position, as well as the influence of rotation duration on the various HIA properties (the number of efforts, total distance covered, total duration, time-frequency, and work-rate) by playing position in each player interchange-rotation.

- To contextualize individual player`s HIA with tactical actions during match-play, and investigate the associations between different playing positions, individual tactical actions, and HIA characteristics.

3. How weekly monitoring variables influence players and team`s match performance in elite futsal players

Ribeiro, J. N., Monteiro, D., Sampaio, J., Couceiro, M., & Travassos, B. (2022). How weekly monitoring variables influence players' and teams' match performance in elite futsal players. *Biology of Sport*, *40*(1), 77-83.

3.1 Introduction

In team sports, the main purpose of the training process is to choose and manage the stimulus that optimize the player/team's performance for competition, i.e. allow the players to start the competition with high levels of fitness, motivation, cognitive capacities and low level of fatigue (Gabbett, 2020).

In elite futsal, the competition phase usually runs for 9–10 months, with official matches played almost every week and sometimes twice a week (Clemente et al., 2019). For this purpose, it is important to define an athlete monitoring system that ensures a balance between training load (the product of type, volume and intensity of training), recovery status (individual athlete's response to that load) and readiness for competition (Bourdon et al., 2017; A. Coutts et al., 2018; Gabbett, 2020).

In recent years, the development of monitoring systems in sport has occurred due to the evolution and availability of wearable technologies. These technologies allow, for example, to track and register internal and external load or even the positional relations between players using global positioning system for outdoor modalities or, more recently, ultra-wideband technology for indoor modalities (Illa et al., 2020; Rago, Brito, Figueiredo, Costa, et al., 2020).

However, for some athletes/teams/squads, insufficient resources can be a major reason for not developing and implementing a monitoring system (Halson, 2014). Based on that, friendly and understandable common tools (Halson, 2014; Ryan et al., 2020) that include subjective well-being questionnaires (mood, stress, fatigue, soreness and sleep) (WBs) and its derivatives, such as Session Rated Perceived Exertion (sRPE) and the Total Quality Recovery (TQR), have been frequently used in team sports (Saw et al., 2016).

In an attempt to build the relationship between training load and WB´s, some authors revealed that the muscle soreness and fatigue measured with a well-being questionnaire, were moderately and inversely correlated with sRPE (Clemente et al., 2020). In line with that, in another study, the authors found that higher TQR seems to be related with better self-report sleep quality (Wilke et al., 2019).

Despite of the reliability and informative value of subjective measures of training load and well-being (Rabelo et al., 2016), these should be combined with more precise and objective variables to ensure a balance between athlete perception and actual performance capacity (Bourdon et al., 2017).

Vertical jump height is one of the most reliable measures to quantify the athletic performance and the training-related fatigue in elite players (Franceschi et al., 2020; Loturco et al., 2017).

However, more than analysing physical and wellness data in isolation, there is a need to contextualize the data for a clear understanding of the results (West et al., 2021). For instance, opponent standard and match outcome seem to affect weekly training load values. When looking particularly to match outcome in elite soccer, it was revealed that players perceived a higher training load after a defeat or a draw compared to a win (Brito et al., 2016; Rago et al., 2021). Despite of the particularities of each sport, in Elite Australian football teams, it was noted that a balance on training load during the week, increases the chances of teams winning the match (Aughey et al., 2016). However, while this relationship is interesting, there is a paucity of research examining the weekly training-performance relationship, particularly in Futsal. In fact, in opposition to previous research, coaches always try to integrate the analysis of weekly training load with match performance indicators to improve the ability to understand the relationship between the process and the result (West et al., 2021).

Match performance indicators can be defined as a selection and combination of variables (e.g., passes, shots, goals, dribbles, interceptions, tackling´s) that characterizes individual or team performance helping to explain the team`s match performance (Lago-Peñas et al., 2011). Studies in other team sports suggest that the match performance indicators are fundamental for coaches to adjust the systems and strategies of play to the next matches and to cogitate about next week`s program (Agras et al., 2016). Previous research has revealed high reliability of such variables and a relationship with match outcome and teams' level (Santos et al., 2020) or even with match external load (Modric et al., 2019).

The aim of the current study was to investigate how weekly training load constraints players and teams' match performance through the influence of previous team performance. It was expected to observe: i) an effect of previous team performance on weekly training load; ii) a negative relationship between Session Rated Perceived Exertion (sRPE), Total Quality Recovery (TQR) and Well-being Score (WBs) with Countermovement Jump variability (CMJ-cv); iii) a negative effect of CMJ-cv on players and teams' match performance.

3.2 Material and Methods

3.2.1 Procedures

An observational descriptive research design was carried out during the competitive phase of 2018-2019 and 2019-2020 seasons. Data from 230 training sessions, and from 46 macrocycles were collected, with only one match per week and 5 days of training session prior to the match. The matches included 23 wins, 5 draws and 18 losses. The weekly training program was planned entirely by the team's coaching staff and aimed to develop an integrated content (i.e., tactical, technical and physical factors were amalgamated) throughout the microcycle, which was divided in 3 physical periodization goals: Recovery

(MD-5 [i.e., 5 days before a match]), Acquisition (MD-4/MD-3 [i.e., 4 and 3 days before a match]) and Tapering (MD-2/ MD-1 [i.e., 2 and 1 days before a match]). As recovery strategies, all players performed a 5-minute cold-water immersion every MD-4 and MD-2 throughout the in-season.

3.2.2 Participants and setting

Data were collected from one single team, comprising 19 professional male futsal players (age: 24.5 ±3.8 years old; height: 173.6±5.4 cm; weight: 70.3±7.6 Kg) that participated in the Portuguese first futsal league (Liga Placard). Of the 15 players that started the 2018-19 season, 11 remained in 2019-20, and 5 new players were part of the new season.

For players to be included in the data analysis, they had to meet the following criteria: (i) have participated in more than 80% of the weekly training sessions, and (ii) have started each week with medical clearance to compete.

The experimental procedures used in this study were in accordance with the Declaration of Helsinki and were approved by the local Ethics and Scientific Committee of University of Beira Interior (CE-UBI-Pj-2018-029). All players in the sample were familiar with the club´s standard monitoring routine. The club and players provided written informed consent to allow the use of data.

3.2.3 Measures

The monitoring tools included the daily analysis of the training load through sRPE and the recovery status using the TQR scale. Hooper´s Index questionnaire was used to record WBs and CMJ was used as a physical performance test and fatigue control measure, both performed only twice a week (see table1). All these data were collected all training sessions over the two in-seasons. Player´s match performance and team match performance were collected from all the matches played over the two seasons.

Table 1: Tracking weekly training variables of athlete monitoring system

Match Day	**MD-5**		**MD-4**		**MD-3**		**MD-2**		**MD-1**		**Game**
Physical Intention	Recovery		Acquisition		Acquisition		Tapering		Tapering		Competition
Monitoring Tools	Before	After	Before	After	Before	After	Before	After	Before	After	After
TQR	**x**		**x**		**x**		**x**		**x**		
sRPE		**x**		**x**		**x**		**x**		**x**	
WBs			**x**				**x**				
CMJ			**x**				**x**				
PMP											**x**
TMP											**x**

TQR - Total Quality Recovery; s-RPE - Session Rated Perceived Exertion; WBs – Well-being Score; CMJ- Countermovement Jump; PMP – Player´s Match Performance; TMP – Team Match Performance

Session Perceived Exertion

The training load was quantified by sRPE method. This method has been validated for monitoring internal training load in futsal (Matzenbacher et al., 2016).
Thirty minutes after the end of each daily training session (6pm - 7pm) athletes were presented with 10-point RPE scale and answered the question, "How intense was the training session?" using a visual analogue scale in which 0 means "not at all" and 10 "maximum effort". The sRPE was calculated by multiplying the reported RPE score and the total time of the session, in minutes, which represents the overall load of the session in terms of AU. Higher values of sRPE correspond to higher values of training load.

State of Recovery

To assess the state of recovery, the players answered the TQR scale. Before the start of the training session, the athletes answered the question "How recovered do you feel?" on a scale of 6-20, with 6 meaning being rested and 20 extremely good recovery. The weekly average TQR score for each athlete was calculated. Higher values of TQR represent good levels of recover during the week.

Well-being Score

Individual responses to training demands were measured by well-being questionnaire and was administered every morning (9am -10am) two times in the week (MD-4 and MD-2). Players completed a short questionnaire on their smartphone using a Google doc form. The questionnaire had 5 separate aspects of player well-being (Hooper & Mackinnon, 1995). These were: 1) How sore do your muscles feel today? 2) How fatigued do you feel today? 3) How well did you sleep last night? 4) How is your mood today? 5) How stressed do you feel today? Each question was score using a 1-5 likert scale with 1 representing a low score and 5 a high score. These responses were then converted into a global WBs (%).

Neuromuscular Performance

In order to monitor fatigue and neuromuscular performance, jump height was measured during a CMJ test (Optojump; Microgate, Bolzano, Italy) performed twice a week: MD-4 and MD-2. The test was performed before the training session in a randomized order. A standard warm up program was completed prior to the test consisting of 10 minutes in a stationary bike followed by dynamic stretching and 3 trial jumps with increased intensity. Finally, they performed 3 jumps with approximately 45-60 seconds recovery between them. All jumps were performed with the players in the tall standing position, with both feet placed hip to shoulder apart and hands akimbo. The mean value of the three attempts of CMJ in the two evaluation moments of the week, was used to calculate the coefficient variation of the jump height (CMJ-cv). The CMJ-cv expresses the variations on athletic performance of players over the week, with lower values representing stable and adjustable weekly training load to players athletic performance.

Player`s Match Performance

The Instat Index (Instat, Moscow, Russia) calculates a match performance indicator for each player. It is a unique parameter that provides an assessment of a player´s match performance based on the combination between 12 to 14 performance variables, with the higher numerical value indicating better performance (Modric et al., 2019). It is created by an automatic algorithm that considers the player´s contribution to the team´s success and the significance of their actions. The rating is created automatically, and each parameter has a factor that changes depending on the number of actions and events in the match.

Team Match Performance

All official matches that allowed a one week of preparation were considered, and for the analysis, the number of points achieved at the end of the match according to the result was considered. That is, 3 points correspond to victory, 1 point to draw and 0 to defeat.

3.3 Statistical Analysis

Descriptive statistics including means, range values and standard deviation, as well as bivariate correlations were calculated for variables under analysis. In addition, a path analysis model via Maximum Likelihood (ML) estimator method in AMOS 23.0 was performed to test the associations across studied variables (Kline, 2018). Bootstrap resampling (1000 samples), via, bias-corrected 95% confidence intervals (CI) was used to assess the significance of the direct and indirect effects. An effect is considered significant (at ≤.05) if it is 95% CI does not include zero (Hayes, 2013; Williams & MacKinnon, 2008). Effect sizes were evaluated as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79), and large (0.80 and greater) (Cohen, 2013). The model fit was assessed through the following traditional goodness-of-fit indexes: Comparative Fit Index (CFI); Tucker-Lewis Index (TLI); Standardized Root Mean Square Residual and Root Mean Square Error of Approximation (RMSEA) and its respective confidence interval (90%). For these indexes, the suggestions of several authors (Byrne, 2016; Hair et al., 2019; Kline, 2018) were adopted: CFI and TLI ≥.90; SRMR and RMSEA ≤.08.

3.4 Results

3.4.1 Preliminary Analysis

The inspection of the data revealed that missing values were less than .1% of the sample considered in present study, and consequently the Full Information Maximum Likelihood estimation (FIML) was considered for analysis (Cham et al., 2017). Additionally, no outliers (univariate and multivariate) were identified. Skewness and kurtosis values were comprised within cut off values revealing no violation from univariate data distribution. Nevertheless, Mardia's coefficient for multivariate kurtosis exceeds the recommended value (Byrne, 2016). Therefore, a bollen-stine boostrapp (2000) was performed for further analysis. Finally, the collinearity diagnosis was checked via variance inflation factor (VIF), and tolerance test assuming values less than to 10 for VIF and greater than to .01 for tolerance test. Therefore, the results showed that both in VIF and tolerance tests scores were below 10 and above .1 respectively, ensuring the appropriate conditions to test the regression model (Hair et al., 2019).

3.4.2 Descriptive Statistics

Table 2 presents the average values and respective standard deviation of the weekly training variables as well as the bivariate correlations between them.

Results revealed that team match performance has a significant positive correlation with the player´s match performance (r=.55**) and in turn, the player´s match performance is significantly influenced by the CMJ-cv (r=-.33*).

All the other variables did not reveal significant correlations and can be found in table 2.

Table 2. Descriptive statistics and bivariate correlations

Variables	M	SD	Range	1	2	3	4	5	6	7
1. PTP	1.45	1.42	0-3	1	-	-	-	-	-	-
2. sRPE	371.08	48.04	254.46 - 463.03	.07	1	-	-	-	-	-
3. TQR	15.70	.91	14.40 – 18.81	.10	-.10	1	-	-	-	-
4. WBs	67.45	4.72	59.33 – 77.56	.07	-.25	.17	1	-	-	-
5. CMJ-cv	.14	.06	.06 - .34	.15	-.16	-.23	-.22	1	-	-
6. PMP	220.12	31.84	160.50 -279.77	-.01	.09	.13	.12	-.33*	1	-
7. TMP	1.61	1.42	0 -3	.23	.10	-.08	-.03	-.02	.55**	1

Note. M = Mean; SD= Standard deviation; PTP= Previous Team Performance; sRPE= Session Rated Perceived Exertion; WBs= Well-being Score; CMJ-cv= Countermovement jump – coefficient variation; PMP= Player´s Match Performance; TMP= Team Match Performance * $p<0.05$; ** $p<0.01$

3.4.3 Path Analysis

The test of path analysis model included previous team performance, sRPE, TQR, WBs, CMJ-cv, player´s match performance and team match performance. Results show that the proposed model fit to the data ($\chi 2$= 14.71 (16); SRMR=.080; B-Sp= .473; RMSEA=.053 [90%CI=.000, .161]; TLI=.909; CFI=.929). Considering direct and indirect effects the proposed model explains 31% of match players' and team performance. The standardized direct effects of each path and sample are displayed in figure 1. The observed effects varied between trivial to medium. Regarding indirect effects, only a negative association between CMJ-cv and team match performance via player´s match performance (β= -.19; CI95% -.342 to -.049) was observed.

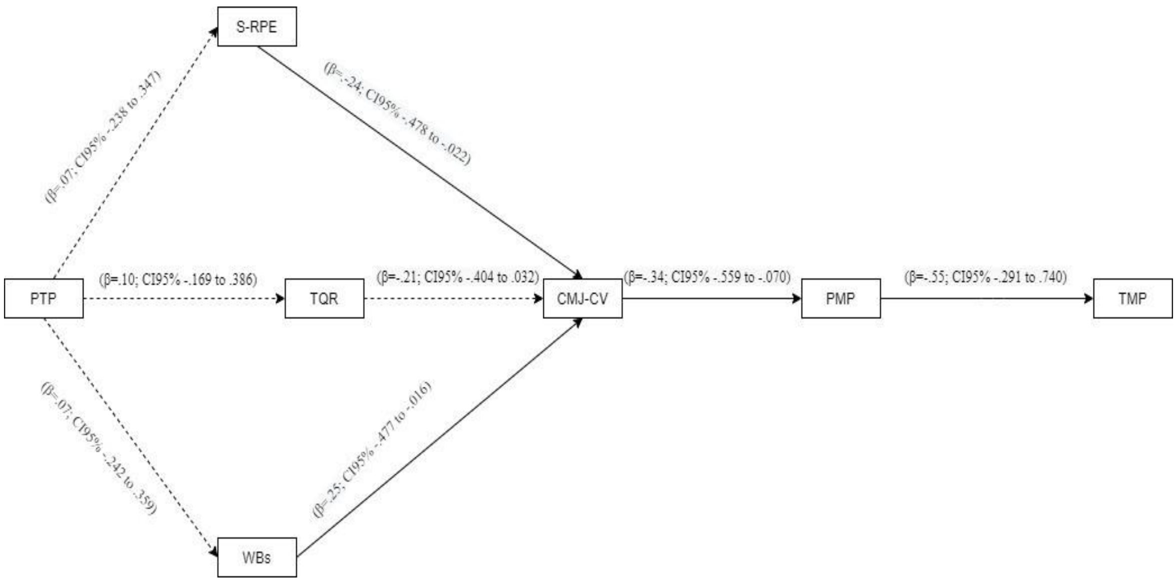

Figure 1. Performance explanatory model. Standardized direct effects of each path and sample

Note: PTP= Previous Team Performance; S-RPE= Session Rated Perceived Exertion; TQR= Total Quality Recovery; WBs= Well-being Score; CMJ-cv= Coefficient variation of Countermovement Jump; PMP=Player Match Performance; TMP= Team Match Performance.

3.5 Discussion

The aim of this study was to investigate how the context defined by the match outcome of the previous match influences the weekly training load and well-being, and its contribution to explain players' and team match performance of the following match. The proposed model for training monitoring process explained 31% of team match performance. Bearing this in mind and knowing that success in futsal is the expression of a complex mix of technical, tactical, physical and mental factors (Agras et al., 2016), as well as all the factors that can affect the players performance or the success of the teams, they demonstrate that the 31% that explain the team match performance appear to be a small, but considerable percentage for management by all the stakeholders in the training process.

The current main findings show no direct relationship between previous team performance and the following week`s training, and WBs variables. In addition, CMJ-cv proved to be a key variable to explain players' and team match performance. To explain this finding, low values of CMJ-cv were related with higher individual and successful team match performance. Interestingly, higher values of weekly load and higher values of WBs were related with lower CMJ-cv.

Previous research in association football revealed a significant increase in perceived training load when a negative result (defeat or draw) occurs in previous matches (Brito et al., 2016). Curiously, another study, with football teams revealed higher total distance covered by players during training sessions after a win compared to a draw or defeat (Rago et al., 2021). Also, with football it seems that when players lose a match, mood and stress are negatively affected, suggesting the disappointment of losing a match could persist for several days (Abbott et al., 2018). Despite this, we find it interesting that regardless of the match result, futsal players manage to maintain their external load level (Spyrou, Freitas, Marín-Cascales, et al., 2022).

In opposition to previous studies with football, and despite of the differences between sports, our results did not reveal any significant relationship between the previous team performance and the weekly training variables (sRPE, TQR and WBs) considered. Thus, it seems that over the two seasons, internal weekly training load in Futsal is not sensitive to previous team performance. These results, in comparison to previous results in football, may be justified by the fact that in futsal there are unlimited substitutions, and by the characteristics of training sessions mostly adopted in Futsal, with the goal of maintaining the monotony in training load over weeks (Illa et al., 2020; Malone et al., 2015). Future studies should take into account the cumulative effect of loads over the weeks and be developed not only considering the match result, but also the subsequent match conditions and even the performance of players during such matches. Also, the analysis method should consider a more individualized approach that accounts for individual variability in time of play and other individual characteristics to further explain individuals' variations on perception of the weekly training load (Ribeiro et al., 2020).

The analysis of the weekly training load using subjective (sRPE, TQR and WBs) and objective (CMJ) measures (Bourdon et al., 2017; Gabbett et al., 2017; Loturco et al., 2017) allow to monitor variations on players' physical performance and the state of readiness for competition.

While subjective measures contributed to evaluate the response of players to the session training load in relation to rest strategies and its influence on the general wellbeing, the objective evaluation of CMJ provided a reliable quantification of athletic performance and training-related fatigue of players (Gabbett et al., 2017; Loturco et al., 2017). In line with that, our results revealed a negative significant relationship between sRPE and WBs with the CMJ-cv (the higher sRPE and WBs values, the lower the weekly CMJ-cv).

Thus, despite of any correlation between sRPE and WBs it seems that higher training load combined with higher wellbeing states could promote lower variation in CMJ and consequently ensures higher performance and readiness for competition (Marques et al., 2019). These findings are in agreement with previous research which suggest that the monitoring process should account for variations on training load and on well-being responses (Ryan et al., 2018). In fact, based on our results, coaches cannot only think that the high sRPE is better. The range (~254 to ~463 AU) and the mean values (~371 AU) of daily sRPE variable, were in line with the optimal range values for daily training load for professional female futsal players (Milanez et al., 2014). Thus, the higher sRPE needs to ensure a balance between training load, recovery status, and WBs (Bourdon et al., 2017). A Correct balance of the training load is related to the greater probability for the success in the match outcome (Aughey et al., 2016). This result revealed that the weekly tracking of sRPE and WBs can give coaches the possibility to better manage training load and players' fatigue state, and performance readiness.

In this study, the analysis of weekly variations of CMJ (CMJ-cv) revealed to be a key factor to synthesize balance on weekly training load with implications for players' readiness to compete and to achieve higher individual performances and collective results. In opposition to previous research, in which external and internal load revealed trivial relationships with match statistics (Ryan et al., 2020), the use of CMJ-cv seems to have clearly captured players readiness for performance.

In line with our results, lower values of CMJ-cv promoted higher players match performance. This is an interesting finding with clear implications for coaches' intervention. This major finding suggests that a correct fluctuation of the training load, recovery status, and WBs during the microcycle (Bourdon et al., 2017; Gabbett et al., 2017) allows players to maintain their level of neuromuscular performance and consequently to achieve high performance results over the match.

One of the limitations of the study is the fact that despite having a database from two full seasons; it only considered one team as a sample, which obviously limits this generalizability of the findings. Longitudinal, multi-team studies are therefore required to make inferences that are more reliable on the effects of individual factors on futsal performance.

3.6 Conclusions

Contextual factors (previous team performance) seem to have no significant influence on the monitoring weekly training program in Futsal. The monitoring system defined by the analysis of the training load (as measured by Session Perceived Exertion, sRPE), recovery status (TQR), players' well-being (WBs) and neuromuscular performance (CMJ-cv) was fundamental to understand players' readiness for competition with implications in their match performance and consequently in the final team result (team match performance). The methodologies we used could be applied to other similar sports to provide novel insights about performance.

4. Activity Profile and Physical Performance of match play in elite futsal players

Ribeiro, J. N., Gonçalves, B., Coutinho, D., Brito, J., Sampaio, J., & Travassos, B. (2020). Activity profile and physical performance of match play in elite futsal players. *Frontiers in psychology*, *11*, 1709.

4.1 Introduction

The improvement on technological capability to collect and analyze data has increased the knowledge about load and physical demands of team sports and helps to improve training programs, optimizing performance and reducing the likelihood of injury on top-level players (Fox et al., 2017; Vanrenterghem et al., 2017). Its importance has been recently reinforced, since FIFA has approved the use of specific microsensors and wearable devices in official soccer and futsal matches, opening new perspectives for the understanding of players' physical performance during competitive scenarios (Roell et al., 2018).

To better perceive the load that players experience during a match, internal load (IL), and external load (EL) should be measured and characterized (Buchheit, 2014; Clemente et al., 2019; Fox et al., 2017). While IL describes the physiological effects of training on the athlete, EL describes the physical demands of training through measures derived from position data, and/or inertial measurement units (IMUs; Gonçalves et al., 2014; Impellizzeri et al., 2019). Actually, the available technology allows establishing individualized performance profiles through the analysis of IL and EL variables and specific algorithms that allow the use of other parameters, like Player Load (PL™), or Metabolic Power (MP™; Bourdon et al., 2017; Illa et al., 2020; Polglaze & Hoppe, 2019; Reche-Soto et al., 2019). External load could be classified into three main categories: (a) kinematics, which quantifies overall movement during exercise; (b) mechanical, which describes a player's overall load during exercise; and (c) metabolic, which quantifies overall movement energy expenditure during exercise (Rossi et al., 2018). The parameters can also be expressed in absolute (total match time) or relative (effective playing time) terms. Still, with the great amount of data available to measure physical load, the challenge is to understand the most reliable and relevant variables that should be collected to characterize activity profiles of players during training sessions and matches (Buchheit & Simpson, 2017).

The scientific knowledge about EL and activity profiles of futsal players is still scarce (Beato et al., 2017; Naser et al., 2017; Taylor et al., 2017). To the best of our knowledge, only five studies have investigated physical demands data in elite futsal players (official matches): one in the Spanish Professional Futsal League—analysis of distances covered and heart rate (Barbero-Alvarez et al., 2008); one in Australian futsal players—analysis of match demands between levels of competition (Doğramacı et al., 2015); and three in Brazil—analysis of sprints (Caetano et al., 2015), distances covered (De Oliveira Bueno et al., 2014), and distances covered, maximum speeds, and heat maps of player displacements (de Pádua et al., 2017). Additionally, most of these studies were developed specifically for physical testing or during simulated games and only reported average values of some EL parameters. From this perspective, more research is required that accurately inform about the physical load experienced by players (Akenhead & Nassis, 2016), as well as data that may help to quantify it.

