Characterization of Elite Rink Hockey Players, Match and Training Demands

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Tese para obtenção do Grau de Doutor em

Ciências do Desporto

(3º ciclo de estudos)

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Fevereiro, 2025

Provas públicas realizadas a 18 de fevereiro de 2025

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Dedicatória

"It takes a village to raise a child."

African Proverb

Aos meu Pais, Henrique Ferraz e Margarida Ferraz, à Carolina e à minha filha Carminho Ferraz

Agradecimentos

A entrega desta tese representa o terminar de uma etapa que me permitiu abraçar não só um desafio pessoal, mas também, uma tentativa de resposta a um anseio profissional que surgiu quando desenvolvi a paixão pelo hóquei em patins.
Fazer a retrospetiva do espaço temporal entre o ponto de partida e chegada desta etapa da minha vida, permite-me reforçar a sorte que tive ao cruzar-me com pessoas tão especiais e que tanto contribuíram para o dia de hoje. Sou um privilegiado pela contribuição, apoio e partilha de tanto, de todos eles.

À primeira equipa técnica, onde tive a sorte de pertencer. **Fernando Fallé**, **António Eduardo Victor** e **Mário Almeida**, obrigado por partilharem comigo a paixão pelo hóquei patins. Isto começou com vocês.

Ao Professor Doutor **Bruno Travassos,** pela incansável capacidade em me orientar sem apresentar "fórmulas mágicas", permitindo que o processo de descoberta e aprendizagem fosse possível, pragmático, mas acima de tudo, que fosse meu, tornando esta jornada única e enriquecedora. A sua capacidade em combinar a exigência do desafio à aplicabilidade do processo, é inspiradora. Muito obrigado!

Aos Professores Doutores **Pedro Duarte-Mendes** e **João Valente-dos-Santos** por contribuírem de forma enriquecedora às diferentes etapas do processo de investigação, permitindo ajustar e agregar valor aos trabalhos desenvolvidos.

Ao Professor Doutor **Manuel João Coelho-e-Silva,** por durante tantos anos me incentivar a seguir a via académica e a prosseguir até ao doutoramento.

A **todos os investigadores** que participaram nos diferentes estudos, que para além de contribuírem de forma tão significativa na qualidade dos trabalhos, possibilitaram-me crescer enquanto membro de equipas de investigação.

Ao **João Nuno Ribeiro** e ao **Farzad Yousefian**, pela amizade, pelas horas de discussão, pela partilha de ideias, pelas convergências e divergências que tanto enriqueceram este processo, levando-me a melhorar gradualmente. Obrigado pelos momentos de atividades científicas e pessoais!

Aos **clubes, federações, dirigentes, treinadores e atletas** de hóquei em patins que permitiram que a recolha de dados fosse possível, tornando esta tese desafiante e inspirada neles.

Aos meus **pais e irmãs** que sempre me incentivaram e apoiaram ao longo dos meus anos de formação académica.

À **Carolina**, pela sua força inabalável nos meus momentos de ausência ao longos destes anos. Por me ouvir e conseguir dar sempre uma palavra de apoio e incentivo nos momentos de dúvidas ou inseguranças.

À minha filha e princesa **Carminho,** por transformar a sua alegria e sorrisos em fonte de inspiração e motivação nesta reta final do doutoramento.

Às instituições e agência de financiamento que apoiaram este projeto, nomeadamente à **Universidade Jean Piaget de Angola**, ao **Centro de Investigação em Desporto**, **Saúde e Desenvolvimento Humano (CIDESD)**, e à **Fundação para a Ciência e tecnologia (FCT)**. Sem o seu apoio institucional e/ou financeiro, este trabalho não teria sido possível.

Por fim, mas não menos importante, gostaria de expressar o meu reconhecimento a todos aqueles que, de alguma forma, contribuíram para a realização desta tese, mas cujos nomes não mencionei. A todos, o meu sincero agradecimento.

Resumo

Este trabalho teve como objetivo desenvolver conhecimento sobre as características dos jogadores, treino e exigências do jogo no hóquei em patins de modo a promover métodos de monitorização do treino e da competição mais ajustados às exigências da modalidade. Para tal foram realizados seis estudos, com os objetivos específicos de: (1) compreender as tendências evolutivas da caracterização dos jogadores e do desempenho no jogo no hóquei em patins masculino; (2) caracterizar a composição corporal e a força de preensão manual de jogadores masculinos de elite e estabelecer a relação entre a etnia na composição corporal e na força de preensão manual; (3) compreender a aplicabilidade dos sistemas de monitorização na última década para análise do desempenho físico nos desportos coletivos a fim de transferir conhecimento válido para a monitorização no hóquei em patins; (4) compreender as dinâmicas de carga externa e interna ao longo da preparação e competição de uma seleção nacional para uma competição internacional; (5) propor uma nova abordagem para caracterizar e classificar a especificidade fisiológica e biomecânica das tarefas de treino e da competição - *sistema de classificação baseado em quadrantes*; (6) classificar as exigências posicionais durante o jogo e o treino usando o sistema de classificação baseado em quadrantes.