In this sense, the present study aimed to characterize the EL of elite futsal match play. In addition, data were computed to identify the external workload metrics that distinguish different futsal players' profiles. The collinearity between EL variables was also analyzed. We expected to identify different profiles of play according to players' EL, aiming to improve the understanding of match-play demands in futsal.

4.2 Material and Methods

4.2.1 Subjects

Twenty-eight elite male futsal players (age: 24.1 _ 3.4 years) from eight futsal teams that participated in the Final Eight of the Portuguese Futsal Cup 2018 (January 2018) accepted to participate in this study. Inclusion criteria were the following: (1) is a field player; (2) did not report any physical limitations or skeletal muscle injury that could affect performance; and (3) played in both halves in each match. All matches were played in the same neutral indoor multisport court. The study protocol followed the guidelines and was approved by the local Ethics Committee of Universidade da Beira Interior (CE-UBIPj-2018-029) and conformed to the recommendations of the Declaration of Helsinki.

4.2.2 Design

An observational research was used to measure and analyze the EL of players who participated in the Final Eight of the Portuguese Futsal Cup 2018. Four matches in the quarterfinals and two matches in the semi-finals of the competition at least 48 h apart were used for the analysis. According to the official futsal rules, two halves of 20 min of effective time were played.

4.2.3 Methodology

Players' activity was assessed using IMUs with ultra-wideband (UWB) tracking system technology from WIMU PRO™ (Realtrack Systems, Almeria, Spain). The sampling frequency of WIMUs for the positioning system was 18 Hz. The devices were turned on about 10 to 15 min before the warm-up and placed on players with a specific custom neoprene vest located on the middle line between the scapulae at C7 level. The system has six UWB antennas, placed 4 m outside the court, and operates using triangulation between the antennas and the units to derive the X and Y coordinates of each unit. Data from the beginning to the end of the match with the exclusion of halftime and time-outs were analyzed using SPRO Software (Realtrack Systems SL, Almeria, Spain). The accuracy and reliability of these devices have been previously reported and validated (Bastida-Castillo et al., 2019). From positional data, variables were extracted based on the three main categories of EL identified (Rossi et al., 2018): (a) kinematics; (b) mechanical; and (c) metabolic. See **Table 3** for details of each variable considered. The absolute and the relative (effective playing time - clock time) values of each variable were calculated.

4.2.4 Statistical Analysis

Normality of the data was tested with the Kolmogorov–Smirnov test. Since normal distribution was not found in all situations, we used the Wilcoxon rank test to identify differences between each half. Mean ± standard deviation (SD) for full-match data and median (Md) and interquartile range (IR) for the first and second halves were calculated.

A two-step cluster with log-likelihood as the distance measure and Schwartz's Bayesian criterion was performed to classify athletes according to their performance profiles over the entire match. The analysis was used to classify the players' performance and to identify the variables that maximized group distances.

This method differs from traditional clustering techniques by the handling of categorical variables (assuming variables to be independent), automatic selection of the number of clusters, and scalability (Tabachnick & Fidell, 2017). Through an ANOVA test, variables were ranked according to the predictor's importance, indicating the relative importance of each predictor in estimating the model (the sum of the values for all predictors on the display is 1). In the functional sense, the predictor importance of each variable provides different weights to support the cluster distribution. A cut-off level of 0.4 was chosen.

Spearman's correlation test was used to verify the collinearity between variables. Data exploration was conducted based on the correlation matrix that is produced with the "corrplot" function in the R programming language. The criteria adopted to categorize magnitudes of correlations (r) were as follows: _0.1, trivial; >0.1–0.3, small; >0.3–0.5, moderate; >0.5–0.7, large; >0.7–0.9, very large; and >0.9–1.0, almost perfect (Cohen et al., 2013). Correlograms were used, with the intensity of the colour increasing as the correlation moves further away from zero. Here, the correlation coefficients were overlain on each symbol, with "red" symbols being used to denote a negative coefficient and "blue" symbols used to denote a positive coefficient.

Table 3. External load variables recorded in this investigation

Type	Variable	Sub-Variable	Unit	Description
Kinematics	Distance covered (m)	Total	m	Total distance covered in meters
	Relative distance covered (m.min^{-1})	Total	m/min	Total distance covered in meters per minute
		Walking	[0-6 Km/h] m/min	Total distance covered between 0-6 Km/h per minute
		Jogging	[6.1-12Km/h] m/min	Total distance covered between 6.1-12 Km/h per minute
		Running	[12.1-18 Km/h] m/min	Total distance covered between 12.2-18 Km/h per minute
		Sprinting	[18.1-30 Km/h] m/min	Total distance covered between 18.1-30 Km/h per minute
	Sprints (n.min)	Total	SPR/n/min	Frequency >18 Km/h during >1s in 1-min window
	Maximum speed (Km/h)	Max	$Speed_{AVG}$	Average max speed
Mechanical	Impacts (Imp/min)	Total	IMP/n/min	Total impacts recorded per minute above 5g force
	Accelerations (n/min)	Total	ACC [>2 m /s^2] n/min	Total positive speed changes per minute
	Decelerations (n/min)	Total	DEC [>-2 m/s^2] n/min	Total negative speed changes per minute
	Jumps (n/min)	Total	JUM/n/min 400ms flight time	Total number of jumps recorded per min
	Dynamic Stress Load (a.u)	Total	DSL/a.u/min	Total of the weighted impacts of magnitude over 2g per/min
	Player Load (a.u)	Total	PL/a.u/min	Accumulated accelerometer load in the 3 axes of movement
Metabolic	Power Metabolic (W/Kg)	Total	MP/min	Product of speed and energy cost of the activity derived from inclination and acceleration
	High Metabolic Load Distance (W/Kg)	Total	HMLD/min	Distance travelled by a player when the metabolic power is >25.5 W/Kg (corresponds to a speed greater than 5.5m/s or 19.8 km/h)

4.3 Results

Physical Demands of Futsal

The analysis of absolute kinematic, mechanical, and metabolic variables revealed statistical differences between halves only for MP™ with the first half requiring more energy expended by players than that in the second half (see **Table 4**).

The analysis of relative kinematic, mechanical, and metabolic variables revealed differences between halves for running (12– 18 km/h), with the second half revealing higher distance covered than the first half. Also, dynamic stress load (DSL) was higher in the second half than in the first half (see **Table 5**).

Table 4. Descriptive statistics of absolute values observed during the 1st and 2nd halves

	Full match M ± SD	1st half MD (IR)	2nd half MD (IR)	Wilcoxon W	*p*
		Kinematics			
Total distance covered	3749 ± 1123	1875 (1179)	1674 (1049)	1.37	.18
Walking (0-6 km/h)	1645.1 ± 442.9	792.7 (374.4)	759.4 (398.1)	0.72	.48
Jogging (6-12 km/h)	1321.5 ± 479.8	674.4 (465.4)	555.7 (547.9)	1.29	.21
Running (12-18 km/h)	675.3 ± 298.1	328.6 (271.5)	317.5 (237.1)	1.60	.12
Sprinting (>18 km/h)	134.9 ± 54.1	73.1 (56.8)	54.8 (55.7)	1.20	.23
Maximum Speed (km/h)	20.3 ± 1.7	20.4 (1.7)	20.6 (2.1)	0.33	.74
		Mechanical			
ACC (N/min)	87 ± 49	44 (43)	34 (36)	1.43	.16
DEC (N/min)	80 ± 32	40 (35)	36 (33)	0.23	.82
Jumps (N)	9 ± 4	3 (5)	4 (2)	0.33	.75
Total impacts (N)	501 ± 388	219 (256)	194 (241)	1.33	.19
Player Load (a.u.)	72.1 ± 22.8	36.1 (19.1)	33.9 (14.7)	2.02	.05
DSL (a.u.)	673.9 ± 247.7	314.9 (221.9)	340.6 (263.7)	-0.27	.78
		Metabolic			
Metabolic Power (W/Kg)	13.96 ± 3.09	7.9 (2.4)	6.5 (2.4)	3.73	.00*
HMLD (W/Kg)	655.79 ± 313.80	301.7 (252.9)	325.4 (263.7)	-0.95	.35

*$p < .001$ significant difference; M=mean; SD=standard deviation; Md=median; IR=Interquartile range

Table 5. Descriptive statistics of relative values observed during the 1st and 2nd halves

	Full match M ± SD	1st half MD (IR)	2nd half MD (IR)	Wilcoxon W	*p*
		Kinematics			
Distance covered/ min	232 ± 71	216 (55)	229 (86)	-1.42	.16
Walking/min (0-6 km/h)	108.3 ± 51.5	92.5 (30.5)	110.8 (54.8)	-1.24	.22
Jogging/min (6-12 km/h)	76.5 ± 24.3	79.5 (16.5)	77.9 (17.9)	-0.54	.59
Running/min (12-18 km/h)	30.0 ± 19.2	15.7 (26.4)	38.6 (12.3)	-5.13	.002*
Sprinting/min (>18 km/h)	8.5 ± 7.9	7.4 (3.8)	7.3 (5.4)	-1.05	.30
Sprints (N/min)	2 ± 1	2 (2)	2 (2)	0.84	.41
		Mechanical			
ACC (N/min)	5 ± 2	5.2 (2)	5.1 (2)	0.48	.63
DEC (N/min)	5 ± 2	5 (2)	5 (2)	-0.77	.44
Jumps (N/min)	0.8 ± 1.1	0.4 (0.5)	0.5 (0.9)	-1.76	.09
Total impacts (N/min)	35 ± 35.2	29 (22.4)	30 (28.1)	0.00	1.00
Player Load (a.u/min)	4.5 ± 2.3	4.1 (1.3)	4.3 (1.8)	-0.93	.36
DSL (a.u/min)	15.0 ± 8.5	11.2 (13.4)	15.1 (13)	-2.73	.004*
		Metabolic			
Metabolic Power/min (W/Kg)	6.9 ± 1.7	0.9 (0.6)	0.9 (0.8)	1.13	.27
HMLD/min (W/Kg)	22.8 ± 10.6	22.2 (18.3)	23.7 (7.2)	-0.94	.35

*$p < .005$ significant difference; M=mean; SD=standard deviation; Md=median; IR=Interquartile range

Cluster of Physical Profiles of Futsal Players

The cluster analysis classified the players into three distinct groups according to their physical profiles as higher, medium, and lower (**Table 6**), containing 4.5, 84.2, and 11.2% of the cases, respectively. The deceleration per minute (mechanical variable), walking per minute, sprinting per minute, jogging per minute, distance covered per minute, and MP™ per minute were in descending order as variables that most contributed to the discrimination of the physical profiles of players. Deceleration per minute revealed significant differences between all profiles ($p < 0.001$), while the other reported variables only revealed significant differences between higher and medium and between higher and lower profiles ($p < 0.05$). High metabolic load distance (HMLD) was the most homogeneous variable, with a low predictor importance value.

Table 6. Classification of cluster physical profiles of futsal players

Variables	Higher M ± SD	Medium M ± SD	Lower M ± SD	Sig. (*p*)	PI
		Kinematics			
Distance Covered/ min	364 ± 180	231 ± 46	185 ± 102	**,++	0.992
Walking/min (0-6 km/h)	249.2 ± 120.3	100 ± 29.5	114.7 ± 64.2	**,++	1
Jogging/min (6-12 km/h)	82.2 ± 67.3	80.5 ±13.2	43.9 ± 37.8	+, #	0.997
Running/min (12-18km/h)	49.8 ± 53.5	30.8 ± 15.3	16.1 ± 17.6	+	0.825
Sprinting/min (>18km/h)	26.7 ± 31.5	8.2 ± 3.18	3.9 ± 3.3	**, ++	1
Sprints (N/min)	3.0 ± 1.0	2.0 ± 1.0	2.0 ± 1.0		0.126
		Mechanical			
ACC (N/min)	5 ± 1	6 ± 2	3 ± 2	##	0.979
DEC (N/min)	10 ± 4	5 ± 1	2 ± 2	**, ++,##	1
N. º of jumps (N/min)	1 ± 1.3	0.6 ± 0.6	0.5 ± 0.46		0.376
Total impacts (N/min)	42 ± 27	29 ± 16	75 ± 86	##	0.968
Player Load (a.u/min)	4.3 ± 0.7	4.3 ± 1.3	6.2 ± 5.7		0.634
DSL (a.u/min)	20.7 ± 11	14.4 ± 7.9	17.2 ± 11.2		0.312
		Metabolic			
Metabolic Power/min	16.9 ± 32.5	1.4 ± 2.6	1 ± 0.6	**, ++	0.989
HMLD/min	24.8 ± 2.3	22.9 ± 11.2	21.3 ± 7.6		0.077

M= Mean; SD= Standard Deviation; PI = Predictor importance; * p<0.05 Higher with Medium; **p<0.001 Higher with Medium; + p<0.05 Higher with Lower; ++p<0.001 Higher with Lower; # p<0.05 Medium with lower; ## p<0.001 Medium with Lower

Collinearity Between EL Variables

Figure 2 presents the level of magnitude of correlations between all the variables used in this study. The variables that showed the highest number of associations were distance covered per minute, deceleration per minute, MP per minute, and jogging per minute. In turn, total impacts per minute, PL™ per min, DSL per minute, and number of jumps per minute did not show any type of correlation with others. The only negative correlation was found between MP™ per min and jogging per minute.

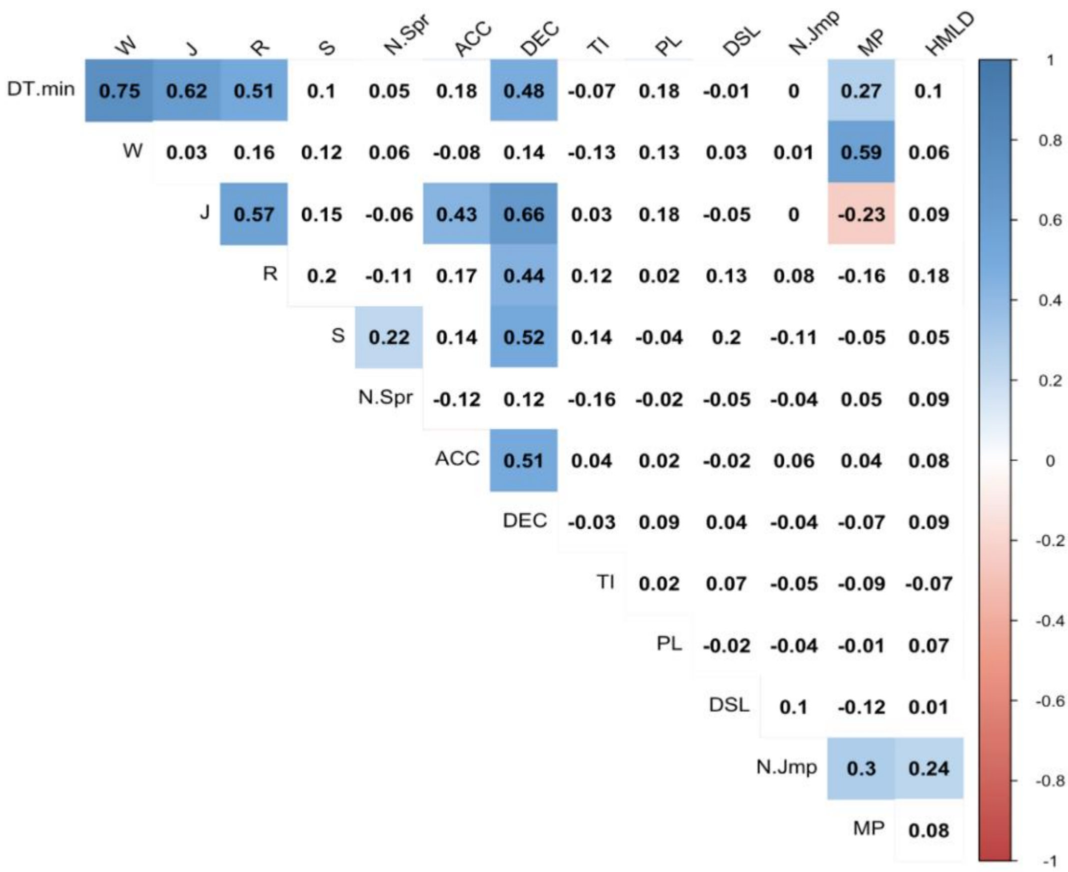

Figure 2. Correlation matrix between external load variables

4.4 Discussion

The aim of the present study was to describe EL of futsal match play and identify the differences between the first and second halves. In addition, data were used to identify the external workload metrics that distinguish different futsal players' profiles. At the end, the collinearity between external workload variables was also analyzed. To the best of our knowledge, this is the first study in official futsal competitions, and consequently, this is the first report on the kinematic, mechanic, and metabolic variables that characterize the physical load of futsal. Generally, no meaningful differences were detected between halves. It was possible to identify three futsal players' profile, based on the results of the following variables: deceleration per minute, walking per minute, sprinting per minute, jogging per minute, distance covered per minute, and MP™ per minute.

Also, the explorative analysis of the collinearity between EL variables allow us to identify the variables that have substantial impact to describe futsal physical demands in a simple way (Buchheit and Simpson, 2017). Distance covered per minute, deceleration per minute, jogging per minute, and MP™ per minute were the variables that revealed a higher correlation with other variables.

Futsal Game Characterization

In contrast to previous studies (Barbero-Alvarez et al., 2008; De Oliveira Bueno et al., 2014), no significant differences in EL were observed between the first and second halves of futsal matches. It seems to corroborate the most recent results in futsal in which no significant differences between the first and second halves were reported in IL indicators such as lactate and maximum heart rate values (Milioni et al., 2016). Such results relaunch the discussion about the capability of futsal players to maintain or even increase their physical performance during the entire match. The fact that futsal is characterized by unlimited substitutions and the score of the game may remain uncertain until near the end could be decisive for such results.

The comparison between absolute and relative workloads revealed different trends. Despite there being no statistical differences, there was a general decrease in the absolute values during the second half compared to the first half. In contrast, the relative values revealed a general increase in physical load per minute with clear higher values of running and DSL in the second half compared to the first half. These findings highlight the use of relative measures as more accurate information about the players' intensity according to their participation in the game (Barbero-Alvarez et al., 2008; Whitehead et al., 2018). In this sense, it is clear that the ability to perform high-intensity actions remains during the entire match. In line with previous research, the average sprints (maximum speed) and the number of sprints remained stable between halves (De Oliveira Bueno et al., 2014). However, an interesting finding from this research was the higher distance covered per minute when compared to past research (Barbero-Alvarez et al., 2008; De Oliveira Bueno et al., 2014; Doğramacı et al., 2015). In fact, approximately twice more distance was covered per minute, and a higher number of sprints were performed.

The present study showed an average value of maximum speed of 20.3 km/h, with peak values of 22.6 km/h. The average values of peak sprinting speed is lower when compared with the values (23.8 km/h) reported in a previous report (de Pádua et al., 2017). Such results could be justified by a general increase in the work intensity of players in the last years, as well as by potential differences between leagues.

It is commonly accepted that mechanical variables such as accelerations and decelerations are the most important variables to be tracked in futsal, since they refer to a more neuromuscular and biomechanical-oriented type of load (Buchheit & Simpson, 2017). As in soccer, in futsal, due to the small space of action, the ability to accelerate and decelerate is considered decisive during critical actions, including changing direction, or rhythm in response to opponents' actions, reaching the ball, and breaking movements to create space and generate or deny goal opportunities (Arruda et al., 2015). As far as we know, only one study reported mechanical and metabolic demands in futsal. However, it was developed with a female team from the Italian second division (Beato et al., 2017). Our results reported higher absolute values of accelerations and decelerations and similar values for metabolic demands in comparison with those of the female team (Beato et al., 2017).

Futsal Player´s Profile

Futsal is characterized by a set of high-intensity efforts that require players with a high level of athletic performance in a multitude of physical abilities (Amani-Shalamzari et al., 2019; Caetano et al., 2015; Miloski et al., 2016). However, little information and consensus exist about the individual physical profile of futsal players. Identifying the variables that best discriminate the physical profiles of elite futsal players provides important data for the prescription and training periodization, thus highlighting the importance of analyzing and monitoring the physical demands of the match of each player according to their specific profile (Rago, Brito, Figueiredo, Costa, et al., 2020; Wilke et al., 2019). Results of cluster analysis revealed three different groups with higher, medium, and lower levels of physical activity. Most of the players analyzed were classified as medium profile. The physical profiles of elite futsal players were discriminated by one mechanical variable (deceleration per minute), four kinematic variables (distance covered per minute, walking per minute, jogging per minute, and sprinting per minute), and lastly one metabolic variable (MP™ per minute). Indeed, it seems that accelerations and decelerations could be used as reliable measures of different activity profiles of players (Arruda et al., 2015; Cormack et al., 2014). This method may allow grouping of players according to their physical and recovery profiles to understand if a slower or faster recovery can be related to different physical profiles (Wilke et al., 2019). Further research is required to improve the understanding between physical and technical–tactical profiles of play. In line with that, such information can also be used for the evaluation and development of young elite futsal players.

External Workload Metrics: Collinearity Between Variables?

To improve the understanding of each variable and reduce the noise in the analysis, it is essential to simplify the results and improve their interpretation to provide reliable and useful information for coaches and strength-conditioning professionals (Buchheit & Simpson, 2017). For that, collinearity analysis between variables is crucial. Our results revealed that, in general, there were higher correlations between the distance covered per minute (kinematic), deceleration per minute (mechanical), and MP™ per minute (metabolic), and other variables. In addition, the distance covered per minute and jogging per minute were the unique variables that revealed significant correlations with kinematic, mechanical, and metabolic variables. In the end, deceleration per minute revealed a high significant correlation with all kinematic variables except for walking per minute.

Regarding the analysis of kinematic variables, the distance covered per minute revealed significant correlations with walking per minute, jogging per minute, and running per minute, which means that distance covered per minute might be computed to generally represent all running speed thresholds between 0 and 18 km/h. So, behind distance covered per minute, it is necessary to monitor distance covered above 18 km/h, in order to characterize all the speed thresholds considered. This evidence is in line with the importance and the need to individualize speed thresholds to provide an insight into players' physical response to training and enable comparisons between player profiles (Rago, Brito, Figueiredo, Krustrup, et al., 2020). Analysis of mechanical variables revealed that deceleration per minute revealed a significant correlation with acceleration per minute. Thus, considering that deceleration per minute was highly associated with almost all kinematic variables, it may suggest that it is a more robust variable for analyzing the physical load of players during futsal training sessions and matches (Cormack et al., 2014). Therefore, it has a large association with the speed threshold of sprinting per minute, which is associated with an increase in heart rate variability, thus being able to play an important role as an indicator of good aerobic fitness (Buchheit, 2014).

The analysis of metabolic variables revealed that only MP™ per minute demonstrated a positive correlation with kinematic variables (distance covered per minute and walking per minute) and a negative correlation with jogging per minute. This evidence suggests that MP™ per minute might be less sensitive to peak demands. Thus, such a variable should be included in the analysis of physical demands of the futsal game as a complement to kinematic and mechanical variables that evaluate high match play requirements (Polglaze & Hoppe, 2019). However, some caution while using this variable is advised as it does not agree with the literature (Gray et al., 2018).

Limitations

As a possible limitation of the present investigation, we acknowledge that the sample size and number of matches should be larger in order to increase the power of the results (Lupo & Tessitore, 2016). In turn, the fact that it is a sample made up of elite players allows us to investigate the data of highly competitive demands. Thus, further research should be developed considering the influence of different contextual and situational variables in players' EL, such as the evolution of match status and style of play (Lago-Peñas & Gómez-López, 2014). It would also be interesting to understand the worst-case scenarios (i.e., peak demands) for some EL variables, in order to prepare players for these specific moments of match play.

4.5 Conclusions and Practical Applications

Overall, similar values were observed in most of the external variables between the first and second half. Interestingly, while the use of absolute results revealed a trend for a decrease from the first to the second half, in turn, the opposite was revealed when relative variables were analyzed according to the effective time of play of each player. Thus, relative measures to evaluate EL in futsal might be preferable, as it allow comparisons between studies and may also contribute to enhancing the comparison between players' performance in both training sessions and matches.

The analysis of players' profiles revealed that deceleration per minute, walking per minute, sprinting per minute, jogging per minute, distance covered per minute, and MP™ per minute were the variables that best discriminated the profiles between players. Such results could help to better discriminate the individual training needs of each player and thus to adjust the prescription of training sessions. At the end, the explorative analysis of the collinearity between EL variables revealed that the distance covered per minute, deceleration per minute, and MP™ per minute were the variables that revealed a higher correlation with other variables. Specifically, it was observed that distance covered per minute and deceleration per minute discriminate intensity while MP™ per minute discriminated the volume of EL demands. Thus, to ensure a reliable analysis of EL demands in futsal, it is not necessary to measure all variables but rather consider those that better reflect the intensity of match play. The transfer of this evidence to the training process is very significant; insofar as knowing the intensity of the match and which variables best characterize it, coaches can concretely manipulate and adjust the physical requirement of practice tasks during the microcycle to match demands in order to optimize players' performance and reduce the risk of injury.

5. Variation in Physical Performance of Futsal Players During Congested Fixtures

Ribeiro, J. N., Monteiro, D., Gonçalves, B., Brito, J., Sampaio, J., & Travassos, B. (2021). Variation in physical performance of futsal players during congested fixtures. *International Journal of Sports Physiology and Performance, 17*(3), 367-373

5.1 Introduction

Futsal is a 5vs5, intermittent, high-intensity, indoor team sport involving short, high-intensity actions, such as accelerations (ACCs), decelerations (DECs), changes of direction, and sprints with short recovery time between efforts (Illa et al., 2021; Impellizzeri et al., 2019; Ribeiro et al., 2020). In fact, futsal players need to have or develop a great capacity for agility and explosive strength of the lower limbs (Naser et al., 2017).

Interestingly, most futsal international competitions and playoffs of the main leagues around the world are played in congested periods with matches played with very short recovery times. The current knowledge about the demands of congested fixtures in team sports has increased the interest of medical and technical staff in developing strategies to improve performance and reduce the probability of injuries (Doeven et al., 2021; Nassis & Gabbett, 2017). When teams play 2 to 3 matches per week, the stress imposed on the players increases; therefore, congested fixtures might increase fatigue levels and injury risk (Bengtsson et al., 2013; Nedelec et al., 2014; Spyrou et al., 2020) Also, performance and muscle function might be affected due to the increased levels of inflammation and muscle damage (Moreira et al., 2016; Mujika et al., 2018).

The concerns about congested periods have been largely debated in the literature of match analysis in football (Gualtieri et al., 2020; Yiannaki et al., 2020) On the other hand, research available on the impact of futsal match play in short congested periods is very scarce and remains unclear. To date, only 2 studies have examined the physical performance of futsal players in congested match periods (Charlot et al., 2016; Dogramaci et al., 2012). Charlot et al., (2016) analyzed the intensity of matches on a 4-day FIFA futsal tournament and reported no differences in heart rate, recovery kinetics, and well-being but a small decrease in sprinting activity between matches. In turn, a second study revealed a general small decrease in sprinting and an increase in walking activity of players after a multiday futsal tournament (Dogramaci et al., 2012) Further information is required to understand the impact of congested fixture periods on the physical performance of elite futsal players (Carling et al., 2016; Dellal et al., 2015).

Most traditional approaches to match analysis in team sports use central tendency measures without considering intraindividual variability between players. However, it is necessary to consider the nonlinear responses of each player during match play2 according to playing time variations caused by coaching decisions, disruptions, and substitutions in futsal (Carling et al., 2016; Mujika et al., 2018). For this purpose, we used the latent growth curve (LGC) modelling: a structural equation modelling technique for longitudinal data that helps to characterize the interplayer and intraplayer growth trajectories (intercept and slope) over the matches (Wu et al., 2009). Such models have

been used on different sports for the evaluation of youth players' development (Coppens et al., 2019; Morais et al., 2014).
The aim of this study was to evaluate the longitudinal variation of physical performance (ie, external and internal load) of elite male futsal players over a short congested period during two 4-day FIFA futsal world cup qualifiers, encompassing 2 periods of 3 games in 4 days. Through the LGC model, we expected to identify interindividual variability and the average growth between each match (Wu et al., 2009).

5.2 Methods

5.2.1 Subjects

The participants were elite male futsal players from the Portuguese National team (n = 12, aged 29.6 [3.9] y). Data were collected in two 4-day periods of the qualifiers for the 2020 FIFA Futsal World Cup. Each period comprised 3 matches. A total of 6 matches against 6 different opposing teams were considered. Players performed 3 matches at each congested period in different moments of the season (match day—1 [MD1], match day—2 [MD2], and match day—3 [MD3]). From MD1 to MD2, there was a 24-hour recovery time, whereas from MD2 and MD3, recovery time was 48 hours. This resulted in 3 matches within 4 days. The characteristics of the matches are presented in Table 7.
Inclusion criteria were the following: (1) outfield player, (2) any report of physical limitations or skeletal muscle injury that could affect performance, and (3) only data from participants who played >5 minutes were analyzed. Goalkeepers were excluded from the analysis. Players were informed that they were free to withdraw their individual data from the study at any time. Written informed consent obtained from all individual participants was included in the study. The study protocol was approved by the local ethics committee of University of Beira Interior (CE-UBI-Pj-2018- 029) and conformed to the recommendations of the Declaration of Helsinki. To ensure player confidentiality, all data were anonymized prior to the analysis.

5.2.2 Procedures

An observational, descriptive research design was used to analyze physical performance of elite male futsal players. Players' activity was assessed using inertial measurement units with ultrawideband tracking system technology (WIMU PRO™; RealTrack Systems, Almeria, Spain). The sampling frequency of the tracking system was 18 Hz. The units were turned on about 10 to 15 minutes before the warm-up and worn by players in a specific custom neoprene vest located on the middle line between the scapulae at C7 level. The system has 6 ultrawideband antennas, placed 4 m outside the futsal court, and operates using triangulation between the antennas and the units to derive the X and Y coordinates of each unit. Data from the beginning to the end of each match, except half time and timeouts, were analyzed using corporative software (SPRO Software; RealTrack Systems). The accuracy and reliability of the system have been reported and validated elsewhere (Bastida-Castillo et al., 2019).

Table 7. Characteristics of qualifying tournament matches

Match	Score	Match outcome
Congested period 1		
MD 1	4-0	Win
MD 2	5-0	Win
MD 3	4-1	Win
Congested period 2		
MD 1	2-1	Win
MD 2	2-2	Draw
MD 3	4-1	Win

Abbreviations: MD1, match day—1; MD2, match day—2; MD3, match day—3.

5.2.3 Measures

The measures of physical performance were classified into external and internal load. External load was measured to identify the capacity of players to maintain highly demanding critical actions over the match in 2 dimensions (Rossi et al., 2018): kinematic and mechanical. Kinematics variables included total distance covered (TDC; in meters), and 2 thresholds were used to evaluate the distances covered in 2 categories of intensity: high-speed running (HSR, 12.1–18 km/h) and sprinting (>18 km/h). Mechanical variables consisted of the number of ACCs (>3 m/s^2) and DECs (> −3 m/s^2).
The selected variables granted a reliable analysis of the most demanding actions required to maintain high levels of performance in futsal (Gualtieri et al., 2020; Serrano et al., 2020). Data were normalized according to the effective playing time of each player during each match (ie,m/min or n/min). To quantify internal load, the rate of perceived exertion (RPE) was used (Borg & Löllgen, 2001). Each player was asked about the global perceived intensity approximately 10 minutes after each match using a scale from 0 to 10, with 0 corresponding to "rest" and 10 to "maximal effort" (Foster et al., 2001). The RPE scores were used to determine the RPE of the session (s-RPE), which was calculated by multiplying the RPE score by the duration of the playing time (in minutes) of each player.

5.2.4 Statistical Analysis

The Shapiro–Wilk test was performed to identify the data distribution. Descriptive statistics including mean and SD were calculated for all studied variables. To analyze the interindividual and intraindividual longitudinal changes of the physical performance of futsal players over the congested fixtures, an LGC model was used. According to Byrne et al., 2016 there are 2 major advantages in testing for individual change with the framework of the structural equation modelling: (1) this approach is based on the analysis of mean and covariance structure and (2) a distinction can be made between observed and unobserved (or latent) variables in the specification of models. In addition, this type of analysis is characterized by estimating intraindividual (growth parameters intercept and slope) and the interindividual (differences among subjects) growth paths (Hair et al., 2019). The intercept and slope are latent variables, which means that they are not directly observed but, rather, inferred. The intercept determines the interindividual differences of participants' performance at the baseline (first match), that is, significant values of intercept suggest the existence of interindividual performance differences in MD1. The slope expresses the different individual trajectories of performance through each game in the congested period, that is, significant values of slope suggest the existence of interindividual performance differences between moments. Thus, it shows the differences between the observed games in congested fixtures and whether interindividual variability exists or not (Byrne, 2016). The covariance between the intercept and slope can reveal the relationship between the initial result (MD1) and the level of growth for MD2 and MD3. A negative result suggests that (high) initial values promoted low growth, and a positive result suggests that (high) initial values promoted high growth between the moments of analysis. A dummy variable designated by playing time was created and included in the model as predictor of growth to generate the following groups: group 1—more playing time (players with an average playing time equal to or greater than the average playing time) and group 2—less playing time (players with an average playing time less than the average playing time) (see Table 8 for more details). Considering the low number of degrees of freedom (df) in the model analyzed, the model adequacy was verified through the normalized chi-square (χ^2/df), and the following cutoff values were adopted: $5 < \chi^2/df$, poor adjustment; $2 < \chi^2/df \leq 5$, reasonable adjustment; $1 < \chi^2/df \leq 2$, good adjustment; and χ^2/df approximately 1, very good adjustment. Besides that, a multigroup analysis was performed to verify how important playtime was to the model, as recommended by Byrne et al., 2016. Therefore, 2 models were created: (1) model with playing time effect and (2) model without playing time effect. The differences between 2 models were assessed via $\Delta\chi^2$, $P > .05$ (Byrne, 2016). The computer software IBM SPSS AMOS (version 20.0) was used to process all models.

Table 8. Descriptive Statistics for the considered variables

Variables	MD1			MD2 (24h)			MD3 (48h)		
	All players	More playing time	Less playing time	All players	More playing time	Less playing time	All players	More playing time	Less playing time
Playtime (min)	14.2±5.6	18.6 ± 3.9	8.7 ± 3.6	14±5.5	18.7 ± 3.6	8.9 ± 2.9	14.2±7.3	19.3 ± 4.1	6.7 ± 3.1
EL TDC (m/min)	211.6±71.5	155.9 ± 41.1	338.7 ± 199.7	256.3±76.2	225.8 ± 23.0	344.4 ±139.8	265±110.1	206.0 ± 37.2	369.2 ± 129.2
HSR (m/min)	31.4±12.4	25.0 ± 11.0	35.2 ± 11.5	34.1±10.4	35.5 ± 8.6	33.8 ± 12.1	35.8±16.9	33.4 ± 12.8	33.4 ± 23.8
SPR (m/min)	6±4	3.6 ± 1.7	9.3 ± 4.4	7.1±3.9	6.8 ± 2.7	7.5 ± 4.9	6.9±4.6	7.4 ± 3.2	5.1 ± 5.9
ACC (n/min)	2.7±2.1	3.1 ± 2.7	5.0 ± 6.4	2.8±2.2	2.4 ± 0.9	3.6 ± 3.2	2.8±2.5	2.7 ± 1.2	5.5 ± 9.6
DEC (n/min)	3.2±3.4	4.2 ± 4.3	9.2 ± 18.0	2.9±2.4	2.3 ± 0.8	3.5 ± 3.3	6.3±6.3	6.2 ±5.0	14.3 ± 15.9
IL s-RPE (a.u)	95.6±67.3	152.5±54.3	47.5±26.9	97.9±61.5	139.7±50.7	48.5±25.5	109.7±71.1	168.7±47.2	39.7±29.5

5.3 Results

A general increase both in internal and external load from MD1 to MD3 (Table 8) was observed for all players. No significant changes were observed according to playing time. In general, players with more competed time revealed lower relative external load metrics and higher internal load than players with less competed time. The goodness-of-fit statistics for all the models with playing time effect can be found in Table 9. The variable sprinting was not included in any model because the results were not significant ($P > .05$) and the model presented a poor fit ($\chi2/df = 7.78$). The analysis of the proposed models revealed a reasonable adjustment for HSR (model B), whereas all the analysis of other variables revealed an excellent, well-fitting adjustment.

The variance of intercept and slope was significant for all variables analyzed, suggesting a heterogeneous growth rate of physical performance and, therefore, an interindividual and intraindividual variation from MD1 to MD2 and MD3. The intercept variance at MD1 revealed significant values for TDC ($\beta = 0.83$, $P < .05$), HSR ($\beta = 0.73$, $P < .05$), ACCs ($\beta = 0.77$, $P < .05$), DECs ($\beta = 0.79$, $P < .05$), and s-RPE ($\beta = 0.91$, $P < .05$), suggesting interindividual variability on the performance in MD1. In addition, the standardized indirect effects between playing time and dependent variables trough intercept and slope showed the following significant effects: TDC (M1 = −.51; M2 = −.52; M3 = −.53), HSR (M1 = −.06; M2 = −.11; M3 = −.01), ACCs (M1 = −.24; M2 =−.23; M3 = −.22), DECs (M1 = −.35; M2 = −.18; M3 = −.38), and s-RPE (M1 = .73; M2 = .75; M3 = .84). Indeed, a nonlinear increase in all variables was observed; from MD1 to MD2, HSR increased by 68%, ACCs increased by 88%, and DECs increased by 82%. In opposition to the s-RPE that only increased from MD1 to MD2, 18% of the total performance increased in congested fixtures period (Figure 3).

To further understand the levels of variability between players' performance in MD1 and between moments (MD2 and MD3), playing time was included in the model as a predictor of growth.

Table 9. Multigroup analysis across models analysed

Models	Δx^2	df	p
TDC (Model A)	12.68	2	.222
HSR (Model B)	.28	2	.869
SPR	16.51	2	<.001
ACC (Model C)	2.64	2	.268
DEC (Model D)	4.11	2	.128
S_RPE (Model E)	20.03	2	.323

Abbreviations: ACC, accelerations; DEC, deceleration; HSR, high-speed running; s-RPE, session of rating perceived exertion; SPR, sprinting; TDC, total distance covered.

Playing time revealed a significant effect on physical performance growth with significant paths to intercept and slope for all models (Figure 3). Players who competed for more time revealed lower initial levels (MD1) of TDC ($\beta = -0.62$, $P < .05$), HSR ($\beta = -0.18$, $P < .05$), ACCs ($\beta = -0.31$, $P < .05$), and DECs ($\beta = -0.44$, $P < .05$) and higher s-RPE ($\beta = 0.81$, $P < .05$) than players who competed for less time. Also, players who competed for more time, and revealed lower initial values, revealed a higher increase in TDC ($\beta = 0.47$), HSR ($\beta = 0.16$), and s-RPE ($\beta = 0.66$) and a lower increase in ACCs ($\beta = -0.21$) and DECs ($\beta = -0.58$) than players who competed for less time from MD1 to MD3.

5.4 Discussion

Despite the advances in the knowledge of futsal demands, information regarding the effects of successive matches in physical performance and their relationship with playing time is still scarce. The concerns about fixture congestion are justified based on the likelihood of increasing residual fatigue, risk of injury, and underperformance due to reduced time for appropriate physical recovery.

With that purpose in view, the present study attempted to evaluate the longitudinal variation of physical performance (i.e., external and internal load) of elite male futsal players over a short congested period.

Results revealed that physical performance did not decrease during the short congested period. In opposition, there was a tendency for an increase in physical performance of players over the congested periods in analysis. Also, players who competed for more time revealed a lower external load and a higher internal load in MD1 with a higher increase from MD1 to MD3 in almost all variables in comparison with players who competed for less time. This evidence reinforces the importance of controlling not only the intensity of performance but also the volume to enhance the performance state of each player during the congested periods. Such results are not in line with previous research in futsal in which a decrease of physical performance was observed during congested tournaments (Dogramaci et al., 2012). These differences could be justified by the differences in the congested periods considered in each study.

Dogramaci et al., (2012) analyzed a competition with 6 matches in 3 days and recommended caution when comparing data from different congested fixtures (eg, number of matches vs number of days). In turn, results from Charlot et al., 2016 were partially in agreement with the results presented here by showing stability in physical performance and a slight increase in the subjective perception of players' effort throughout the competition without decreasing the high level of physical performance.

Our results revealed that elite male futsal players have an appropriate level of conditioning and an adequate capacity for the body to recover and regenerate after multiple stress stimuli. More than that, interindividual variability in performance was observed from MD1 to MD3. Even knowing that different players can reveal different recovery profiles (Wilke et al., 2019) in general, all players seemed to maintain the levels of performance between matches. Nevertheless, in future studies, the variations in internal and external load should be interacted with other variables of fatigue and recovery to better understand the real impact of match play in the level of players' readiness.

Interestingly, considering the significant effect of playing time on physical performance growth, it was observed that the players who competed for more time revealed lower intensity per minute in each game but increased their performance (high TDC and HSR) over the congested periods (from MD1 to MD3) more than the players who competed for less time. However, they also revealed higher increase in s-RPE than the players who competed for less time. Corroborating this finding, others authors have noted that the capacity of players to maintain physical intensity between matches in congested periods can be strongly associated with individual strategies of pacing management in a conscious or unconscious way (Julian et al., 2021). Knowing the number of matches needed to successfully perform, players may adjust their performance strategies to preserve energy and maintain the ability to perform high intensity actions (Waldron & Highton, 2014). This is very interesting and reopens a new discussion about the relationship between individual pacing management and playing time of players and the individualization of the load analysis and its variability.

In addition, another interesting finding is that players who competed for more time revealed a lower increase in mechanical variables, including ACCs and DECs, than players who competed for less time fromMD1 to MD3. In fact, the increase on internal load and the associated fatigue did not decrease the kinematic capacity of players to perform but really might have limited the mechanical capability of players to perform ACCs and DECs,

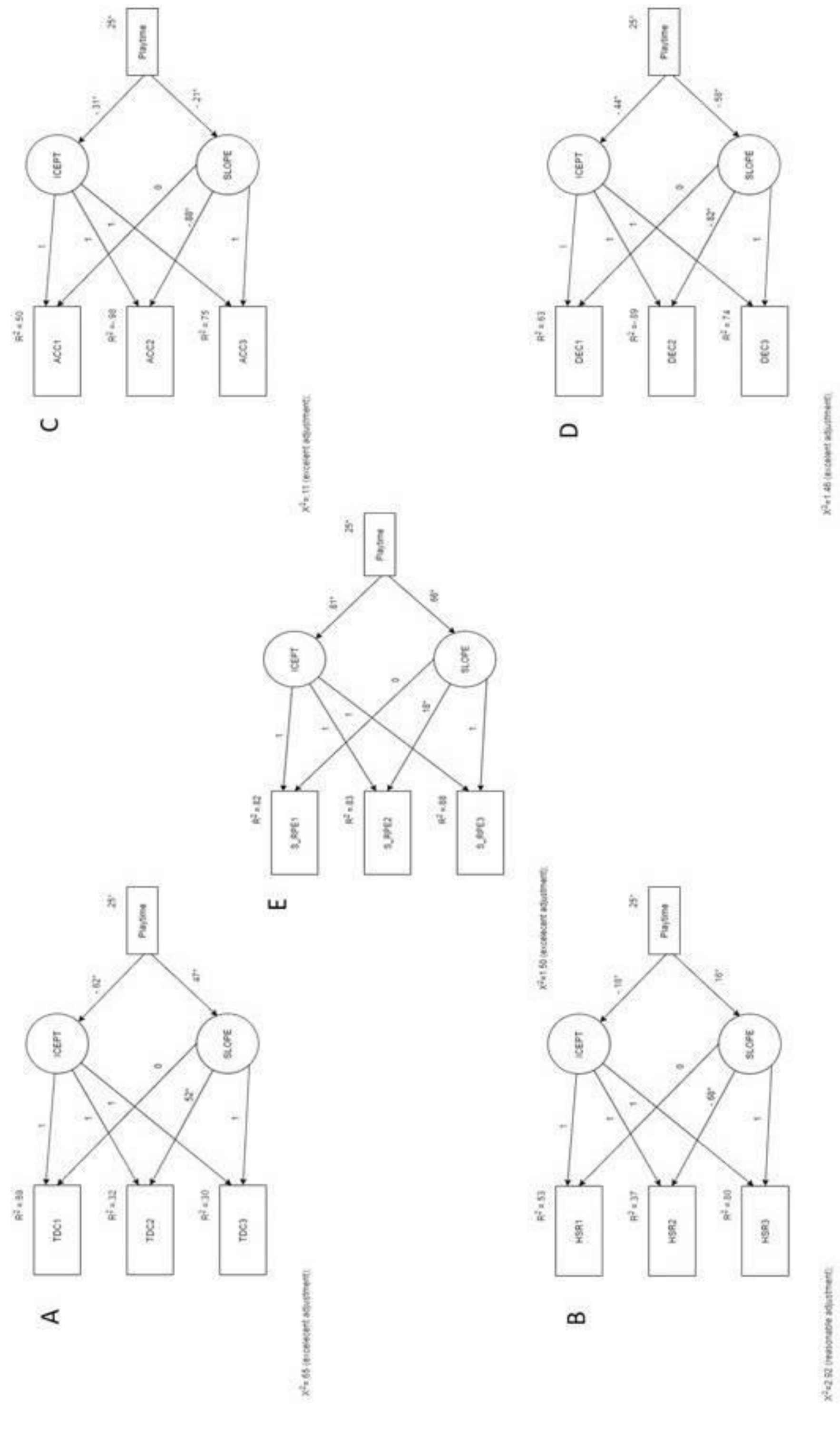

Figure 3. Latent growth curve models for the considered variables. ACC indicates acceleration; DEC, deceleration; HSR, high-speed running; ICEPT, Intercept; s-RPE, session rating of perceived exertion; TDC, total distance covered.

probably due to increased neuromuscular fatigue (Nedelec et al., 2014). Indeed, other researchers noted changes in countermovement jump, high-intensity ACCs (Russell et al., 2016), and hard changes of directions (ie, sudden changes in direction during running) at 24 hours (Nedelec et al., 2014) and in DECs after 48 hours (de Hoyo et al., 2016). Further research is required to evaluate the variation in players' strength and muscle damage over congested fixture periods.

Under this scope, the literature reported a decrement in muscle function, increasing players' muscle damage and inflammation (De Moura et al., 2013), which can remain up to 72 to 94 hours post-match (Nédélec et al., 2013). On the other hand, and knowing the impact of playing time in players' capabilities to perform, it seems that the futsal players were able to manage and increase their performance levels with 24- and 48-hour recovery times between matches. The unlimited rolling substitutions that are allowed in futsal, in opposition to football (Carling et al., 2016; Dellal et al., 2015), and the good management of each player's playing time by the coach can also allow players to suffer lower muscle damage and general fatigue. Also, as noted in football, the issue of the congested fixtures cannot be viewed as a linear problem related to the physical aspects per se.

It is a multidimensional issue in which physical, tactical, and psychological issues interact to constrain the individual performance of each player. Further research is required linking the different dimensions of the problem (physical, technical, tactical, and psychological) for a better understanding of players' adaptations to congested periods. Further analysis should also consider analyzing the performance of teams from lower levels of quality.

The high level of the team included in this study can serve as an important reference concerning physical demands of futsal in congested periods; however, it is also important to understand these trends at lower quality levels.

5.5 Practical Applications

Knowledge transfer from sports science to futsal coaches needs further improvement; a realistic view of the match exertion is needed for the team and each individual player. Coaches who are well informed about variation in players' match exertion are better prepared to find the optimal balance between exertion and recovery and to subsequently prevent underperformance.

Despite the capacity of players to maintain performance over the short-congested fixture periods in analysis, it is suggested that coaches manage players' performance and fatigue based on their individual capabilities. The interplayer variability should be considered in the process of match management and recovering. Technical staff and coaches should develop strategies of monitoring and recovery that allow then to further characterize and understand the individual needs of the players (Wilke et al., 2019).

5.6 Conclusions

The main findings showed that congested periods did not affect match physical performance in futsal. Furthermore, playing time was a key performance factor, thus verifying that player who competed for more time had a lower external load and a higher internal load than players who competed for less time. Following intercept and slope, we observed individual patterns of response where improvements in some external variables were not necessarily associated with improvements in playing time.

There is strong evidence for considerable heterogeneity in the responsiveness to physical performance over congested periods.

This evidence reinforces the idea that analyzing just the average values of the external load metrics may not be sensitive enough to detect patterns of fatigue. The analysis of variability from match to match through LGC modeling allows us to assess real changes/ differences in match play, training intensity, and load. This would eventually facilitate effective planning and timing of subsequent training and recovery sessions to ensure that the required physiological stimuli are applied.

6. Exploring the effects of interchange rotations on high-intensity activities of elite futsal players

Ribeiro, J. N., Gonçalves, B., Illa, J., Couceiro, M., Sampaio, J., & Travassos, B. (2022). Exploring the effects of interchange rotations on high-intensity activities of elite futsal players. *International Journal of Sports Science & Coaching*, 17479541221119659.

6.1 Introduction

Futsal is a team sport characterized by the high-intensity nature of its efforts, as previously described in terms of its high physical demands (Illa et al., 2020; Ribeiro et al., 2020). According to previous research, during a futsal match, players covered approximately 4km, which corresponds to 135 m sprinting (>18km/h) and 3 high accelerations and decelerations per minute (Ribeiro et al., 2022b; Spyrou et al., 2020). Futsal players must achieve fast straight movement speeds by developing power, strength, and agility, which results in a greater ability to sprint, brake, or change direction (Spyrou et al., 2020). Furthermore, the ability to run at high speeds and accelerate/decelerate was the variable with the highest correlation power between different kinematic, mechanical, and metabolic variables, as well as the most important predictor of different activity profiles (Ribeiro et al., 2020). As a result, it can be considered the most direct and reliable predictor of high-intensity activities in futsal (Ribeiro et al., 2020).

However, research has shown that these variables (high-intensity running, accelerations and decelerations) account for a significant component of the high-intensity external load, imposing distinct and disparate physiological and physical demands on players (Vanrenterghem et al., 2017). Furthermore, while accelerations have a higher metabolic cost (Hader et al., 2016), decelerations have a higher mechanical load (Dalen et al., 2016), likely caused by high-eccentric force impact peaks and loading rates promoting damage in soft-tissue structures (Verheul et al., 2021). As such, the frequency of high-speed running actions and high-intensity accelerations/decelerations completed during match play are commonly associated with decrements in neuromuscular performance capacity with higher post-match muscle damage (Harper et al., 2019).

Besides the high demands of futsal matches, recent investigations have found that elite futsal players can maintain physical performance between the first and second half of the match (Ribeiro et al., 2020; Serrano et al., 2020). This evidence has been linked to the fact that players are regularly interchanged on and off the court, allowing for periods of rest interspersed with periods of activity (work-rest ratio). Players' interchange is implemented during futsal matches for a number of reasons; however, given the high-intensity nature of the match, interchanges are arguably most commonly used to delay the onset fatigue (Dos-Santos et al., 2020; Montgomery & Wisbey, 2016).

This idea is supported by other recent research, which found that players performed two interchanges on average in each half, and had similar lactate concentrations (8.46 3.01 vs. 8.17 2.91 mmolL1) and heart rate values (89.61 2.31 vs. 88.03 4.98 percent HRmax) in the first and second halves (Milanez et al., 2020). Furthermore, we know that energy metabolism pathways, particularly system phosphagen, play an important role in futsal (Castagna & Álvarez, 2010), and that adenosine triphosphate-phosphocreatine (ATP CP) replenishes after nearly 3 minutes (Ulupınar et al., 2021), which could be done while players are on the bench.

Previous research in team sports with unlimited substitutions, such as futsal (Barbero-Alvarez et al., 2008; Milanez et al., 2020) (without local positioning systems), basketball (García et al., 2020; Vázquez-Guerrero et al., 2019), and field hockey (McGuinness et al., 2022), produced contradictory results, with the authors confirming a decrease in players' physical performance throughout the game. These disparities in results could be attributed to changes in coaching strategy (type of play of each player; game pace; strategy of play) or other situational and contextual factors (game result; game balance; number of fouls) that slowed the game's pacing or influencing the players' ability to maintain the physical performance. From a strategic standpoint, managing the number and length of player interchanges is critical in futsal in order to anticipate substitutions caused by fatigue, foul trouble, poor performance, tactical changes, or other team strategic factors, and thus achieve positive effects on match outcome (Clay & Clay, 2014; Gómez et al., 2017).

Despite the perceived benefit of such practices, futsal research provides little evidence to support such assumptions. Nonetheless, it is assumed that a variety of situational factors can influence the magnitude of high-intensity activities during the match. For instance, the current time of occurrence within the match half or period, the number of players` interchanges, the minutes played by the player, the accumulated load in the period immediately preceding the high-intensity activities, the strength of the opposition or the current score, among others things (Novak et al., 2021).

In practice, to improve performance, it is necessary to understand the variability in the activity profiles of players to create training segments that better replicate the specific demands of match-play and periods of recovery similar (Gabbett, 2020). Despite the significant practical applications that this information can provide for coaches, the impact of interchange rotation management throughout the match on high-intensity activities has never been described.

Hence, this study aimed to 1) quantify the high-intensity activities between players' interchanges in the match; 2) identify the effect of match time and work-rest ratio along the interchanges on the high-intensity activity profile of elite futsal players.

The obtained results might help to determine the most adjustable work-rest ratio to improve futsal players' performance, the effect of playing time and players` interchanges in high-intensity activities, and the effect of variations of previous variables in the high-intensity activities profile of elite futsal players.

6.2 Material and Methods

This study included seventeen professional futsal players (age: 28.8±2.4 years, weight: 73.7 ± 6.2 kg, height: 175.9 ± 5.9 cm) from a Spanish elite team that competes in the premier Spanish Futsal League as well as the Union of European Football Associations (UEFA) Futsal Champions League. Based on a preliminary power analysis (Cohen's d effect size of 0.8, probability of error of 0.05, and power of 0.89), a sample size of 15 futsal players is required. The eligibility criteria defined were: only players with more than one rotation were included in the study; rotations lasting less than 15s were excluded; goalkeepers were not included in this study because they are not a position with common player interchanges.

A retrospective observational study was undertaken to quantify and analyze high-intensity external load activities in elite futsal players during 12 official matches. Four games played at home from each season (2018-2019, 2019-2020, and 2020-2021), with balanced result, were examined in order to increase the sample size on the same competitive period. Players averaged 4 to 5 rotations per game, resulting in 450 interchanged rotations. The experimental procedures used in this study were carried out in accordance with the Declaration of Helsinki and were approved by the local Ethics and Scientific Committee.

During the entire match, players were tracked using a local positioning system (WIMU Pro™, Realtrack Systems, Almeria, Spain). The sampling frequency of the tracking system was 18 Hz. About 30 minutes before the warm-up, the units were turned on. The following systems have been installed on the court: 6 ultra-wideband antennas were installed 5 meters from the court's perimeter line. Recently, the WIMU PRO system demonstrated a high intraclass correlation coefficient (ICC) for the x-coordinate (0.65), a very high one for the y-coordinate (0.85), and a good technical measurement error of 2% (Bastida-Castillo et al., 2019).

The external load data was only analyzed when the players were competing on court, excluding resting time after substitutions and inactivity time between periods. It was decided not to analyze the specific data collected while one of the teams implemented a fly goalkeeper (fly Gk + 4 vs 4 + Gk) due to the technical-tactical and physical specific demands of those moments of the match.

WIMU PRO software (SPRO™, Realtrack Systems SL, version 946) was used for the computation of each physical demand measure of interest in each player rotation. Since players keep and may need to perform high-intensity activities while the ball is out of play (Illa et al., 2020) both ball in play time (corresponds to the time the ball is in play) and total time (corresponds to the total time of the match, including the time while the ball is out of play and the one-minute discount periods that both coaches are able to request in each half) were recorded.

More particularly, the following physical demand variables were measured and reported: number of high-speed running actions (>18 km·h^{-1}); number of high-intensity accelerations (≥3 m·s^{-2}) and number of high-intensity decelerations (≤−3 m·s^{-2}). The sum of these three variables was measured on each player to calculate the average of the number of high-intensity activities per player interchange.

The match periods were divided into 5 minutes thresholds: Period 0 – (starters 1st Half); Period 1- (0-5min); Period 2- (5-10min); Period 3- (10-15min); Period 4- (15-20min); Period 5- (starters 2nd half); Period 6- (20-25min); Period 7- (25-30min); Period 8- (30-35min) and Period 9- (35-40min). The rest time before each player interchange, the work-rest ratio, and the accumulation of match time, rest time and the work-rest ratio throughout the match were also registered and analyzed.

Normality of the data was tested with the Kolmogorov–Smirnov test. Mean ± standard deviation (SD) for each data interchange rotation were analyzed. A two-step cluster with log-likelihood as the distance measure and Schwartz's Bayesian criterion was performed to classify players using the number of high-intensity activities (Tabachnick & Fidell, 2017). The obtained clusters were used as an independent variable to analyze the differences between players' rotation and match period. Afterwards, a 1-way ANOVA was conducted to identify which variables best differentiate the previously obtained clusters. Pairwise differences and post hoc comparisons were tested with Bonferroni post hoc test. Effect size (ES) was presented as partial eta-squared ($\eta p2$) and interpreted by the following criteria: small (ES ≤ 0.06), medium (0.06 < ES ≤ 0.14) and large (ES > 0.14) (Cohen, 2013). All data sets were tested for each statistical technique`s corresponding assumptions. Statistical significance was set at 0.05 and the computations were carried out using IBM SPSS Statistics for Windows (version 28.0, Armonk, NY: IBM Corp).

6.3 Results

Table 10 shows the average time values that the players spent on the field and on the bench during each interchange rotation, as well as the number of different high-intensity activities.

Table 10. Mean time on court and bench durations per individual player rotation and counting of different high-intensity actions.

Time Variables					External Load Variables			
Playing Time		Rest Time		Work rest-ratio	ACC	DEC	HSR	HIA
Effective time	Total time	Effective time	Total time					
3.9±1.1	7.6±2.3	3.9±2.9	7.6±5.4	1.0±0.4	8.0±5.3	8.0±5.1	4.0±2.4	20.0±11.2

Legend: ACC: high-intensity accelerations; DEC: high-intensity decelerations; HSR: High speed running: HIA: high-intensity activities (sum of ACC, DEC and HSR).

The cluster analysis classified the players into three distinct groups based on their average physical performance values: lower (≈10 HIA), medium (≈21 HIA), higher (≈38 HIA), (Table 11). Figure 4 represents the distribution of the different activity profiles. The average silhouette measure of cohesion and separation was 0.6 (good quality).

Table 11. Cluster characterization

Clusters	Count	%	Minimum	Maximum	Mean±SD
Lower	176	39.1	1	15	10.3±3.5
Medium	184	40.9	16	28	20.8±3.8
Higher	90	20.0	29	61	38.2±7.9

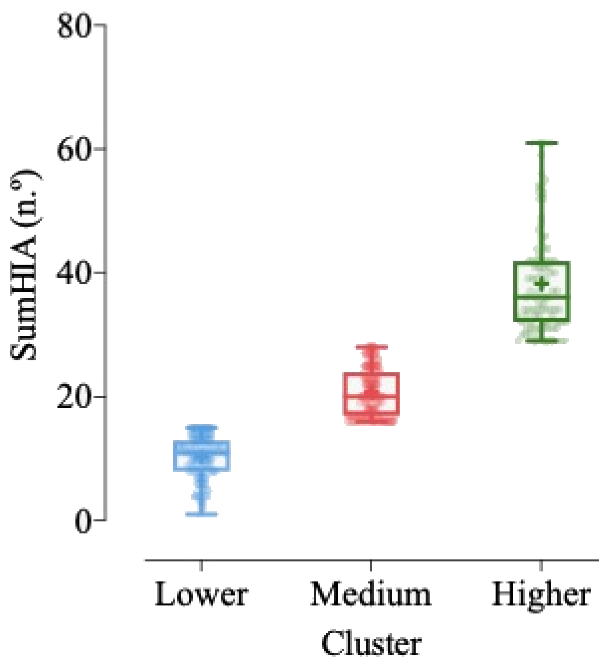

Figure 4. Clusters' distributions. The whiskers connect all points, from the minimum to the maximum; + represents the mean; and the box middle solid line represents the median.

No statistically significant differences were observed over the match' rotations in the three different activity profiles (see Figure 5).

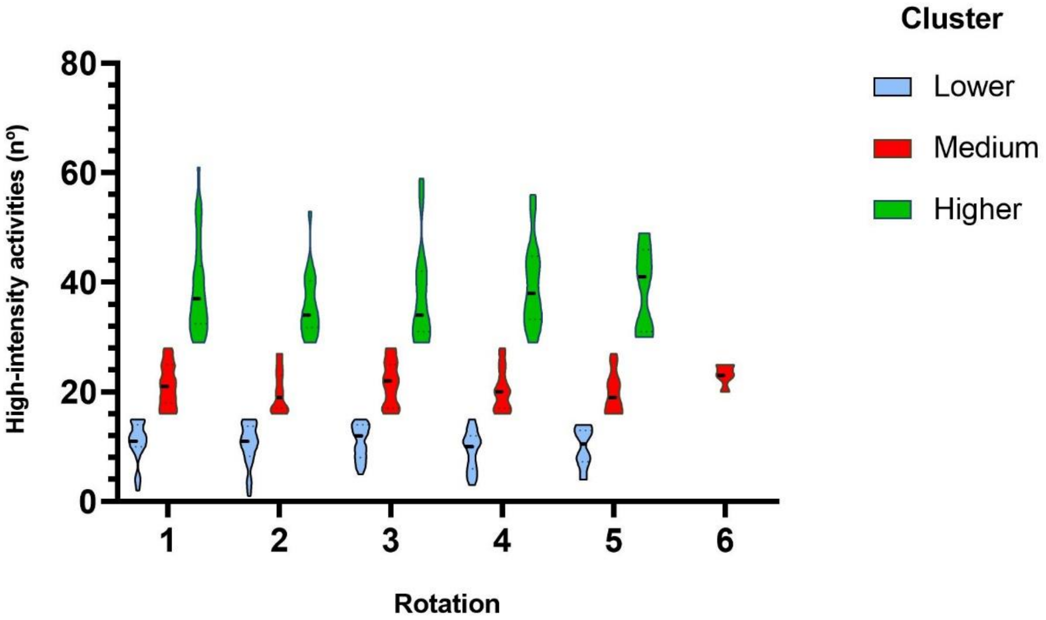

Figure 5. The mean and distribution of high-intensity activities between match interchange rotations for the three clusters.

Through the periods (Figure 6), the same analysis revealed a small wave of high-intensity activities in the activity profiles over the match. However, no significant differences were registered between match periods.

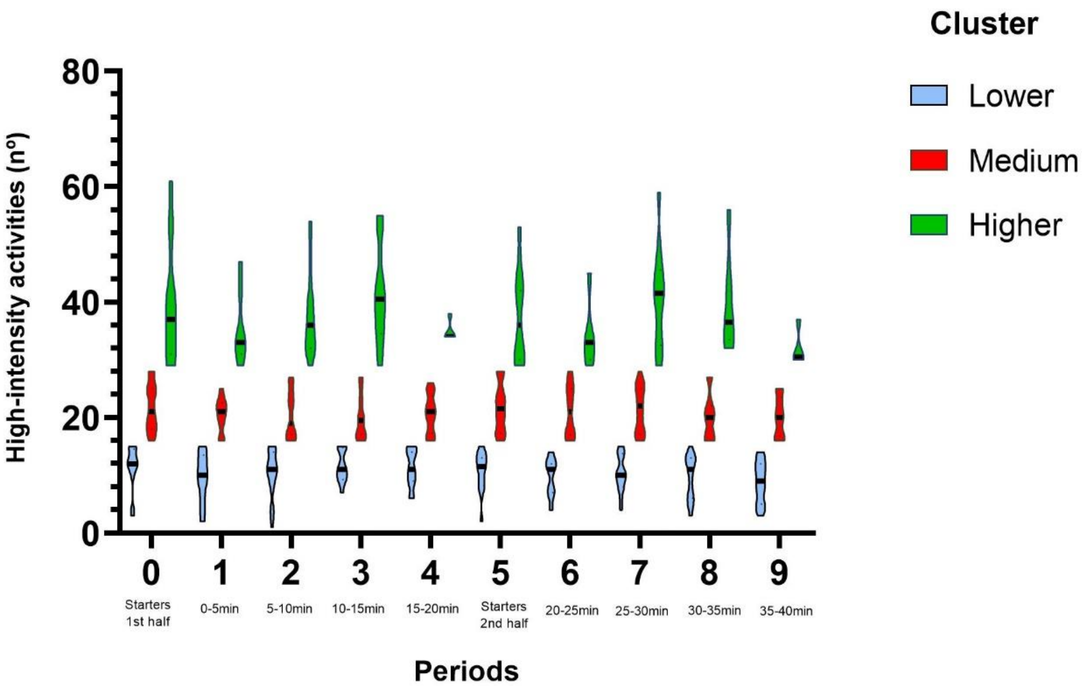

Figure 6. The mean and distribution of high-intensity activities for the three clusters between match periods.

Through a 1-way ANOVA analysis of clusters (Table 12) it was possible to identify that playing time (*F*=40.9, *P*<.001), work-rest ratio (*F*=15.6, *P*<.001), accumulated work-rest ratio (*F*=7.98, *P*<.001) and accumulated rest time (*F*=7.66, *P*<0.001) were the variables that most contributed to the differentiation of the players' activity profiles.

Table 12. Summary of clusters and ANOVA analysis

Variables	Cluster (mean±SD)					ANOVA	
	Lower	Medium	Higher	F	ηp2	p	Post hoc*
Playing Time	3.4±1.2	4.0±0.9	4.6±1	40.9	0.155	<.001	a,b,c
Work-Rest ratio	0.8±0.4	1.0±0.4	1.1±0.6	15.6	0.066	<.001	a,b,c
Accumulated Work-Rest ratio	1.0±0.5	1.2±0.6	1.4±0.8	7.98	0.035	<.001	a,b,c
Accumulated Rest Time	10.8±6.2	9.4±5.9	7.8±5.9	7.66	0.033	<.001	b
Rest time	4.3±2.8	3.9±2.9	3.4±2.7	3.09	0.014	0.046	b
Playing Time Accumulated	10.2±4.7	10.8±5.5	10.6±6	0.43	0.002	0.648	n.a

*a = lower vs medium; b = lower vs higher; c = medium vs higher

6.4 Discussion

In general, results revealed that elite futsal players from this study performed an average of twenty high-intensity activities per interchange rotation. Through a clusters analysis, it was possible to identify a high variability in their activity profiles, being possible to isolate three distinct patterns: players with a low activity profile that performed an average of ten high-intensity activities per interchange; players with a medium activity profile that performed an average of twenty-one high-intensity activities per interchange; and players with a high-intensity profile that performed an average of thirty-eight high-intensity activities per interchange.

Data analysis of the temporal effects of interchange rotations on the frequency of high-intensity activities revealed that players were capable of maintaining a stable number of high-intensity activities during the match based on the activity profile. This data suggests that, regardless of the match context (result, strategy, number of fouls, model system, opponent´s level), players maintain the ability to perform high-intensity activities.

The work-rest ratio is one of the factors that may justify a player`s ability to perform multiple high-intensity activities during the match. (Barbero-Alvarez et al., 2008; Doğramacı et al., 2015). The players in this study competed for an average of 3.9 minutes per interchanged on the court and the same ball in play time on the bench, corresponding to an average of 2 to 3 interchanges per half with a ratio of 1:1. Our findings are consistent with the literature on energy systems, emphasizing the importance of developing a training program that specifically emphasizes the work-rest ratio (energy system) required to play futsal. The ATP-CP replenishment time is close to 20 seconds of rest, and the

intramuscular reserve restoration time is approximately within the average time that elite futsal players are on the bench (3.9 min) (Ulupınar et al., 2021).
In this regard, the teams that use a higher frequency interchange rotation strategy predispose their players to be physically available for offensive and defensive actions, putting them closer to success (Clay & Clay, 2014). This is probably due to the fact that after each interchange, there is an increase in the distance covered and the ability to sprint in futsal players (Milanez et al., 2020).
The main findings of this study may generate some reflections on the concept of analyzing the physical demands and the most demanding periods of futsal matches. In a recent study, authors found that elite futsal players have the ability to repeat high-demanding scenarios in the course of a single match instead of being a "one off" event (Illa et al., 2020).
As situational aspects play an extremely important role in the interpretation of physical demands (Novak et al., 2021), the second aim of this study was to analyze the eventual relation between some match time variables and the frequency in which high-intensity activities are achieved along the interchange rotations that players perform during the match. Our results showed that the playing time and the work-rest ratio were the variables that most contributed to the classification of the match activity profiles of the players. Furthermore, the accumulation of the work-rest ratio and the rest time must also be taken into consideration.
This evidence brings a new discussion regarding the proposals that merely consider only the athletes` ball in play time in relation to the total match time to calculate the values of the external load variables. In fact, this approach leads to an understanding that players who are less time on the court tend to present higher physical performance values per minute when compared to players with more playing time (Ribeiro et al., 2022b). However, according to our results, when the physical effort per minute was calculated not considering the total playing time but the playing time per interchange rotation and considering the work-rest ratio, the players that spent more time in the court than in the bench were the ones that achieved the highest level of match effort. In our opinion, and given that futsal is a sport with unlimited substitutions, calculating the match effort per minute without considering the work-rest ratio of play does not provide sport scientists and coaches with a correct understanding of the impact that physical demands of futsal matches have on their players. In this sense, our study suggests that futsal players' performance analysis should focus on the time that each player has per rotation, since it constitutes the clearest method to understand the real physical demands of a futsal match.
Finally, the fact that in our study the players with more resting time are those with less ability to perform HIA may be related to a decrease in body temperature (García et al.,

2020; Silva et al., 2018) which results in a limitation in the players ability to repeat high-intensity activities, which could mean that the first rotation in each half has the same impact in the players' capacity to perform as the "warm up".

6.5 Conclusions

The findings of our study led us to the conclusion that high-intensity activities can cause significant variation between elite futsal players. However, within each individual activity profile, these athletes can manage to maintain their profile stable during the forthcoming match rotations.

Furthermore, we observed that in a balanced team, the length of an on-field interchange rotation period has a clear impact in performance. Players with more playing time and with a work-rest ratio equal to or greater than 1 are the ones with the higher capacity to repeat high-intensity activities. On the other hand, players who accumulate more resting time and a work-rest ratio less than 1 are less able to perform high-intensity activities.

The main findings of this study may generate some reflections on the concept of analyzing the physical demands and the most demanding periods of futsal matches. Whilst recent research has analyzed and described the physical demands and therefore, the high-intensity activities that elite futsal players are exposed to during official futsal matches in terms of average values (Illa et al., 2020; Ribeiro et al., 2020) and in terms of the most demanding scenarios (Illa et al., 2021), in this study, only the mean values of high-intensity activities per interchange rotation over the match have been considered. In this sense, we believe that further research should focus on investigating the fluctuation of the most demanding periods over the playtime that each player has per interchange, instead of focusing only on investigating the most demanding period in the match or in the mean values per team.

The results of our study allow strength and conditioning coaches to plan and design drills with individually optimized time variables to improve the most suitable physiological adaptations to the physical demands that players have per interchange rotation during the match. Furthermore, it is recommended that players who play less time and spend more time on the bench, have a preset rewarming to minimize the effect of physical inactivity as much as possible. Thus, it would be pertinent to find out if the space available for futsal players to warm up is sufficient and what kind of equipment could be allowed to boost their readiness to compete.

This study has some limitations that should be considered. Given the difficulty to collect data from professional futsal teams, only one team was analyzed, and some caution is required to interpret the data obtained. In turn, the fact that these data was collected in high-level futsal team adds a lot of interest and can be very enriching in the possible knowledge produced (Hecksteden et al., 2021). In addition, we have only examined the quantity of interchange rotations. Future studies could further develop our findings by examining the most intense periods per interchange rotation, the influence of player position, and more situational factors on players performance outcomes. Finally, it would also be interesting to identify the technical-tactical actions associated with high-intensity activities to create a physical performance test based on the most frequent and specific high-intensity actions of match play.

7. The effect of interchange player rotation on different high-intensity activity properties in professional futsal players

Ribeiro, J. N., Farzad, F., Monteiro, D., Illa, J., Couceiro, M., Sampaio, J., & Travassos, B. (2023). “The effect of interchange player rotation on different high-intensity activity properties in professional futsal players” Journal of Human Kinetics, Volume 90/2024

7.1 Introduction

In intermittent team sports such as futsal (indoor soccer), previous research has shown that to understand player performance, it is necessary to consider the high demands on players' actions over time as a function of the characteristics of the competition (Ribeiro et al., 2022b). Currently, local positioning systems (LPS), based on ultra-wideband technology, are utilized to measure external load metrics and the physical demands of high-intensity activities (HIA) during a futsal match (Ribeiro et al., 2020). The collective HIA is composed of the sum of external load variables including mechanical (acceleration and deceleration) and kinematic (speed and distance covered) dimensions, which are measured from high-intensity thresholds. Thus, the combined mechanical and kinematic variables allow for a more holistic analysis of the physical requirements of the game, rather than analyzing the respective performance variables individually. Futsal is an energetically demanding sport, with frequent bouts of repeated sprints, accelerations, and decelerations, interspersed with short recovery periods. Therefore, considering the competition demands, the importance of a well-developed aerobic and anaerobic energy system underpins the ability to repeatedly perform HIA throughout a match (Barbero-Alvarez et al., 2008; Ribeiro et al., 2020). Previous literature surrounding football performance have reported a positive association between successful teams and their ability to perform HIA (Di Salvo et al., 2009; Krustrup et al., 2006).

In fact, coaches claim that information regarding HIA is required and routinely included in their physical performance reports (Nosek et al., 2021), which inform the development of sport-specific training drills that maximize competition performance (Impellizzeri et al., 2020).

Recent research on the analysis of HIA in futsal competitions has shown that elite futsal players can maintain their physical performance during matches (Illa et al., 2020; Ribeiro et al., 2020; Serrano et al., 2020), between and within matches, and even during congested periods (Ribeiro et al., 2022b). Together with the coaches` ability to manage player interchange rotations, for which there are no limits in futsal, playing time and rest time (work-to-rest ratio) appears to be one of the most important factors in supporting the players' ability to maintain a high level of performance throughout the game (Dos-Santos et al., 2020; Ribeiro et al., 2022b).

Previous research has shown that teams implementing a high-frequency rotation strategy, with a work-rest ratio close to 1:1 (Barbero-Alvarez et al., 2008; Doğramacı et al., 2015), contributed to maintaining high levels of player performance throughout the match (Clay & Clay, 2014; Milanez et al., 2020).

Considering the variability of activity duration and playing time in futsal, not only should the general values of HIA be considered, but also research in other sports that takes into account other HIA characteristics such as the distance travelled and the duration of each HIA, the temporal frequency of each action, and the distance travelled by players to adjust physiological responses to training design (Buchheit & Laursen, 2013). Thus, there is a need to identify new metrics for HIA that consider the playing and rest times in each player rotation, which could allow for a more relevant assessment of the overall physical performance according to the various HIA characteristics. To facilitate the transfer of this knowledge to the field, which is essential for the effective design of timed drills, recovery periods, and individualization of a training program, it is also necessary to better understand the responses to HIA in futsal as a function of playing position and time (Illa et al., 2021; Serrano et al., 2020).

In effect, this approach is expected to provide a comprehensive assessment of position-specific differences in physical performance to inform practitioners working with futsal players to (1) tailor and personalize interventions based on the specific needs of athletes rather than relying on a "one-size-fits-all" approach, (2) better apply position-specific recovery strategies, and (3) strategize player rotations to allow sufficient time between HIA, which function to reduce injury risk and achieve optimal performance outcomes.

Therefore, our research objectives were threefold: 1) to analyze the HIA characteristics (number of efforts, total distance covered, total duration, time-frequency, and work-rate) by playing position in each player interchange rotation, 2) to investigate the rate of change in performance work-rate across player interchange rotations for each playing position, and 3) to investigate the effect of interchange rotation duration on the various HIA characteristics.

7.2 Material and Methods

A retrospective observational study was conducted to quantify and analyze positional differences in high-intensity external load activities of elite futsal players during seven official matches from the premier Spanish Futsal League (2018-2021; n=266 observations).

7.2.1 Participants

Data were collected from nineteen professional futsal players (age: 28.8 ± 2.4 years, weight: 73.7 ± 6.2 kg, height: 175.9 ± 5.9 cm). Players were classified according to their playing position into defenders (*n* =6), wingers (*n* =10), and pivots (*n* = 3). Goalkeepers were not included in this study because their position is very specific and their locomotor dynamics are different from the outfield players (Serrano et al., 2021). The monitoring process of the players was routine for all players. All participants were informed of the purpose of the study and gave written informed consent before the study was conducted. The experimental procedures used in this study were conducted according to the Declaration of Helsinki and were approved by the local Ethics and Scientific Committee.

7.2.2 Design and Procedures

All official matches were played on the same official indoor court under similar environmental conditions. An LPS performance tracking system (WIMU PRO™, Realtrack Systems, Almeria, Spain) was used to monitor and collect external load data. The LPS devices were placed in the upper part of the back in tight-fitting harnesses. The LPS system was installed on the court as follows: 6 antennas with ultra-wideband technology were placed 5 meters from the court perimeter line. Recently, the WIMU PRO system showed a high intraclass correlation coefficient (ICC) for the x-coordinate (0.65), a very high one for the y-coordinate (0.85), and a good technical measurement error of 2% (Bastida-Castillo et al., 2019). The WIMU PRO software (SPRO™, Realtrack Systems, Almeria, Spain) was used to calculate the physical demands of interest in each player rotation.

Players were continuously monitored throughout the match using LPS systems, but external load data were only analyzed when players were on the court. It was decided not to analyze the specific data recorded while one of the teams was using a flying goalkeeper (fly Gk + 4 vs 4 + Gk), since technical-tactical changes may occur during these moments of the match.

7.2.3 Measures

The duration of each player's rotation was measured in absolute time (the total time of the match, including when the ball was not in play) to better understand the workload characteristics. The following physical demand variables were measured and reported as the number of high-speed running activities (>18 $km \cdot h^{-1}$), high-intensity accelerations (≥3 $m \cdot s^{-2}$), and high-intensity decelerations (≤−3 $m \cdot s^{-2}$). The sum of these three variables was calculated for each player per rotation to measure the individual HIA per rotation. The HIA properties were calculated as (1) the number of HIA efforts (n; HIA effort), (2) the total distance covered in meters for each HIA (m; HIA distance), (3) the duration in seconds of each HIA (s; HIA duration), (4) the time in seconds between each HIA (s; HIA time-frequency), and (5) the total HIA distance covered during the duration of the rotation (m/min; HIA work-rate).

7.2.4 Statistical Analyses

The normal distribution of the data was confirmed using the Shapiro-Wilk test. Differences in mean HIA properties (dependent variables) between rotations, players, as well any interactions between the independent variables were determined using linear mixed-effects models. Five rotations (R1-R5) and three positions (defender, DF; winger, WG; and pivot PV) were included as fixed effects. A repeated measures model was used to analyze differences between rotations, and players were included as random effects. Bonferroni *post-hoc* tests were used to identify differences between means in the event of a significant effect.

A mixed effects regression model with random intercepts was used to compare differences in the average rate of change in HIA number of efforts, HIA frequency, and HIA work-rate per subsequent interchange rotation between playing positions. HIA performance variables (HIA efforts, HIA frequency, and HIA work-rate) were included as fixed effects, subjects were included as random effects, and the rotation number was treated as a continuous variable. Therefore, the regression slope indicates the average rate of change in the respective HIA performance variable as a function of subsequent interchange rotations. Spearman Rho correlation analysis was used to determine the relationship between HIA properties across rotations. Results of the correlation analysis were interpreted according to: 0.9-1.0, very high; 0.7-0.9, high, 0.5-0.7, moderate, 0.3-0.5, low; and 0.0-0.3, trivial (Mukaka, 2012). Data are presented as estimated marginal mean ± 95% confidence intervals unless otherwise stated. The significance level was set at $P \leq 0.05$. Statistical analyses were performed using IBM SPSS for Windows statistics version 25.0 (IBM Corp., Armonk, NY, United States).

7.3 Results

The overall mean duration of each rotation was 5.88 min (5.6-6.2), with wingers (WG) having the greatest overall rotation time at 6.01 min (5.6-6.4), followed by defenders (DF) at 5.88 min (5.3-6.5), and 5.52 min (4.7-6.3) for pivots (PV).

Table 13 displays the HIA properties according to players' positions and interchange rotations. In general, statistically significant ($p \leq 0.05$) differences were observed in HIA efforts across positions and rotations. Wingers performed a significantly greater number of HIA efforts overall and across their rotations than both DF ($p \leq 0.05$; ES=0.4) and PV ($p \leq 0.001$; ES=0.9). Furthermore, WG have a higher total HIA work-rate than PV ($p \leq 0.001$; ES=0.8). There were also significant differences in HIA time frequency between positions, with WG ($p \leq 0.05$; ES=0.7) and PV ($p \leq 0.001$; ES=1.9) demonstrating lower values. Overall, a significantly greater number of HIA efforts were performed during the first rotation (n=17.64 (16.9-19.4)) compared to subsequent rotations. Similarly, there was a significant effect of rotation number on HIA work-rate ($p \leq 0.01$; ES=0.6), with the first rotation HIA work-rate being significantly greater than the third ($p \leq 0.01$; ES=0.6), fourth ($p \leq 0.05$; ES=0.6) and fifth rotation ($p \leq 0.05$; ES=0.8).

Table 13. Estimated Marginal Means [95%CI] in HIA demands for rotations and playing positions.

	R	Duration (min.)	ES	HIA Effort (n)	ES	HIA time-frequency (s)	ES	HIA Duration (s)	ES	HIA Work-Rate (m/min)	ES	HIA Distance (m)	ES
	R1	6.73 [6.4 ; 7.1]	-	19.47 [17.9 ; 21.1]	-	21.79 [20.3 ; 23.2]	-	1.73 [1.7 ; 1.8]	-	20.93 [19 ; 22.9]	-	5.36 [5.1 ; 5.6]	-
	R2	6.23 [5.7 ; 6.7]	-	16.19 [14.4 ; 18] *	0,5	24.62 [22.5 ; 26.7]	-	1.72 [1.7 ; 1.8]	-	19.26 [16.8 ; 21.7]	-	5.68 [5.4 ; 6]	-
	R3	5.48 [4.8 ; 6.2] *	0,6	13.39 [11.5 ; 15.3] **	0,9	24.5 [22.4 ; 26.6]	-	1.77 [1.7 ; 1.8]	-	15.96 [13.6 ; 18.3] **	0,6	5.54 [5.2 ; 5.9]	-
	R4	5.3 [4.5 ; 6.1] *	0,7	13.4 [11.6 ; 15.2] **	0,9	23.73 [21.6 ; 25.8]	-	1.76 [1.7 ; 1.8]	-	16.55 [14.1 ; 19] *	0,6	5.97 [5.5 ; 6.4]	-
	R5	5.66 [4.7 ; 6.6]	-	13.58 [11.5 ; 15.7] **	0,9	24.3 [21 ; 27.6]	-	1.73 [1.6 ; 1.8]	-	15.32 [12.1 ; 18.5] *	0,8	5.68 [5.1 ; 6.2]	-
	Total	5.88 [5.6 ; 6.2]	-	15.2 [14 ; 16.4]	-	23.79 [22.4 ; 25.2]	-	1.74 [1.7 ; 1.8]	-	17.61 [16.1 ; 19.1]	-	5.64 [5.4 ; 5.9]	-
DF	R1	6,26 [5,6 ; 6,9]	-	17,41 [14,6 ; 20,2] #	2,2	22,21 [20,1 ; 24,3]	-	1,72 [1,6 ; 1,8]	-	19,31 [15,9 ; 22,7]	-	5,27 [4,8 ; 5,7]	-
	R2	6,83 [5,9 ; 7,8]	-	17,65 [14,3 ; 21] #	1,7	26,74 [23,5 ; 30]	-	1,68 [1,6 ; 1,8]	-	21,66 [17,3 ; 26,1]	-	5,49 [4,8 ; 6,1]	-
	R3	5,91 [4,5 ; 7,3]	-	14,07 [10,6 ; 17,6]	-	27,07 [23,5 ; 30,6]	-	1,71 [1,6 ; 1,8]	-	15,31 [10,9 ; 19,8]	-	5,21 [4,6 ; 5,8]	-
	R4	5,6 [4,2 ; 7]	-	12,26 [9 ; 15,5]	-	24,67 [20,6 ; 28,8]	-	1,74 [1,6 ; 1,9]	-	15,3 [11,1 ; 19,5]	-	5,41 [4,5 ; 6,3]	-
	R5	4,78 [3,1 ; 6,5]	-	9,42 [6,4 ; 12,5]	-	24,58 [17,9 ; 31,2]	-	1,6 [1,4 ; 1,8]	-	9,58 [4,4 ; 14,7]	-	5,08 [4,1 ; 6]	-
	Total	5,88 [5,3 ; 6,5]	-	14,16 [12,3 ; 16]	-	25,05 [22,9 ; 27,2] α	0,9	1,69 [1,6 ; 1,8]	-	16,23 [13,8 ; 18,7]	-	5,29 [4,8 ; 5,7]	-
WG	R1	6,99 [6,5 ; 7,4]	-	21,85 [19,9 ; 23,8] α β	1.3; 0.7	19,28 [17,8 ; 20,7]	-	1,74 [1,7 ; 1,8]	-	23,39 [20,9 ; 25,9]	-	5,16 [4,5 ; 5,8]	-
	R2	5,93 [5,3 ; 6,6]	-	16,73 [14,5 ; 19] **	0,8	22,15 [19,8 ; 24,5]	-	1,72 [1,7 ; 1,8]	-	19,92 [16,9 ; 22,9]	-	6,08 [5,3 ; 6,9]	-
	R3	5,03 [4,1 ; 6]	-	13,8 [11,3 ; 16,3] **	1,1	20,87 [18,4 ; 23,4]	-	1,77 [1,7 ; 1,9]	-	16,99 [13,9 ; 20,1]	-	5,81 [4,9 ; 6,7]	-
	R4	5,67 [4,6 ; 6,7]	-	15,16 [12,7 ; 17,7] **	1,1	22,11 [19,4 ; 24,8]	-	1,8 [1,7 ; 1,9]	-	18,06 [14,7 ; 21,4]	-	5,67 [4,6 ; 6,8]	-
	R5	6,41 [5,2 ; 7,7]	-	17,24 [14,9 ; 19,6] * Δ Φ	0.8; 1.8; 1.8	21,67 [17,1 ; 26,2]	-	1,79 [1,7 ; 1,9]	-	20,05 [16,1 ; 24]	-	4,42 [3,1 ; 5,8]	-
	Total	6,01 [5,6 ; 6,4]	-	16,96 [15,7 ; 18,2] α β	0.9; 0.4	21,21 [19,7 ; 22,7] α β	1.9; 0.7	1,77 [1,7 ; 1,8]	-	19,68 [17,9 ; 21,4] α	0,8	5,86 [5,6 ; 6,2]	-
PV	R1	6,51 [5,6 ; 7,4]	-	13,67 [9,8 ; 17,5]	-	31,16 [28,2 ; 34,1]	-	1,71 [1,6 ; 1,8]	-	14,47 [9,8 ; 19,2]	-	5,46 [5,1 ; 5,8]	-
	R2	6,41 [5,1 ; 7,7]	-	11,22 [6,7 ; 15,8]	-	29,3 [23,7 ; 34,9]	-	1,79 [1,7 ; 1,9]	-	11,33 [4,9 ; 17,7]	-	5,66 [5,2 ; 6,1]	-
	R3	6,38 [4,6 ; 8,2]	-	10,33 [5,4 ; 15,3]	-	33,31 [27,9 ; 38,7]	-	1,84 [1,7 ; 2]	-	12,65 [6,4 ; 18,9]	-	5,62 [5,2 ; 6,1]	-
	R4	3,57 [1,7 ; 5,5]	-	8,99 [4,6 ; 13,3]	-	29,31 [24 ; 34,6]	-	1,69 [1,5 ; 1,9]	-	13,48 [7 ; 20]	-	6,32 [5,7 ; 6,9]	-
	R5	4,74 [2,3 ; 7,1]	-	8,52 [4,2 ; 12,9]	-	32,78 [24,6 ; 41]	-	1,76 [1,5 ; 2]	-	10,24 [3 ; 17,5]	-	6,26 [5,6 ; 6,9]	-
	Total	5,52 [4,7 ; 6,3]	-	10,55 [8 ; 13,1]	-	31,17 [28,2 ; 34,1]	-	1,76 [1,7 ; 1,8]	-	12,44 [8,9 ; 15,9]	-	5,43 [4,8 ; 6]	-

R: Rotation, R1: Rotation 1, R2: Rotation 2, R3: Rotation 3, R4: Rotation 4, R5: Rotation 5; DF: Defender, WG: Winger, PV: Pivot; * significantly different than R1 ($p \leq 0.05$); ** significantly different than R1 ($p \leq 0.01$); # significantly different than R5 ($p \leq 0.01$); Δ significantly different than PV ($p \leq 0.01$); α significantly different than PV ($p \leq 0.001$); β significantly different than DF ($p \leq 0.05$); Φ significantly diffferent than DF ($p \leq 0.001$). ES: Cohen's *d* effect size, reported only for significant differences.

The rate of change in HIA variables was considered across five interchange rotations, as it represented the maximum number of rotations observed in the data set. The estimates of fixed effects, which represented the mean initial rotation, for the number of HIA efforts (n) was significantly ($p \leq 0.001$) lower for PV when compared to DF and WG (PV: 13.2 ± 3.6; DF: 18.26 ± 2.6; and WG: 19.9 ± 1.8). Mean initial rotation HIA frequency was significantly lower for WG (19.63 ± 1.4s) and the highest for PV ($p \leq 0.001$; 30.96 ± 2.8s) when compared to DF ($p \leq 0.05$; 23.04 ± 2s). The mean initial rotation HIA work-rate (m/min) was significantly lower ($p \leq 0.001$;) for PV when compared to DF and WG (PV: 13.92 ± 4.2m/min; DF: 20.76 ± 3 m/min; WG: 22.09 ± 2.1 m/min).

No statistically significant ($p \geq 0.05$) differences were observed in the slopes of HIA properties between playing positions. However, the HIA efforts and HIA work-rate revealed changes in the slope across subsequent interchange rotations for DF and WG, while a significant increase in the slope was observed for HIA frequency for DF and WG (Figure 7).

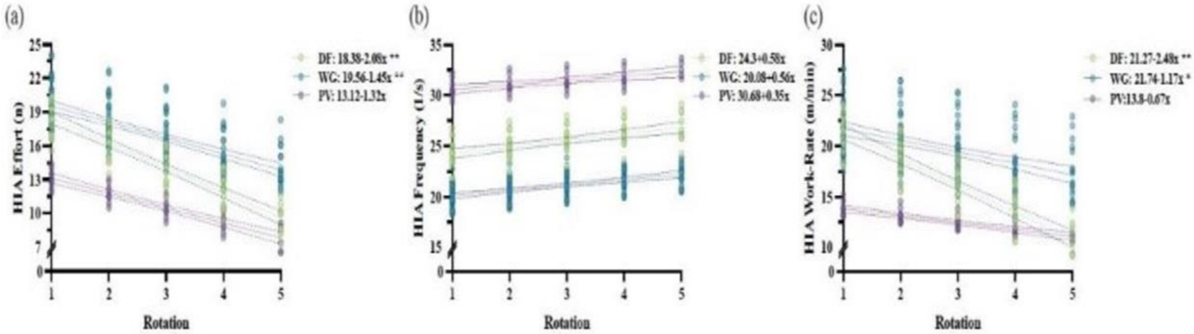

Figure 7. Linear mixed effects regression model equations and predicted values for the rate of change in (a) HIA effort (n), (b) HIA frequency (1/s), and (c) HIA work-rate (WR: m/min) between positions as a function of interchange rotation number. WG: wi

The relationship between rotation duration and HIA properties is presented in Table 14. Rotation duration revealed a significant positive moderate correlation between HIA effort and HIA work-rate. Further, the HIA work-rate revealed statistically significantly positive low and moderate correlations with all of the variables with exception of HIA time-frequency, which revealed a low negative significant correlation.

Table 14. Spearman Rho Correlation of HIA properties

	R Duration (min.)	HIA Effort (n)	HIA time-frequency (s)	HIA Duration (s)	HIA WR (m/min)
HIA Effort (n)	.732**	-			
HIA time-frequency (s)	.164*	-.457**	-		
HIA Duration (s)	-0,041	0,002	-0,087	-	
HIA WR (m/min)	.598**	.896**	-.454**	.347**	-
HIA Distance (m)	-0,051	0,08	-.159*	.852**	.478**

Significant correlation * $p \leq 0.05$; ** $p \leq 0.01$.

7.4 Discussion

The purposes of our study were to (1) analyze the HIA properties (the number of efforts, total distance covered, total duration, time-frequency, and work-rate) of player interchange rotations according to playing position, (2) to investigate the rate of change in performance work-rate across player interchange rotations for each playing position, and (3) to investigate the influence of rotation duration on the different HIA properties. In general, the results revealed variations in some HIA properties across positions and rotations. Interestingly, HIA properties did not reveal changes in the rates of change (slope) between positions, but only across interchange rotations within positions including DF and WG.

In line with our initial hypotheses, rotation duration revealed a significant relationship with HIA properties, namely HIA effort and HIA work-rate.

HIA are dependent on playing positions

The primary findings of this study revealed that based on the analysis of HIA properties (number of efforts, time-frequency, and work-rate), physical demands during elite futsal competition are position-dependent. HIA duration and distance covered did not reveal any difference according to playing positions. These findings are consistent with previous research, in which the authors reported similar values of physical demands between positions based on mean values (Serrano et al., 2020), as well as the most demanding scenarios (Illa et al., 2021). In fact, it may be possible to assume that the HIA duration and distance covered could be defined as variables that characterize general match demands, while HIA effort, work-rate and time-frequency as variables that define the structure of match demands according to playing positions.

The interpretation of these findings strengthens the evidence that a futsal player requires a high capacity to perform repeated HIA, implying that the activity profile of elite futsal players is dependent on both aerobic and anaerobic energy metabolism pathways, particularly the phosphagen system (Castagna & Álvarez, 2010). Behind this scope, our results are consistent with the literature on energy systems, which highlights the importance of developing a training program that specifically emphasizes the HIA work-rate (energy system), to play elite futsal. During passive recovery, 50 percent of muscle adenosine triphosphate-phosphocreatine (ATP-CP) stores are restored within 20 seconds of rest and intramuscular reserves are restored after almost 3 minutes (Bogdanis et al., 1996; Ulupınar et al., 2021). Thus, the ATP-CP replenishing time is similar to the average duration between HIA, and the restoration of intramuscular reserves is approximately within the average time that elite futsal players are on the bench (Ribeiro et al., 2022a). It is therefore plausible to suggest that futsal players can maintain consistency in performing HIA throughout a match and during their rotation (playing time) due to the intermittent nature of the sport as well as the rest time afforded between rotations. However, some caution is required when interpreting this association, because the time between HIA is not spent passively resting, but rather engaging in less intense activities.

In line with this, despite the similarities between the duration and distance covered per HIA effort, the match demands of futsal players differ according to playing positions (Ribeiro et al., 2020). The winger, as expected, was the most demanding position, with higher values of HIA properties followed by defender and pivot. These findings could be explained by the fact that wingers, usually play with constant variations in the space of play to explore 1 vs 1 situations or to create numerical and positional superiorities and promote defensive imbalances (Ohmuro et al., 2020; Santos et al., 2020). This evidence is consistent with the findings of previous research, which investigated the areas of the field covered by players and concluded that wingers occupied more court space areas in the middle pitch line and with more variability than other playing positions (Serrano et al., 2021).

Work-rate performance changes across player rotations

One of the most difficult challenges in indoor team sports is detecting fatigue patterns. Unlimited substitutions in the match influence fatigue management during the competition. One of these possible outcomes is that elite futsal players have a work-rest ratio (playing time-to-rest time) near 1:1 (Barbero-Alvarez et al., 2008; Doğramacı et al., 2015; Ribeiro et al., 2022a).

With this finding in mind, we observed the effects of subsequent interchange rotations to confirm the loss or gain variation in the different HIA properties. The results were very interesting, revealing significant losses (all positions except the pivot) in all HIA properties (effort, time frequency, and work-rate) per subsequent rotation compared to the initial rotation.

This phenomenon may occur because the game pace may decrease in the players' final rotation, towards the end of the match, as a result of tactical strategies (e.g., advantageous/disadvantageous score line, match score, or accrued match fouls). Furthermore, temporary declines in physical performance could be related to the increased amount of time the ball is out of play and thus fewer opportunities to engage in match activities (Carling & Dupont, 2011). Moreover, fatigue is not caused by a single factor, and the sustained decline in HIA performance of wingers and defenders (higher profile) compared to the first rotation could be associated with a decrease in muscle glycogen (Krustrup et al., 2006) or an increase in potassium in the muscle (Mohr et al., 2005). In soccer, research has found that players with higher physical demands in the first half have lower physical performance in the second half when compared to players with low and moderate physical profiles in the first half (Bradley & Noakes, 2013). This evidence is especially significant because different positions have different activity profiles and probably different bioenergetic requirements.

It is acknowledged that HIA may be influenced by other contextual factors (Novak et al., 2021), and in consequence, we cannot conclude that any decrease in physical performance observed is due to the development of fatigue. However, in futsal, the final result is usually determined in the final moments of the game, resulting in a period marked by high physical and emotional demand, as well as different variations in game dynamics (Méndez-Domínguez et al., 2019). These findings highlight the importance of further studies investigating several contexts to gain a better understanding of HIA in elite futsal.

Effects of rotation duration on HIA properties

Playing time is considered a performance factor, especially in sports where substitutions are unlimited and *ball-in-play* time is considered important (Ribeiro et al., 2022b). In this regard, and in response to a growing interest in match demands and their impact on match outcomes, practitioners have begun to monitor the duration of players' interchange rotations (Ribeiro et al., 2022a).

Interestingly, the structural properties of match-play demands (effort, time-frequency, and work-rate) revealed strong correlations with rotation duration. This evidence supports previous findings and emphasizes the significance of the relationship between playing time and rest time (work-to-rest ratio) (Ribeiro et al., 2022a). Furthermore, the strong negative association between HIA effort and time-frequency, as well as the strong positive correlation between HIA effort and work-rate, support this statement. To be more specific, as players increase their HIA effort in match-play, the time between HIA decreases, increasing their workload intensity and, as a result, increasing the distance covered per minute during the duration of the rotation. This evidence is supported by results observed for wingers, concerning the overall match and the first rotation (the most demanding), when compared to other positions. While acknowledging differences in modalities, this trend was consistent with other research findings, which concluded that HIA by professional soccer players occurred within the first 15 minutes of the match (Oliva-Lozano et al., 2021).

The combination of our findings provides critical insight into training prescription, especially when considering positional requirements and adapting these activities to prepare players for such high-demanding competition exposures (Illa et al., 2021). In particular, the findings of this study can contribute to informing the creation of simulation matches, or drills based on the specific HIA performance characteristics of a player`s position and rotation during a futsal match.

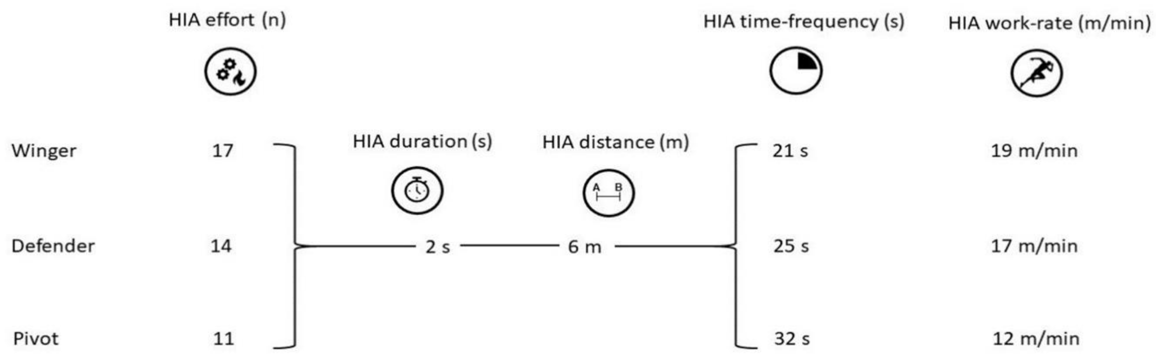

Figure 8. HIA properties mean values per interchange rotation in different playing position

These repeated bouts (figure 8) should be incorporated into drills for approximately 6-minute periods, which represent the average absolute playing time limits per rotation and should be used for the development of more ecologically valid futsal physical tests that incorporate HIA interspersed with different work-rest ratios.

In addition, analyzing the rate of change in HIA performance could be used as a performance indicator to monitor playing positions or even changes in individual performance across the season. It is expected that such information can support decision-making processes for the prescription and manipulation of training load during training sessions as well as in competition.

Our findings suggest that physical demands in futsal are position and time-dependent. Coaches and the performance team must optimize the training session to prepare their team to train together not only according to the overall values of the match demands but also according to the physical demands of each position to individualize their specific needs. Such differences are likely to affect performance and injury risk.

Interestingly, HIA duration and distance are relevant properties to characterize activities with high intensity, while effort, time-frequency and work-rate are relevant properties to characterize the structure of the match-play demands. Moreover, our findings could suggest combining the HIA effort with the HIA work-rate to monitor the training load of a player, a group of players during a given rotation, and the team.

According to player rotation analyses, the first rotation is more physically demanding in all positions. A decrease in the ability to perform HIA (effort, time-frequency, and work-rate) was observed with an increase in the number of rotations, for the higher activity profile positions (wingers and defenders), across all rates of performance change analyses. Even though this evidence provides novel insights into the physical demands of team sports with unlimited substitutions, some caution is required when interpreting these findings due to the limitations of the current study. To begin, despite using data from three different seasons, the study sample was limited to one professional futsal team. Furthermore, the fact that there are only three players for the pivot position makes the generalization of position results difficult. Lastly, to the best of our knowledge, this is the first study to present information on different HIA properties per playing position and player rotation in futsal, which makes it difficult to compare with the literature.

8. Relating external load variables with individual tactical actions with reference to playing position: An integrated analysis for elite futsal

Ribeiro, J. N., Farzad, F., Monteiro, D., Illa, J., Couceiro, M., Sampaio, J., &Travassos, B. "Relating external load variables with individual tactical actions with reference to playing position: An integrated analysis for elite futsal". Submitted.

8.1 Introduction

Futsal is characterized by the relationship of cooperation and opposition between players, in which each team competes to score a goal while avoiding conceding a goal to win the match (Travassos et al., 2012). It is a team sport distinguished by its fast pace and a myriad of physical, psychological and tactical – technical parameters that sustain team performance (Spyrou et al., 2020).

Due to restrictions in space and time, and the constant variations in the contexts of play (Méndez et al., 2019), futsal can be characterized as a high-intensity intermittent sport, in which players frequently perform high-intensity actions (HIA) to change their speed or direction, and perform high braking events (Spyrou et al., 2020). HIA are composed of the sum of external load variables consisting of both mechanical (acceleration and deceleration) and kinematic (speed and distance covered) dimensions, which are measured at specific velocity thresholds. Analysis of HIA, which considers both mechanical and kinematic variables, allows for a more holistic approach towards better understanding the physical requirements of the game.

Over the years, most of the research has characterized futsal efforts by neglecting the relationship between physical outcomes and individual tactical actions (contextual information) of the game (Arjol-Serrano et al., 2021; Bradley & Ade, 2018; Pino-Ortega & Rico-González, 2021). Understanding the frequency of HIA is just as important as understanding context during which HIA occur (Ju, Lewis, et al., 2022). More than a reductive quantification of efforts, HIA should be contextualized and associated with specific match events (Nosek et al., 2021). In fact, there is a need to understand the relationship between high intensity efforts, such as changes of direction, as well as increasing and decreasing velocity (Ribeiro et al., 2022b; Spyrou et al., 2020), with offensive and defensive individual tactical actions (Bradley & Ade, 2018). Thus, the contextualization of HIA is critical for the analysis and development of individual athletic performance and team-based training (Santos et al., 2020).

For example, the passes, dribbles, marking actions or defensive returns, correspond to the specific tactical actions that players perform individually to contribute to the collective success of the team. From an ecological dynamics perspective, these individual tactical actions emerge from the relationship between the players' capabilities to play (perceptive, physical, coordinative, technical, etc.) and variations in the game environments, during two specific phases of the game: (a) with ball possession and (b) without ball possession (Corrêa et al., 2012). Also, it is currently acknowledged that variations in individual tactical actions and also in the physical efforts of players may be associated with variations in playing positions or individual specificities of each players' actions during match play

(Serrano et al., 2020). In this regard, recent research has demonstrated that a team is characterized by players with different activity profiles, described by high inter- and intra-player variability (Ribeiro et al., 2020; Ribeiro et al., 2022b). Such findings provide further evidence that "one size does not fit all" and emphasizes the need to contextualize players' activities to optimize training and monitoring processes.

As a result, one of the major challenges of team sports analysis is to integrate and contextualize physical data with individual tactical actions (Torres-Ronda et al., 2022). The best training results are achieved when the training stimulus replicates the physiological demands and movement patterns of the sport (Gabbett, 2010). Based on this premise, coaches and strength and conditioning professionals should be aware of specific match contexts and activities when designing training drills as a means of improving the behaviours and physical performance levels of team sports athletes (Gabbett et al., 2009). To the best of the author`s knowledge, no previous research has focused on investigating the relationship between physical and individual tactical data in futsal to provide coaches with concise information to better prepare training sessions.

Therefore, this study aims to: (i) contextualize individual players' HIA with tactical actions during match play; and (ii) investigate the associations between different playing position, individual tactical actions, and HIA characteristics. Furthermore, this study presents a novel concept towards understanding the relative contribution of specific HIA variables, measured by acceleration, deceleration and high-speed running, to specific tactical actions. From a practical standpoint, this study suggests how each physical variable should be integrated with individual tactical actions to provide a holistic understanding of elite futsal players' performance according to playing position (Ju, Lewis, et al., 2022). The findings of this study will inform relevant practitioners to integrate individual and collective physical and tactical performance behaviours, so as to enhance player physical capacity for the match and, as a result, improve overall team performance.

8.2 Material and Methods

A retrospective observational study was conducted to quantify and analyze a total of 4234 HIA efforts and tactical actions according to positional differences in elite futsal players across seven official matches from one team that competes in the Liga Nacional de Fútbol Sala (LNFS) 1st Spanish Division (2018-2021) as well as the Union of European Football Associations (UEFA) Futsal Champions League.

8.2.1 Subjects

Tracking and match video data were collected from nineteen professional futsal players (age: 28.8 ± 2.4 years, weight: 73.7 ± 6.2 kg, height: 175.9 ± 5.9 cm). Players were classified according to their playing position into defenders (DF; *n* =6), wingers (WG; *n* =10), and pivots (PV; *n* = 3). Goalkeepers were not included in this study because their tactical position is very specific and their positioning dynamics are different from outfield players (Serrano et al., 2021). All players were informed of the purpose of the study and gave written informed consent before the study was conducted. The experimental procedures used in this study were based on the ethical principles of the Declaration of Helsinki and were approved by the local Ethics and Scientific Committee.

Procedures

Matches were randomly selected while simultaneously controlling various situational factors (phases of the season, all official matches were played on the same indoor court under similar environmental conditions, and team or opponent standards) by previously outlined approaches (Ju et al., 2022). Matches were included only if they were close games (goal differential ≤2) and were excluded if a player was dismissed, as this can affect overall work-rates (Ju et al., 2022). A Local Positioning System performance tracking system (WIMU PRO™, Realtrack Systems, Almeria, Spain) was used to monitor and collect external load data when players were on the court. The devices were placed in the upper part of the back in tight-fitting harnesses. The WIMU PRO system showed a high intraclass correlation coefficient (ICC) for the x-coordinate (0.65), a very high ICC for the y-coordinate (0.85), and a good technical measurement error of 2% (Bastida-Castillo et al., 2019). The external load data was analyzed using the SPRO™ (Realtrack Systems, Almeria, Spain) software, which uses timeline monitors to determine when each external load variable (specifically HIA) occurred. To identify the HIA and associate the respective individual tactical actions, the game video footage was synchronized with this timeline. This synchronization is only possible because the player tracks his movements with positional data. Each player's analysis had to be done separately in order to facilitate and eliminate errors in order to identify the HIA. The following individual tactical actions were analyzed by the first and the last authors, who are UEFA qualified coaches, with more than ten years of experience in futsal video analysis. An almost perfect inter-rater reliability (Kappa statistic, *k*=0.85) were observed between observers and perfect intra-rater reliability (k= 0.96) (Ju et al., 2022; McHugh, 2012; Oliva-Lozano et al., 2022) after one month from the first analysis. In the cases of disagreement, the decision was defined by mutual consent.

8.2.2 Measurements

The following physical demand variables were measured and reported as the number of high-speed running activities (HSR; >18 km·h^{-1}), high-intensity accelerations (ACC; ≥3 m·s^{-2}), and high-intensity decelerations (DEC; ≤−3 m·s^{-2}). Table 15 provides descriptions of all individual tactical actions with ball or without the ball analyzed by the research and the observers in each HIA based on previous proposals (Ju, Lewis, et al., 2022; Lupescu, 2017).

Table 15. Descriptions of the variables utilized within the integrated approach.

Variables	Description
With ball	
Dribble	Player moves with the ball in order to progress in some direction.
Interception	Player intercepts a pass by the opposition.
Dynamic ball control	Player receives a pass and moves the ball with intention.
Ball protection	Player uses their body to protect the ball from opponents.
Pass	Player passing the ball towards a teammate.
Shot	Player intends to direct the ball towards the apposition goal.
Disarm	Player intervention and attempt to take the ball away from a direct rival.
Static ball control	Player receives a pass and retains control of the ball in the same place.
Without ball	
Defensive return/loss reaction	The player runs back towards his own goal, immediately following the loss of possession.
Support movements – Away	Player moves to receive a pass from a teammate or to create/explore space (usually at depth).
Support movements – Break	Player moves to receive a pass from a teammate or to create/explore space (usually arrives short to receive ball)
Support movements – Strategy	Players moves to receive a pass from a teammate on strategical situations (e.g., corner kick and free kick)
Marking – Ball trajectory	Player runs following the movement of the ball towards the opponent
Marking – Opponent trajectory	Player runs following the direction of his opponent's movement
Marking – Individual duel	Player in base defence posture preventing opponent's advance
Help Coverage	Player moves to provide defensive cover for teammate

8.2.3 Statistical Analysis

The association between the overall HIA efforts and tactical actions (with and without the ball) variables were determined using a chi-square test and the associated effect size was estimated using Cramer`s V based on the following criteria: ≤0.2, small; 0.2-0.6, moderate; and >0.6, large association (Ho, 2014). The adjusted residual values greater than 1.96 or less -1.96, for each category analyzed, were considered significant (Ho, 2014). A Pearson one sample chi-square test was used to investigate the relationship between HIA within each individual tactical action, with and without the ball. A follow-up binomial test was used to identify statistically significant differences between HIA within each individual tactical action and in instances where only two HIA actions were associated with a specific tactical action. To account for the type I error rate, the *p*-value was adjusted to an α-level of $p \leq 0.02$ based on the number of contrasts performed. The magnitude of statistically significant observations were assessed using Cohen's *W*, for Pearson chi-square tests, and Cohen's *h*, for assessing the magnitude of differences in proportions from binomial tests, and were based on the following criteria: Cohen's *W* ES: 0.1-0.3, small; 0.3-0.5, medium; ≥0.5, large; Cohen's *h* effect size: 0.2-0.5, small; 0.5-0.8, medium; and ≥8, large (Cohen, 2013). The α-level of statistical significance was set as $p \leq 0.05$, unless otherwise stated. All statistical analyses were conducted using IBM SPSS, version 27.0 (Armonk, NY: IBM Corp).

8.3 Results

Individual tactical actions without the ball (n=3497) have a higher frequency in terms of HIA than individual actions with the ball (n=737). Statistically significant differences were observed between the number of HIA efforts (ACC, DEC, and HSR) distribution for general individual tactical actions with or without ball (χ^2= 183.27 (2, N=4234), $p \leq 0.001$) with a small effect size (V = 0.21). Specifically, the frequency of DEC is greatest, followed by ACC and HSR in individual tactical actions with the ball. In individual tactical actions without ball, the contribution of ACC is greatest, followed by DEC, and HSR increases.

Table 16 presents the detailed characterization each individual tactical action with and without the ball according to specific HIA efforts. Generally, the tactical actions performed with the ball, such as static ball control, disarm, shot and pass, revealed prominent frequencies of DEC efforts, compared to ACC and HSR. Thus, such individual tactical actions with the ball can be considered as *unidimensional* as a function of unique DEC efforts.

Tactical actions with the ball, such as dynamic ball control and interception revealed both DEC and ACC efforts, with significantly higher frequencies of DEC compared to ACC efforts (p≤ 0.001; h=≥0.8). Thus, such individual tactical actions with the ball can be considered as *bidimensional* as a function of both DEC and ACC contributions. Conversely, dribble revealed a contribution of all three HIA effort measures (ACC, DEC and HSR), with a significant high frequency of ACC ($\chi 2$= 103.45, (2, *N*=273), p≤0.001; *W*= 0.62), and can be considered as *multidimensional*.

Table 16. Frequency of HIA effort (ACC, DEC, HSR) according to action with (+) and without (-) the ball

	Action	ACC	DEC	HSR	Pearson Chi Square/Binomial Statistics
Actions: + Ball	Static Ball Control	-	64	-	-
	Disarm	-	60	-	-
	Shot	-	72	-	-
	Pass	-	111	-	-
	Ball Protection	13	10	-	p= 0.68; *h*= 0.13
	Dynamic Ball Control	5	**75** **†	-	**p≤0.001**; *h*= 1.1
	Interception	5	**49** **†	-	**p≤0.001**; *h*= 0.95
	Dribble	**169**	64 **α	40 **β #α	χ2= 103.45, df= 2, **p≤0.001**; *W*= 0.62
Actions: - Ball	Help Coverage	**142**	91 **α	5 **† ##†	χ2= 120.87, df= 2, **p≤0.001**; *W*= 0.71
	Marking – Individual Duel	19	**74 **β**	5 **β ##†	χ2= 81.45, df= 2, **p≤0.001**; *W*= 0.91
	Marking - Opponent Trajectory	**341**	272 **	55 **† ##β	χ2= 200.07, df= 2, **p≤0.001**; *W*= 0.55
	Marking - Ball Trajectory	417	**504** **	30 **† ##†	χ2= 401.70, df= 2, **p≤0.001**; *W*= 0.65
	Support Movements – Strategy	**21**	**20**	5 **β ##β	χ2= 10.48, df= 2, **p= 0.01**; *W*= 0.48
	Support Movements – Break	**120**	74 **α	13 **† ##β	χ2= 83.51, df= 2, **p= 0.01**; *W*= 0.64
	Support Movements - Away	**479**	321 **α	186 **α ##α	χ2= 130.87, df= 2, **p≤0.001**; *W*= 0.36
	Defensive Return	**152**	84 **α	67 **α	χ2= 40.06, df= 2, **p≤0.001**; *W*=0.36

Significantly different than ACC (**p≤0.001; * p≤0.05). Significantly different than DEC (## p≤0.001; # p≤0.05). Cohen's *W* effect size (ES): 0.1-0.3, small; 0.3-0.5, medium; ≥0.5, large. Cohen's *h* ES: 0.2-0.5, small (α); 0.5-0.8, medium (β); ≥0.8: large (†). ACC: high-intensity acceleration (≥ 3 $m{\cdot}s^{-2}$); DEC: high-intensity deceleration (≤-3 $m{\cdot}s^{-2}$); HSR: high-speed running (≥ 18 $km{\cdot}h^{-1}$). WG: winger; DF: defender; PV: pivot. Adjusted *p*-value for Pearson Chi Square test p≤0.02. Statistically significant observations are bolded for clarity.

Individual tactical actions without the ball, in contrast to the individual actions with the ball, require a combination of HIA efforts to be performed, and can therefore be considered as *multidimensional* tactical actions. The frequency of ACC is significantly (p≤0.001) greater than DEC and HSR in specific tactical actions without the ball, including help coverage, marking – opponent trajectory, support movements – break and away and defensive return. However, the frequency of DEC is significantly greater than both ACC and HSR in marking – individual duel and marking – ball trajectory (p≤0.001).
The data characterizing individual tactical actions with and without the ball regarding HIA efforts (ACC, DEC, and HSR) according to playing position is presented in Tables 17 and

18. In general, individual tactical actions with the ball revealed quite similar efforts across playing positions. Individual tactical actions without the ball revealed quite similar efforts across playing positions in line with the previous results observed regarding tactical in the actions with the ball. Slight differences were observed in help coverage, marking – individual, and support movement break in WG that require a combination of HIA efforts to be performed in contrast to DF and PV, which require ACC and DEC efforts.

Table 17. Frequency of HIA effort (ACC, DEC, HSR) related to actions with (+) the ball according to playing position (WG, DF, and PV)

	Position	Action	ACC	DEC	HSR	Pearson Chi Square/ Binomial Statistics
Actions: + Ball	**WG**	Static Ball Control	-	38	-	-
		Disarm	-	24	-	-
		Shot	-	37	-	-
		Pass	-	75	-	-
		Ball Protection	11	5	-	p= 0.21; *h*= 0.38
		Dynamic Ball Control	-	53	-	-
		Interception	-	24	-	-
		Dribble	**127**	47 **α	29 **β	χ2= 80.43, df= 2, **p≤0.001**; *W*= 0.63
Actions: + Ball	**DF**	Static Ball Control	-	9	-	-
		Disarm	-	30	-	-
		Shot	-	26	-	-
		Pass	-	25	-	-
		Ball Protection	5	5	-	p= 1.00; *h*= 0.00
		Dynamic Ball Control	-	12	-	-
		Interception	5	**18** *β	-	**p= 0.01**; *h*= 0.60
		Dribble	**23**	9 *α	7 **β	χ2= 11.69, df= 2, **p≤0.001**; *W*= 0.55
Actions: + Ball	**PV**	Static Ball Control	-	17	-	-
		Disarm	-	6	-	-
		Shot	-	9	-	-
		Pass	-	11	-	-
		Ball Protection	-	-	-	-
		Dynamic Ball Control	5	10	-	p= 0.32; *h*= 0.34
		Interception	-	7	-	-
		Dribble	**18**	7	6 **β	χ2= 8.58, df= 2, **p= 0.01**; *W*= 0.53

Significantly different than ACC (**p≤0.001; * p≤0.05). Significantly different than DEC (## p≤0.001; # p≤0.05). Cohen's *W* effect size (ES): 0.1-0.3, small; 0.3-0.5, medium; ≥0.5, large. Cohen's *h* ES: 0.2-0.5, small (α); 0.5-0.8, medium (β); ≥0.8: large (†). ACC: high-intensity acceleration (≥ 3 $m \cdot s^{-2}$); DEC: high-intensity deceleration (≤ -3 $m \cdot s^{-2}$); HSR: high-speed running (≥ 18 $km \cdot h^{-1}$). WG: winger; DF: defender; PV: pivot. Adjusted p-value for Pearson Chi Square test p≤0.02. Statistically significant observations are bolded for clarity.

Table 18. Frequency of HIA effort (ACC, DEC, HSR) related to actions without (-) the ball according to playing position (WG, DF, and PV)

	P	Action	ACC	DEC	HSR	Pearson Chi Square/Binomial Statistics
Actions: - Ball	**W**	Help Coverage	**104**	65 **α	5 **† ##†	χ2= 85.76, df= 2, **p≤0.001**; *W*= 0.70
		Marking – Individual Duel	13	**45** **β	5 **α ##†	χ2= 42.67, df= 2, **p≤0.001**; *W*= 0.82
		Marking - Opponent Trajectory	**207**	**166**	41**β ##β	χ2= 108.36, df= 2, **p≤0.001**; *W*= 0.51
		Marking - Ball Trajectory	252	**334** **	19 **† ##†	χ2= 264.86, df= 2, **p≤0.001**; *W*= 0.66
		Support Movements – Strategy	12	8	-	p= 0.50; *h*= 0.20
		Support Movements – Break	**56**	37 **α	8 **† ##β	χ2= 34.71, df= 2, **p≤0.001**; *W*= 0.59
		Support Movements - Away	**306**	218 **	128 **α ##α	χ2= 72.90, df= 2, **p≤0.001**; *W*= 0.33
		Defensive Return	**99**	50 **α	40 **α	χ2= 31.65, df= 2, **p≤0.001**; *W*= 0.41
Actions: - Ball	**D**	Help Coverage	33	21	-	p= 0.13; *h*= 0.22
		Marking – Individual Duel	5	**24** **β	-	**p≤0.001**; *h*= 0.71
		Marking - Opponent Trajectory	**97**	**82**	6 **† ##†	χ2= 77.20, df= 2, **p≤0.001**; *W*= 0.65
		Marking - Ball Trajectory	**126**	**120**	6 **† ##†	χ2= 108.86, df= 2, **p≤0.001**; *W*= 0.66
		Support Movements – Strategy	5	7	-	p= 0.77; *h*= 0.17
		Support Movements – Break	**33**	**28**	5 **† ##β	χ2= 20.27, df= 2, **p≤0.001**; W= 0.55
		Support Movements - Away	**118**	78 **α	33 **β ##α	χ2= 47.38, df= 2, **p≤0.001**; *W*= 0.45
		Defensive Return	**43**	22 **α	20 **α	χ2= 11.46, df= 2, **p≤0.001**; *W*= 0.37
Actions: - Ball	**P**	Help Coverage	5	5	-	p= 1.00; *h*= 0.00
		Marking – Individual Duel	-	6	-	-
		Marking - Opponent Trajectory	**37**	**24**	8 **β ##β	χ2= 18.35, df= 2, **p≤0.001**; *W*= 0.52
		Marking - Ball Trajectory	**39**	**50**	5 **† ##†	χ2= 35.13, df= 2, **p≤0.001**; *W*= 0.61
		Support Movements – Strategy	7	7	-	p= 1.00; *h*= 0.00
		Support Movements – Break	**31**	9 **β	-	**p≤0.001**; *h*= 0.58
		Support Movements - Away	**55**	25**α	25 **α	χ2= 17.14, df= 2, **p≤0.001**; *W*= 0.40
		Defensive Return	10	12	7	χ2= 1.31, df= 2, p= 0.52; *W*= 0.21

Significantly different than ACC (**p≤0.001; * p≤0.05). Significantly different than DEC (## p≤0.001; # p≤0.05). Cohen's *W* effect size (ES): 0.1-0.3, small; 0.3-0.5, medium; ≥0.5, large. Cohen's *h* ES: 0.2-0.5, small (α); 0.5-0.8, medium (β); ≥0.8: large (†). ACC: high-intensity acceleration (≥ 3 $m \cdot s^{-2}$); DEC: high-intensity deceleration (≤ -3 $m \cdot s^{-2}$); HSR high-speed running (≥ 18 $km \cdot h^{-1}$). WG: winger; DF: defender; PV: pivot. Adjusted p-value for Pearson Chi Square test p≤0.02. Statistically significant observations are bolded for clarity.

Finally, Figures 9 and 10 illustrate the most representative individual tactical actions within each position. Thus, it is possible to verify that the three most representative and statistically significant (p≤0.01) tactical actions with the ball for wingers are dribble (43.19%), pass (15.96%), and dynamic ball control (11.28%). Similarly, the three most prominent and statistically significant (p≤0.01) actions for DF are dribble (22.41%), disarm (17.24%), and shot (14.94%). Similarly, PV are distinguished by dribble (32,29%), static ball control (17,71%), and dynamic ball control (15,63%), which are statistically significantly greater when compared to all other tactical actions (p≤0.01).

Figure 9. Frequency proportion of actions with the ball for each position. Significance and effect size are indicated for the top three greatest proportion actions for clarity. Significant differences are indicated by the corresponding action number with in positions: Static Ball Control (StatBallCtrl), Disarm, Shot, Pass, Ball Protection (BallProt), Dynamic Ball Control (DynBallCtrl), Interception, and Dribble. WG and DF adjusted significance p-value: p≤0.002. PV adjusted significance p-value: p≤0.0024. Cohen's *h* effect size (*h*): 0.2-0.5; small (α); 0.5-0.8, medium (β); >0.8, large (†).

Regarding individual tactical actions without the ball (Figure 10), the three most representative actions for WG include support movement – away (29.4%), marking - ball trajectory (27.28%), and marking - opponent trajectory (18.67%). The following tactical actions were observed for DF: marking - ball trajectory (27.63%), support movement – away (25.11%), and marking – opponent trajectory (20.29%). Finally, the three most prominent tactical actions for PV are as follows: support movement – away (28.61%), marking - ball trajectory (25.61%), and marking - opponent trajectory (18.80%).

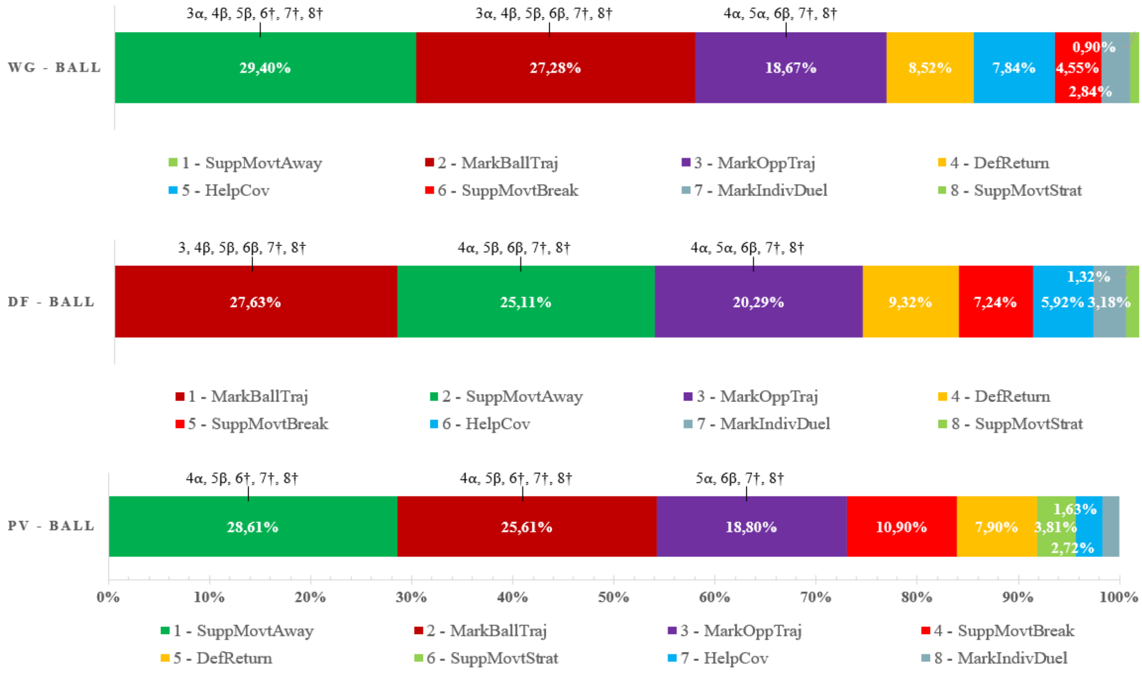

Figure 10. Frequency proportion of actions without the ball for each position. Significance and effect size are indicated for the top three greatest proportion actions for clarity. Significant differences are indicated by the corresponding action number within positions: Help Coverage (HelpCov), Marking – Individual duel (MarkIndivDuel), Marking - Opponent Trajectory (MarkOppTraj), Marking - Ball Trajectory (MarkBallTraj), Support Movements – Strategy (SuppMovtStrat), Support Movements – Break, (SuppMovtBreak), Support Movements - Away (SuppMovtAway), and Defensive Return (DefReturn). Adjusted significance p-value: $p \leq 0.002$. Cohen's h effect size (h): 0.2-0.5; small (α); 0.5-0.8, medium (β); ≥0.8, large (†).

8.4 Discussion

The analysis of physical demands in futsal has been investigated within the last years with some detail and following different approaches (Illa et al., 2020; Ribeiro et al., 2020; Serrano et al., 2020). However, despite the advances in knowledge, the relationship between physical demands and individual tactical actions with and without ball in futsal remains unclear. The main objectives of this research were to contextualize the HIA with the individual tactical actions of players during official match play and investigate the associations between different playing positions, individual tactical actions, and HIA characteristics.

In general, a large percentage of HIA in futsal occurred without the ball, which is in line with the observation that only a single player can maintain ball possession at any given time. However, such actions require cooperation from the other three teammates based on where the player with the ball is positioned and their distance from the opponent (Vilar et al., 2012), which may potentially increase the number of HIA performed. In turn, when the team loses ball possession, the four players of the team without possession, must make efforts to recover the ball and as a result may be required to perform greater HIA efforts.

Furthermore, the results of this study demonstrate that individual tactical actions in futsal, both with and without ball, are predominantly mechanical (ACC+DEC), with high-intensity movements in small and restricted spaces. However, while individual tactical actions with the ball tend to require DEC efforts (*unidimensional*), tactical actions without the ball require a combination of ACC and DEC efforts and a lesser contribution of HSR efforts (*multidimensional*).

The fact that most actions with the ball occur with a high frequency and magnitude of deceleration promotes a higher mechanical load (Dalen et al., 2016) caused by high-eccentric force impact peaks and loading rates, which promotes damage in soft-tissue structures (Verheul et al., 2021). In this regard, it was noted that tactical actions with the ball have the highest proportion of *unidimensional* characterization. That is, in such instances the actions of a pass, shot, disarming, and static reception of the ball all exclusively involve high DEC efforts.

It is interesting to note that this variable has already been mentioned in the literature as one of the most relevant and reliable for monitoring external load fatigue (Ribeiro et al., 2020), and is considered critical for the match outcome (Rhodes et al., 2021). According to previous research, individual tactical actions of shooting and disarming have the greatest impact on the outcome of the game and, as a result, the team's success (Santos et al., 2020). Thus, coaches must ensure that players develop sufficient eccentric strength to be prepared to perform these actions frequently in game, as well as to improve the context of these actions during training exercises and the match.

Tactical actions without the ball have a higher HSR contribution than ball actions, which may suggest that high-intensity kinematic efforts are more pronounced in these moments of the game. This evidence supports the notion that sprint actions occur more frequently when there is no ball possession (Oliva-Lozano et al., 2022), which is consistent with previous futsal research findings (Ohmuro et al., 2020). Previous studies in association football have also found that increasing the number of actions with the ball reduces the distances covered and the speeds at which these distances are covered (Bradley et al., 2013; García-Calvo et al., 2022). However, it is crucial to recognize that the futsal field dimension (40x20) inhibit players from reaching maximum speeds, which may explain the reasons for less frequent observations of HSR when compared to ACC and DEC. Such a notion allows for the evaluation of physical requirements and their impact on players regardless of whether they have the ball or not. Following this line of thought, future research should further investigate which types of individual tactical actions are more physically demanding. Our findings suggest that when multidimensional efforts (ACC+DEC+HSR) occur in the same individual tactical action, they may be associated with more physically demanding activities. Furthermore, clarifying these physical efforts may contribute towards understanding when the most intense periods in a futsal match occur.

Therefore, it may be more relevant to investigate the context during which players accelerate, decelerate, or run at high speeds rather than the discrete frequency or magnitude of ACC, DEC, HSR efforts, to explain the modulators of physical efforts during match play. Our findings may allow coaches to design the physical intentions for each exercise by manipulating the individual tactical actions with or without the ball and combining them. For instance, to promote more strength exercises with a higher frequency of ACC and DEC actions or more resistance or velocity exercises with a higher frequency of HSR actions. Furthermore, our findings suggest that ACC and HSR are related to moments on the field when a team explores more open spaces to progress or recover, such as dribbling or support movements - away, defensive return and marking - opponent trajectory actions. Conversely, the combination of ACC and DEC efforts may be associated with match moments when players or teams want to close the space to prevent the opponent from progressing on the field through actions such as marking - ball trajectory, individual duel, and interception. Additionally, from an individual standpoint, this evidence will allow a better understanding of the physical impact that individual actions with or without the ball have on players, and according to a recent review, it could also help in injury prevention by identifying the actions that most commonly cause injury in football (Aiello et al., 2022).

The results also revealed that individual tactical actions, with or without the ball, tend to present similar physical characterization of external load (HIA) regardless of playing position. Such observations support the notion that, regardless of different tactical constraints of playing positions, individual tactical actions are strongly associated with specific physical requirements. However, previous research has found that futsal players in different positions have different physical performances (Illa et al., 2021; Ohmuro et al., 2020; Ribeiro et al., 2022b; Serrano et al., 2020; Spyrou et al., 2020) with the authors tending to justify this over time (without proving sufficient evidence) as a result of the different roles and functions required for each playing position. Thus, the frequency and type of individual tactical actions required in different playing positions may be what distinguishes the physical demands that players experience during a match or training session.

Our findings are consistent with the literature, suggesting that wingers and pivots are the most dissimilar positions. Wingers have a higher frequency of HIA (Ribeiro et al., 2022a), which renders them as the most physically demanding position. When wingers have the ball, they increase the number of 1v1 situations by increasing dribbling actions, dynamic receptions, and, as a result, ball protections. Tactical actions without the ball actions are usually represented by many offensive depth movements to create space or capitalize on goal-scoring opportunities (Ohmuro et al., 2020), which is represented in this study by the support movements – away tactical action. Also, the winger position demonstrates a higher frequency of defensive coverage actions, probably due to the players lateral positioning on the field (Serrano et al., 2021), as well as many individual duels, which are represented by marking – ball and opponent trajectory tactical actions. Interestingly, wingers and defenders have the most similar profiles, which is likely due to the game's common rules and functions (Serrano et al., 2020). However, due to the role of playing position, defenders have a higher incidence of disarming and interception actions with the ball, marking in individual duels, and support movements- away without the ball. In turn, pivots have the lowest frequency of HIA (Ohmuro et al., 2020; Ribeiro et al., 2022a), and usually maintain a tactical position on the field that is near to the goal (Serrano et al., 2020). Therefore, pivots usually play with their back turned to the opposing goal, in order to assist or shoot on goal (Sarmento et al., 2016), which is consistent with the representative ball actions found in current study for the pivot position, which are represented by dynamic and static receptions.

These findings provide novel information for using an integrated approach that contextualizes match physical performance, which would progress the field towards a better understanding of the global match demands. Furthermore, a recent descriptive study of training load monitoring and player performance and fatigue assessment practices in Portuguese and Spanish professional futsal teams (Spyrou, Freitas, Herrero Carrasco, et al., 2022) found that the performance or fatigue assessments used by strength and conditioning coaches were all analytics, implying that physical tests were performed without context. The challenge for the future is to develop physical tests that contextualizes the most relevant individual tactical actions of each playing position based on the current findings. To improve players` match performance, training tasks must be designed to expose players to game contexts which reflect technical, tactical and physical demands and represents the competitive environment of an official match.

Limitations

The present investigation has some limitations that should be considered. First, despite the sample size being constituted by elite players, the sample size is limited and the number of players per position is not equal. The analysis also neglected the team formation used by the team in each match. Thus, the generalization of results should be interpreted with caution (Hecksteden et al., 2021). Future studies should address these limitations to confirm drawn conclusions. Finally, while individual tactical actions were analyzed, other match-related contextual variables such as team level, style of play, players' age, or match status were not considered and might be considered in future studies.

8.5 Conclusions

The individual tactical actions with and without the ball have different physical requirements due to their respective HIA requirements and characteristics. It was found that in tactical actions with the ball there was a higher frequency and contribution of DEC and ACC when compared to HSR. Conversely, in tactical actions without the ball, there is a tendency for greater ACC and HSR frequency and performance when compared to DEC.

The high-intensity physical demands in elite futsal have an essential mechanical dimension (ACC+DEC), with high-intensity movements in a short space being a critical component of performance in the sport. It was discovered that regardless of the position of the player on the field, individual tactical actions tend to have the same physical characterization (HIA), suggesting that such tactical actions are strongly associated with physical requirements despite the different tactical role of playing positions.

The frequency and type of individual tactical actions that each player most frequently performs, according to the rules and specificities of playing positions, will distinguish the different activity profiles and their physical demands. These findings have important implications for practice as coaches are better informed and have a greater understanding of the load that their players are exposed to during match play, which therefore allows them to organize and manage training sessions from both perspectives: performance enhancement and injury prevention.

9. General Discussion

The purpose of this thesis was to investigate the complex nature of futsal to better explain the physical requirements during elite futsal match-play, as well as to identify metrics and suggest methods that will eventually better represent these demands. To accomplish with that purpose, six studies were developed in this thesis. The sequence of the studies come from issues related with the athlete monitoring systems and the variables used to a deeper understanding of the performance of players in the futsal context. The first goal was to contribute to the transformation of data into straightforward and powerful knowledge that improves the monitoring systems procedures and communication related with the physical demands of futsal. Second, it was expected that the contextualized information can serve as a springboard for the development of coaching strategies of game management or training management to promote the individualized performance of players. As a result, all field professionals will be able to apply some of these findings to develop exercises and training tasks that accurately simulate global and individualized match-play demands.

Development an athlete monitoring system in elite futsal

Previous research has identified futsal as the most demanding team sport due to match play characteristics (Agras et al., 2016; Barbero-Alvarez et al., 2008; Naser et al., 2017; Spyrou et al., 2020). Athlete monitoring systems were found to be extremely important in this context, particularly for professional team sports, in order to achieve the best state of physical performance. In other words, it is well understood that in order to achieve peak performance, athletes must find the optimal balance between load and recovery so that they are at their maximum capacity of competition readiness (Mujika et al., 2018).

In the first study, the proposed model for training monitoring (subjective [sRPE, TQR and WBs] and objective [CMJ] measures) explained 31% of team match performance. Given that, player and teams' performance in futsal result from a complex mix of technical, tactical, and psychological factors (Agras et al., 2016), in which 31% were explained by physical variables. Furthermore, Countermovement Jump- coefficient variation (CMJ-cv) was found to be an important variable that influenced player and team match performance. This evidence is explained by the fact that lower CMJ-cv values were associated with better individual and team match performance. In this study, higher values of weekly load and higher values of WBs were related to lower CMJ-cv.

The analysis of the coefficient of variation of CMJ values , allowed to understand the players and teams' performance in relation intra-player variability. Recognizing that a proper balance of training load is related to a higher probability of success in match outcome (Ryan et al., 2020), the analysis of individual weekly variations of CMJ (CMJ-cv) have significant implications for players' readiness to compete and to achieve higher individual performance and collective results.

Future studies should investigate into the relationship between external load demands and other training load measures in an athlete monitoring model in order to better predict readiness in elite futsal players.

Also, the analysis of the weekly training load using subjective measures (sRPE, TQR and WBs) contributed to evaluate the response of players to the session training load and its wellbeing, with the individual variability in CMJ providing an objective evaluation of readiness for performance (Bourdon et al., 2017; Gabbett et al., 2017; Loturco et al., 2017). In line with that, our results revealed a significant negative relationship of sRPE and WBs with the CMJ-cv (the higher the sRPE and WBs values, the lower the weekly CMJ-cv).

The understanding of the external load variables that best describe the physical demands of the game and how players cope with these demands during match-play was the purpose of study 2, which develops the course of the thesis assumptions.

To the best of our knowledge, this second paper was the first to be published with physical performance analysis data collected during official futsal matches using LPS technology.

Characterization of futsal demands – external load metrics

Identifying the variables that best discriminate the physical roles of elite futsal players provides important data for prescription and training periodization, highlighting the importance of analyzing and monitoring each player's physical demands of the match based on their specific profile (Rago, Brito, Figueiredo, Krustrup, et al., 2020; Wilke et al., 2019).

This study established that players have distinct capacities to perform physical activity, allowing for the identification of three distinct activity profiles via cluster analysis: higher, medium, and lower. These findings imply that variability should be considered when planning and interpreting data, with differentiated attention paid to load individualization and recovery process.

Research has shown that high-intensity running (HSR), accelerations, and decelerations account for a significant component of the high-intensity external load, imposing distinct and disparate physiological and physical demands on players (Vanrenterghem et al., 2017). Furthermore, while accelerations have a higher metabolic cost (Hader et al., 2016), decelerations have a higher mechanical load (Dalen et al., 2016), likely caused by high-eccentric force impacts peaks and loading rates promoting damage in soft-tissue structures (Verheul et al., 2021). As such, the frequency of HSR actions and high-intensity accelerations and decelerations completed during match play are commonly associated with decrements in neuromuscular performance capacity with higher post-match muscle damage (Harper et al., 2019).

Our results found that the external load variables with the highest predictor importance value to distinguish player activity profiles were: deceleration per minute (mechanical), distance covered per minute, walking per minute, jogging per minute and sprinting per minute (kinematics), and lastly metabolic power per minute (Metabolic).

In addition, we analysed the collinearity between the variables to synthesize information, simplify and improve the interpretation of the data for coaches and strength and conditioning professionals. Our results revealed that, in general, there were higher correlations between the distance covered per minute (kinematic), deceleration per minute (mechanical) and metabolic power per minute (metabolic), with the other variables. It should be noted that these variables were previously identified as part of the predictor importance group to distinguish the different activity profiles, which reinforces their validity and reliability in measuring physical performance in futsal players.

Furthermore, distance covered per minute was found to have significant correlations with walking per minute, jogging per minute, and running per minute, implying that distance covered per minute could be tabulated to represent all running speed thresholds between 0 and 18km/h. In order to characterize all of the speed thresholds, it is necessary to monitor distance covered above 18km/h in addition to distance covered per minute. This suggestion is consistent with the significance and necessity of individualizing speed thresholds in order to provide insight into players' physical responses to training and enable comparisons between players' profiles (Rago, Brito, Figueiredo, Krustrup, et al., 2020). Considering that deceleration per minute was strongly related to almost kinematic variables, it may be a robust variable to analyse the physical load of players during futsal training sessions and matches. The metabolic power per minute analysis suggests that it may be less sensitive to peak demands, but it could be included in the analysis of physical demands of a futsal match as a supplement to kinematic and mechanical variables to evaluate high match-play requirements (Polglaze & Hoppe, 2019). To summarize, distance covered per minute and decelerations per minute highlight intensity, whereas metabolic power per minute distinguishes the volume of external load demands.

Based on the findings from this study, we proceed to propose a multifactorial concept identified as high-intensity activities (HIA), which represents the sum of external load variables with mechanical (accelerations and decelerations) and kinematic (speed and distance covered) dimensions (Ribeiro et al., 2022a). Furthermore, by combining mechanical and kinematic variables allows for a more holistic analysis of the physical requirements of the match, rather than analysing it individually.

Considering that in the competition, the ability to perform HIA repeatedly is considered critical for player, it is interesting to note that in the football literature some studies found that less successful teams had a decrease in their ability to perform HIA over the match (Di Salvo et al., 2009; Krustrup et al., 2006). In fact, coaches claim that information regarding HIA is required and are most commonly included in their physical performance reports (Nosek et al., 2021), which inform the development of sport-specific training drills that maximize competition performance (Impellizzeri et al., 2020).

Physical performance during match-play

Another significant finding of this study was that futsal players in competition were able to maintain their physical performance from the first to the second half, indicating that there was no decrease in physical activity performed. These findings contradict previous futsal research findings, in which the authors observes a decrease in distance covered, distance covered at high speed, and mean HR (Barbero-Alvarez et al., 2008; De Oliveira Bueno et al., 2014). These differences in results could be explained by the instruments used, sample characteristics, and potential league differences. In turn, our results corroborate the evidences found by Milioni et al., (2016) which revealed no significant differences between the first and second halves in internal load indicators such as lactate and maximum HR values. This topic reopened the debate about players' ability to maintain or even improve their physical performance throughout a match.

For example, Serrano et al., (2020), which also used the LPS system, confirmed our findings. The study included an analysis of 10 official matches from a top team in the Spanish futsal league, with the main finding being that there were no significant differences between the first and second halves. The fact that futsal is characterized by unlimited substitutions and that the score of the match can remain uncertain until near the end of the match could be decisive for such outcomes.

Future research in this area is warranted to investigate the impact of playing time and different competitive contexts and situational factors on top-level futsal players' external load.

In order to gain a deeper understanding of the futsal physical demands, and taking into account the recent evidence of study 2, we investigated the longitudinal player physical performance variability during a short congested periods in study 3, which has been one of the most debated topics in football literature but is still very scarce in futsal (Gualtieri et al., 2020; Yiannaki et al., 2020).

Physical performance during congested period – managing playing time is crucial

The concerns about fixture congestion are justified based on the likelihood of increasing residual fatigue, risk of injury, and underperformance due to reduced time for appropriate physical recovery. According to the findings of the study 3, physical performance did not decrease during the congested period. Also, players who played more time revealed a lower external load per minute than the players that played less in Match Day 1 (MD1). The biggest increase occurs from MD1 to Match day 3 (MD3) in almost of variables (total distance covered [TDC], high-speed running [HSR], acceleration [ACC] and deceleration [DEC]) for players that played more time in comparison with players who played less time. This evidence reinforces the importance of controlling not only the intensity of performance but also the volume to improve the performance state of each player during the congested period.

This evidence contradicts previous futsal research, which found a decrease in physical performance during a congested tournament with six matches in three days (Dogramaci et al., 2012). These disparities may be explained by differences in the congested periods considered in each study (e.g., number of matches vs number of days). In turn, the findings of Charlot et al., (2016) were partially consistent with the findings presented here, demonstrating stability in physical performance and a slight increase in the subjective perception of players' effort throughout the competition without lowering the high level of physical performance.

Our results suggest that elite male futsal players have an appropriate level of conditioning as well as the ability to recover and regenerate after multiple stressors. Furthermore, from MD1 to MD3, there was interindividual variability in performance. Despite the fact that different players have different recovery profiles (Wilke et al., 2019), all players appeared to maintain their performance levels between matches.

Interestingly, considering the significant effect of playing time on physical performance growth, it was observed that the players who competed for more time revealed lower intensity per minute in each match but increased their performance (high TDC and HSR) over the congested periods (from MD1 to MD3) more than the players who competed for less time. However, they also revealed higher increase in s-RPE than the players who competed for less time. Corroborating these findings, others authors have noted that the capacity of players to maintain physical intensity between matches in congested periods can be strongly associated with individual strategies of pacing management in a conscious or unconscious way (Julian et al., 2021). Knowing the number of matches required to perform successfully, players can adjust their performance strategies to preserve energy and maintain the ability to perform high-intensity efforts (Waldron & Highton, 2014).

These findings may also be justified by the unlimited rolling substitutions allowed in futsal, which, if well managed by coaches with a good player interchange rotation, may allow players to suffer less muscle damage and general fatigue.

The issue of congested fixtures cannot be viewed as a linear problem relating exclusively to physical aspects per se; it is a multidimensional issue in which physical, tactical, and physiological issues interact to constrain each player's individual performance.

Future research should investigate the multidimensional problem of performance, linking the different dimensions (physical, technical, tactical and psychological) for a better understanding of players adaptations to congested periods.

Study 4 was planned to close the gap in the existing literature by considering the effect of unlimited substitutions in physical performance as well as in the methods used to measure it. Considering the previous results, it is necessary to investigate not only the effect of playing time, but also the rest time during the match interchange rotations in players physical performance.

Futsal players performance measured by interchange rotation

In the study 4, three distinct patterns were isolated using cluster analysis: players with a low activity profile that performed an average of 10 HIA per interchange rotation; players with a medium activity profile that performed an average of 21 HIA per interchange; and players with a high-intensity profile that performed an average of 38 HIA per interchange.

Based on the activity profile, data analysis of the temporal effects of interchange rotations on the frequency of HIA revealed that players were capable of maintaining a consistent number of HIA during the match. This data suggests that players maintain their ability to perform HIA regardless of match context (result, strategy, number of fouls, model system, and opponent's level), which is an interesting finding of this work.

The players in this study competed for an average of 3.9 min per interchange rotation on the court and on the bench, resulting in two or three interchanges per half with approximately a 1:1 ratio. Our findings about the ratio are in agreement with previous literature (Naser et al., 2017), and are consistent with the literature on energy systems, emphasizing the importance of developing a training program that specifically emphasizes the work-rest ratio (energy system) required to play futsal. The ATP-CP replenishment time is close to 20s of rest, and the intramuscular reserve restoration time is approximately within the average time that elite futsal players are on the bench (3.9 min) (Ulupınar et al., 2021). In this regard, teams that employ a higher frequency interchange rotation strategy predispose their players to be physically available for offensive and defensive actions, putting them in a better position to succeed (Clay & Clay, 2014).

As situational aspects play an extremely important role in the interpretation of physical demands (Novak et al., 2021), our results showed that playing time and the work-rest ratio were the variables that most contributed to the classification of the math activity profiles of the players. Furthermore, the accumulation of the work-rest ratio and the rest time must also be taken into consideration.

This evidence brings a new discussion regarding the proposals that merely consider only the athletes' ball in play time in relation to the total match time to calculate the values of the external load variables. In fact, this approach leads to the understanding that players who are less time on the court tend to present higher physical performance values per minute when compared to players with more playing time (Ribeiro et al., 2022b). However, according to our results, when the physical effort per minute was calculated not considering the total playing time but the playing time per interchange rotation and considering the work-rest ratio, the players that spent more time on the court than on the bench were the ones that achieved the highest level of match effort. In our opinion, and given that futsal is a sport with unlimited substitutions, calculating the match effort per minute without considering the work-rest ratio of play does not provide sport scientists and coaches with a correct understanding of the impact that physical demands of futsal matches have on their players.

Future research should investigate futsal players physical performance in different contexts at lower quality levels, which may have a different pattern in playing time and interchange rotation management.

Following the work 4, study 5 was developed to address challenges that had not been fully answered in the last works, based on two previous evidences: the importance of time in understanding HIA capacity, and the observed variability in activity profiles.

HIA properties of elite futsal players by playing position

The primary findings of study 5 revealed, based on the analysis of HIA properties, effort, time-frequency, and work rate, that physical demands during elite futsal match-play are position-dependent. HIA duration and distance covered did not reveal any difference according to playing position. These findings are consistent with previous research, in which the authors reported similar values of physical demands between positions based on mean values (Serrano et al., 2020), as well as the most demanding scenarios (Illa et al., 2021). In fact, it is possible to assume that the HIA duration and distance covered could be defined as variables that characterize in general match demands, given that values are consistent across all playing positions. In turn, and due to the observed differences in their

values, HIA effort, work rate, and time frequency are variables that defined the structure of match demands based on player positions.
The interpretation of these findings strengthens the evidence that a futsal player requires a high capacity to repeat HIA, implying that the activity profile of elite futsal players is dependent on both aerobic and anaerobic energy metabolism pathways, particularly the phosphagen system (Castagna & Álvarez, 2010). Furthermore, the fact that each HIA is repeated on average every 26 seconds (Wingers-21s, Defenders- 25s Pivots- 32s), which is approximately the time it takes for 50% of the ATP-CP to be replenished, helps to explain futsal players' ability to frequently repeat high-intensity efforts. However, when interpreting this association, some caution is required because the time between HIA is not spent passively resting, but rather engaging in less intense activities.
In line with this, despite the similarities between the duration and covered distance of each HIA, the match demands of futsal players differs according to playing positions. Wingers, as expected, were the most demanding position, with higher values of HIA properties followed by defenders and pivots. These findings could be explained by the fact that wingers, usually play with constant variations in the pace of play to explore 1 vs 1 situations or to create numerical and positional superiorities and promote defensive imbalances (Ohmuro et al., 2020; Santos et al., 2020). This evidence is consistent with the findings of previous research, which investigated the areas of the field covered by players and concluded that wingers occupied more court space areas in the pitch`s middle line and with more variability than other playing positions (Serrano et al., 2021).
The second main finding from Study 5 found a decrease in the rate of change in physical performance for wingers and defenders throughout the match. Pivots maintain a constant physical performance across interchange rotations. This findings from the winger and defender positions contradicts what we found in our previous study (Ribeiro et al., 2022a), but such differences may be due to methodological issues, such as analyzing players by position rather than classification by clusters.
The cluster analyses help us in understanding that different playing times, rest times, or work-rest ratios that futsal players have during match play distinguish the different activity profiles. Adopting player-specific intensity zones, in our opinion, can add value to the interpretation of GPS data by assisting coaches' decisions regarding subsequent training dose prescription based on individual capacity and needs, which is critical for optimizing performance and reducing injury risk (Rago, Brito, Figueiredo, Krustrup, et al., 2020).
It is acknowledged that HIA may be influenced by other contextual factors (Novak et al., 2021), and in consequence, we cannot conclude that any decrease in physical performance observed is due to the development of fatigue. However, in futsal, the final result is usually

determined in the final moments of the match, resulting in a period marked by high physical and emotional demands, as well as different variations in match dynamics. These findings highlight the importance of further investigating an experimental protocol in a simulating match with varying playing times and recovery times (different work-rest ratios) to better understand the variation in players physical performance, measuring not only the external load but also the internal load with blood biomarkers. Under this scope, the last study (6) from this thesis, intent to explore the associations between the HIA and individual tactical actions.

Individual tactical actions behind HIA

Despite some important advances in knowledge, the relationship between physical demands and individual tactical actions with and without ball in futsal remains unclear.

The results of study 6 demonstrate that individual tactical actions in futsal, both with and without ball, are predominantly mechanical (ACC+DEC), with high-intensity movements in small and restricted spaces. However, while individual tactical actions with the ball tend to require DEC efforts (*unidimensional*), tactical actions without the ball require a combination of ACC and DEC efforts and a lesser contribution of HSR efforts (*multidimensional*).

Curiously, the most actions with the ball occur with a high frequency and magnitude of deceleration promotes a higher mechanical load (Dalen et al., 2016) caused by high-eccentric force impact peaks and loading rates, which promotes damage in soft-tissue structures (Verheul et al., 2021). In this regard, it was noted that tactical actions with the ball have the highest proportion of *unidimensional* characterization. That is, in such instances the actions of a pass, shot, disarming, and static reception of the ball all exclusively involve high DEC efforts.

The decelerations has been previously finding in ours previous work as one of the most relevant and reliable for monitoring external load fatigue (Ribeiro et al., 2020), and is considered critical for the match outcome (Rhodes et al., 2021). Furthermore, individual tactical actions like shooting and disarming that are unidimensional (have a contribution from only one external load variable, in this case deceleration), have the greatest influence on the result of the game and, consequently, the success of the team (Santos et al., 2020). Coaches are responsible for ensuring that players achieve a level of eccentric strength that will enable them to perform these actions frequently in match, as well as to improve the context of the actions during training sessions.

Tactical actions without the ball showed a higher HSR values than ball actions, which may suggest that high-intensity kinematic efforts are more pronounced in these moments of the game. This evidence supports the notion that sprint actions occur more frequently when there is no ball possession (Oliva-Lozano et al., 2022), which is consistent with previous futsal research findings (Ohmuro et al., 2020). Previous studies in association football have also found that increasing the number of actions with the ball reduces the distances covered and the speeds at which these distances are covered (Bradley et al., 2013; García-Calvo et al., 2022). However, it is crucial to recognize that the futsal field dimension (40x20) inhibit players from reaching maximum speeds, which may explain the reasons for less frequent observations of HSR when compared to ACC and DEC. Such a notion allows for the evaluation of physical requirements and their impact on players regardless of whether they have the ball or not. Following this line of thought, future research should further investigate which types of individual tactical actions are more physically demanding. Our findings suggest that when multidimensional efforts (ACC+DEC+HSR) occur in the same individual tactical action, they may be associated with more physically demanding activities.

Another interesting finding from study 6 is that regardless of playing position, individual tactical actions, whether they involve the ball or not, tend to present similar physical characterizations of external load (HIA). Such observations support the notion that, regardless of different tactical constraints of playing positions, individual tactical actions are strongly associated with specific physical requirements. However, previous research has found that futsal players in different positions have different physical performances (Illa et al., 2021; Ohmuro et al., 2020; Ribeiro et al., 2022b; Serrano et al., 2020; Spyrou et al., 2020) with the authors justifying this as a result of the different roles and functions required for each playing position. Thus, the frequency and type of individual tactical actions required in different playing positions may be what distinguishes the physical demands that players experience during a match or training session.

Our findings are consistent with the literature, suggesting that wingers and pivots are the most dissimilar positions. Wingers have a higher frequency of HIA (Ribeiro et al., 2022a), which renders them as the most physically demanding position. When wingers have the ball, they increase the number of 1v1 situations by increasing dribbling actions, dynamic receptions, and, as a result, ball protections. Tactical actions without the ball actions are usually represented by many offensive depth movements to create space or capitalize on goal-scoring opportunities (Ohmuro et al., 2020), which is represented by the support movements – away tactical action. Also, the winger position demonstrates the higher frequency of defensive coverage actions, probably due to the players lateral positioning on the field (Serrano et al., 2021), as well as many individual duels, which are represented by marking – ball and opponent trajectory tactical actions. Interestingly, wingers and defenders have the most similar profiles, which is likely due to the game's common rules and functions (Serrano et al., 2020). However, due to the role of playing position, defenders have a higher incidence of disarming and interception actions with the ball, marking in individual duels, and support movements- away without the ball. In turn, pivots have the lowest frequency of HIA (Ohmuro et al., 2020; Ribeiro et al., 2022a), and usually maintain a tactical position on the field that is near to the goal (Serrano et al., 2020). Therefore, pivots usually play with their back turned to the opposing goal, in order to assist or shoot on goal (Sarmento et al., 2016), which is consistent with the representative ball actions found in current study for the pivot position, which are represented by dynamic and static receptions.

These findings provide novel information for using an integrated approach that contextualizes match physical performance, which would progress the field towards a better understanding of the global match demands.

Future research should investigate others match-related contextual variables such as team level, style of play, players age, or match status.

As a general limitation of this thesis, we highlight the small sample sizes, which is common in all studies and requires careful data interpretation. However, because the samples always consisted of elite athletes and teams and were collected in official competitions, the data has a unique content that only the competitive environment can provide, because it can be influenced by several factors and produce multidimensional results. Furthermore, collaboration between elite team sports and research institutions should be encouraged in order to use data to benefit both science and practitioners.

10. Conclusions

The thesis presented here allows us to propose evidence for improved monitoring of elite futsal athletes, and consequently a better understanding of the game's physical and tactical demands. However, due to the game's complexity and the countless variables that can influence performance and, as a consequence, the team's final result, we believe that this topic is not closed in this work, and there are advantages in continuing to explore the relationship between physical performance and different contextual information of the match-play to improve game knowledge and coaches intervention.
The main conclusions drawn from the six studies on current investigation were:

1) Planning is an essential part of training process, whereby athlete monitoring system data can play a vital role. Furthermore, the performance staff's goals are to manage the fatigue-recovery process to improve performance and reduce injury risk. Our findings highlight the significance of an effective athletic monitoring system defined by the analysis of training load, recovery status, player well-being, and neuromuscular performance in understanding players' readiness for competition, with clear implications for their match performance and, consequently, the final team result. The CMJ-cv revealed to be a key factor in balancing the weekly training load.

2) To improve load monitoring systems, our findings suggest that deceleration per minute (mechanics), distance covered per minute (kinematics), and metabolic power per minute (metabolic) are the best metrics to represent the physical demands of futsal match-play. Also, distance covered and deceleration may be important variables in identifying intensity, whereas metabolic power distinguishes the volume of external load demands.

3) To detect the different activity profiles observed in elite futsal players, performance staff should incorporate the walking per minute, sprinting per minute and jogging per minute into their athlete monitoring system (in addition to the variables mentioned above). These findings allow strength and conditioning coaches to individualize the thresholds to the specific requirements of each player.

4) One of the outcomes of our thesis was the proposal of the concept of high-intensity activities (HIA) to analyse physical performance in futsal, which is supposed to be closer to detecting fatigue patterns due to the chosen metrics with

high thresholds (accelerations ≥3 m.s-1; decelerations ≥-3 m.s-1; and high-intensity running ≥18km/h) and better represent match-play demands.

5) Once establish the best metrics to improve the accuracy of tracking systems, attention should be turn to the analysis process in different competitive contexts. Under this scope, our findings suggest that elite futsal players can maintain physical performance between the first and second halves, as well as during congested periods, where our results suggest that players can maintain physical performance throughout the match competition schedule.

6) Playing time is a key factor in futsal to determine the ability of players to perform HIA. In this regard, and given that futsal is a sport with unlimited substitutions, our thesis proposes that futsal player performance analysis should be done per each player interchange rotation (time that each player has per rotation), which should include the work-rest ratio and rest time in the analysis process.

7) More research is required (with larger sample sizes and integration of internal load variables and biomarker data) to confirm how much physical capacity variation occurs over the course of player interchange rotations; however, the first interchange rotation is accepted to be the most physically demanding.

8) Our findings show that players have different activity profiles with different capacities to perform HIA. Wingers remaining the position with the greatest ability to perform HIA, followed by defenders and pivots.

9) Individual tactical actions with the ball have a higher frequency and contribution of DEC and ACC when compared with HSR. Conversely in tactical actions without the ball, there is a tendency for higher frequency of ACC and HSR efforts when compared to DEC. Furthermore, our findings revealed that intense physical demands in elite futsal have an essential mechanical dimension (ACC+DEC), with high-intensity movements in a short space being a critical component of sport performance.

10) Individual tactical actions tend to have the same physical characterization (HIA), suggesting that such tactical actions are strongly associated with physical requirements despite the different tactical role of playing positions.

We conclude that variability in HIA abilities is closely related to playing time and rest time (work-rest ratio), and to the type of individual tactical actions that each specific position requires of the players, as well as the frequency with which these demands are imposed during the game.

These conclusions are intended to provide knowledge to all futsal stakeholders, field professionals, and sport sciences, allowing them to be better informed and have a holistic understanding of the load to which futsal players are exposed during match play. Furthermore, clear information will improve all dimensions of athlete monitoring systems from both perspectives: performance enhancement and injury prevention. Based on our findings, we conclude this thesis by suggesting Practical Applications (table 19) and proposing a futsal monitoring system (table 20).

11. Practical Applications

This chapter intends to summarize our thesis' findings and practical applications. Table 19 contains practical applications based on our evidence, as well as a proposal for a futsal athlete monitoring system (table 20).

Table 19. Findings and practical applications from our thesis

Is an athlete monitoring management system important for improving player match performance in elite futsal?

Findings	Practical Applications
*CMJ-cv was identified as a key player and team match performance variable *↓CMJ-cv = ↑individual & team match performance	CMJ-cv should be included in futsal monitoring systems to monitor players' readiness and intra-player variability during the microcycle.

Which metrics best measure physical demands in futsal?

Findings	Practical Applications
*Players revealed ≠ activity profiles according to the time of play	Players with different activity profiles should be analysed using specific and individualized thresholds. Match external load values should be used to manage the training load over the microcycle (e.g., MD-5 to MD-1). [Load Periodization].
<u>*Best predictor variables of ≠ profiles:</u>	
i) Relative number of decelerations (n/min; mechanical)	Develop acute and chronic ratios for longitudinal analyses.
ii) Relative distance covered (m/min; kinematic) iii) Relative specific thresholds distance covered (e.g., walking, jogging, sprinting) (m/min; kinematic)	To improve load management, S&C coaches could classify field exercises according to the technical staff's expectations (e.g., increasing/decreasing mechanical, kinematic, or metabolic loads).
iv) Metabolic Power (au;metabolic)	Use the concept of HIA (sum of high-intensity ACC, DEC and HSR) to control efforts during match or training session.

Is it possible for players to maintain high-intensity physical performance during a futsal match-play? And during congested periods?

Findings	Practical Applications
*Physical Performance ≈ 1st Half and 2nd Half *Physical Performance ≈ Congested Periods (3 matches in 4 days) *Playing time  factor	Coaches who are better informed about match exertion values and understand the variation in players' match demands are better prepared to obtain the optimal balance between exertion and recovery, thus, allowing players to better cope with competition demands.

What is the best methodology to monitor player physical performance (external load) in futsal?
How do the characteristics of inter-change rotations affect futsal players' performance?

Findings	Practical Applications
*Physical performance in futsal should be analysed per interchange rotation: the 1st rotation is usually the most demanding. *Work-rest ratios equal to or slightly higher than 1:1 allow players to maintain physical performance throughout the match.	To develop the rotation analysis in a real time and to enable the integration of various physical, technical and tactical information, an online application was developed in collaboration with Sport Performance Analytics INC (*BreakAway Time*). The program has been tested in different clubs during the current season. Measuring the work-rest ratio is an effective strategy to manage performance during the match and to plan and design training tasks according to the demands of the competition; it is also possible to individualize training targets and recovery strategies according to each player's individualized work-rest ratio.

How will the properties of HIA differ in terms of playing positions?

Findings	Practical Applications
*Physical demands in futsal are position- and time-dependent.	Optimization of the training session requires that coaches consider the demands of each playing position. Measuring different HIA properties (number, distance, duration, time-frequency, and work-rate) allows S&C coaches to customize high-intensity efforts (analytic drills) or futsal exercises based on playing position.
*High-intensity activities (HIA) should be evaluated not only in terms of the number of efforts but also in terms of time-frequency and work-rate.	Develop drills for approximately 6-minute periods (the average absolute playing time per rotation) with different rest ratios for each playing position. ***Winger*** – effort (17)/distance (6m)/time-frequency (21s) and work-rate (19m/min) ***Defender*** - effort (14)/distance (6m)/time-frequency (25s) and work-rate (17m/min) ***Pivot*** - effort (11)/distance (6m)/time-frequency (32s) and work-rate (12m/min) These reference values could also be used to design return-to-play protocols.

What are the physical requirements of each tactical action of a futsal player, depending on the playing position?

Findings	Practical Applications
*Individual tactical actions with and without the ball have different physical requirements – with ball= + DEC and ACC; without ball= + ACC and HSR *High-intensity physical demands in elite futsal have an essential mechanical	Coaches should manage the drills/exercises based not only on general physical efforts but also according to the frequency of individual tactical actions required to understand further its impact on players' mechanical and kinematic loads. Such information allows S&C coaches to be aware of the

dimension (ACC+DEC) *The frequency and type of individual tactical actions differentiate the activity profiles between futsal playing positions.	external load associated with each playing position's most frequently performed actions, thereby informing coaches about the "*real world*" demands and physical implications of each exercise.

Note: ≠different; ≈ similar; HIA: high-intensity activities; ACC – accelerations; DEC – decelerations; S&C – Strength and Conditioning;

11.1 Futsal Physical Monitoring System Proposal

The data presented in Table 20 is intended to address the needs of technical staff and sports scientists on the field by developing athlete monitoring systems useful for training sessions and official matches.

Table 20. Futsal Physical Monitoring System Proposal based on our thesis findings

TRAINING			
	Instruments	**Metrics**	**Methodological Procedures**
Training Load	<u>*External Load*</u> Local Positioning Systems (LPS)	▪Acceleration (>3m·s^{-2}) ▪Deceleration (>-3 m·s^{-2}) ▪ Distance Covered/min ▪High-intensity running (≥18 km·h^{-1})	Only effective time of practice should be considered to measure the training load.
	<u>*Time Load*</u> BreakAway Time	▪Work-rest ratio (time working / time resting)	Calculation of the working and rest time with dedicated software allow the calculation of effective time of practice and passive recovery.
	<u>*Internal Load*</u> Session Rating of Perceived Exertion (sRPE)	▪10 point RPE-scale (Borg & Löllgen, 2001) "*How intense was the training session*"? 0-not at all 10-maximal effort	Session RPE= volume (training session duration (s)) x RPE scale; 30 min after the end of each training session.
Recovery Status	<u>Scale</u> Total Quality Recovery (TQR)	▪6-20 TQR scale (Hooper & Mackinnon, 1995) "*How recovered do you feel*"? 6-being rested 20-extremely recovered	Before the start of each training session.
	<u>Questionnaire</u> Well-being Score (WBs)	Five questions related to: 1) muscle soreness; 2) fatigue; 3) sleep; 4) mood; and 5) stress. Each question is scored	Every morning players should complete a short questionnaire on a dedicated app or using an on-line questionnaire in their smartphone

		using a 1–5 Likert scale, with 1 representing a low score and 5 representing a high score.	
Neuromuscular Performance	▪Force Platform ▪Video recorder ▪Contact mats Countermovement Jump (CMJ)	▪CMJ-coefficient variation (CMJ-cv) or ▪Reactive Strength Index (RSI) (Bishop et al., 2022)	Twice a week: Beginning of the microcycle (to determine the neuromuscular impact of the previous match), and ending of the microcycle (to assess the readiness to play). The coefficient of variation of CMJ should be used (CMJ-cv).
MATCH			
	Instruments	**Metrics**	**Methodological Procedures**
Training Load	*External load* LPS	Equal to training	Following the training procedures (to compare training load vs match load), only the effective time (interchange rotation) was measured. Total match time or ball playing time should be both considered.
	Time Load Break-Away Time	Equal to training	Following the training procedures (to compare training work-rest ratio vs match work-rest ratio), the effective time load was calculated for each player. Based on the calculation of effective time it was possible to calculate the match's "pacing," (total match time - ball playing time).
	Internal Load Session Perceived Exertion (sRP) 10 point RPE-scale	Equal to training	Session RPE= volume (training session duration (s)) x RPE scale; 30 min after the end of each training session.

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