De forma geral os resultados obtidos nos 6 estudos desta tese apresentam uma proposta de aplicabilidade prática que engloba a caracterização do perfil do jogador, e a monitorização do treino e do jogo. No estudo 1 verificou-se que a escassa literatura existente no hóquei em patins apresenta uma abordagem holística sobre (1) as exigências fisiológicas e funcionais (2) adaptações cardiorrespiratórias, (3) características do treino; (4) antropometria, composição corporal e perfil condicional; (5) caracterização do jogo e (6) lesões. Os estudos são realizados maioritariamente em atletas jovens. Assim, considerou-se fundamental direcionar a investigação para a caracterização do atleta de elite e para as exigências físicas do treino e do jogo. Nesse sentido, o estudo 2 sublinha que as características da modalidade e consequente adaptação neuromuscular, promovem no atleta de elite um perfil antropométrico específico, indicando que o percentil de gordura é melhor explicado pela etnia, circunferências da coxa e do gémeo direito, enquanto a força de preensão manual é melhor descrita pela idade, circunferência distal da coxa direita e etnia. Considerando que a monitorização através da tecnologia de análise posicional no hóquei é quase inexistente, no estudo 3, procurou-se entender de que forma a investigação com recurso a sistemas de posicionamento indoor pode contribuir para uma melhor compreensão das exigências físicas da modalidade. Verificou-se que a maioria dos estudos se incide na análise da performance, gestão de carga, lesões e nutrição. A análise integrada de variáveis cinemáticas e mecânicas com associação às variáveis de carga interna surge como estratégia de

investigação para potenciar o estudo da performance de atletas. Nessa lógica, no estudo 4 observou-se que numa preparação para uma competição internacional as exigências do treino não correspondem às da competição e que os impactos de alta intensidade seguidos das desacelerações, têm elevada influência na perceção subjetiva de esforço dos atletas durante a competição. Parece assim fundamental ajustar o treino, de forma a explorar os impactos e as desacelerações. Assim, nos estudos 5 e 6 procurou-se desenvolver uma proposta que caracterizasse as exigências fisiológicas e biomecânicas em situação de treino e competição. No estudo 5 verificou-se que nenhuma categoria dos exercícios analisados replica as exigências fisiológicas e biomecânicas do jogo, ou seja, enquanto que o jogo é caracterizado por elevadas exigências fisiológicas e biomecânicas, no treino, à exceção dos exercícios realizados em meio-campo e campo inteiro (elevadas exigências fisiológicas e médias exigências biomecânicas), a maioria dos exercícios são de baixa exigência fisiológica e biomecânica, Ainda no estudo 5, não se verificou nenhuma categoria de exercícios que fosse simultaneamente de elevada exigência biomecânica e baixa exigência fisiológica. Por fim, no estudo 6 observou-se um desalinhamento entre as exigências específicas posicionais quando comparando o jogo, com o treino. Ou seja, embora o jogo seja caracterizado por elevados esforços fisiológicos e biomecânicos, os jogadores avançados tendem a atingir um perfil fisiológico e biomecânico inferior aos defesas-médios. Essas diferenças não são tidas em consideração no treino. Os resultados em ambos estudos, permitem-nos assumir que as variáveis que melhor caracterizam as exigências fisiológicas no hóquei patins são a frequência cardíaca média, máxima e as distâncias patinadas a alta intensidade. Por sua vez, as que melhor integram as exigências biomecânicas são os impactos de alta intensidade, as desacelerações e as acelerações.

Em suma, os resultados sugerem que o treino não atinge as exigências do jogo, comprometendo a capacidade de resposta adequada por parte dos atletas, principalmente as exigências biomecânicas do jogo. Considerando a estrutura do treino e a individualização posicional do jogador, denota-se uma falha na replicação destas exigências em treino, principalmente pela ausência de exercícios que promovam impactos de alta intensidade associados a desacelerações e acelerações. A proposta apresentada nos estudos 5 e 6, oferece às equipas técnicas uma abordagem que permite visualizar e ajustar a estrutura do treino à especificidade dos jogadores, promovendo dessa forma, um ambiente que melhor replique as exigências da competição.

Palavras-chave

Monitorização de carga, atletas de elite, sistemas de monitorização, análise da performance, desportos coletivos

Abstract

This work aimed to provide valuable insights into the characteristics of players, training, and game demands in rink hockey, applying the knowledge developed towards a more suitable method for monitoring training and competition to enhance player performance. To achieve this, six studies were conducted with specific objectives: (1) to understand the evolutionary trends in the characterization of players and game performance in men's rink hockey; (2) to characterize the body composition and grip strength of elite male rink hockey players and establish the relationship between ethnicity in body composition and grip strength; (3) to understand the applicability of monitoring systems for physical performance analysis in team sports over the last decade in order to develop knowledge for load monitoring in rink hockey; (4) to understand the dynamics of external and internal load throughout the 2-week training period and competition week of a rink hockey International Championship; (5) to propose a new approach to characterize and classify the physiological and biomechanical specificity of training tasks in relation to elite competition - a quadrant-based classification system; (6) to apply the quadrant-based classification system to characterize and classify load demands, considering the physiological and biomechanical requirements of training and games according to positional dimensions.

Overall, the results obtained in the six studies of this thesis promoted a proposal for practical applicability from player profiling to training and game monitoring. Study 1 revealed that the literature on rink hockey is scarce and generally presents a holistic approach to physiological and functional demands, cardiorespiratory adaptations, training characteristics, anthropometry, body composition, conditional profile, game characterization, and injuries in rink hockey. However, most studies are conducted on young athletes, with few studies on elite athletes. Thus, it was essential to conduct research toward characterizing elite athletes and the physical demands of training and competition. Study 2 described that given the characteristics of the sport and its neuromuscular adaptation, elite rink hockey players show a specific anthropometric profile considering percentile values of fat and characteristic grip strength for this sport, with ethnicity, right thigh circumference, and right calf circumference being the variables that best describe fat percentile, while age, distal circumference of the right thigh, and ethnicity better describe grip strength. Considering that monitoring through positional analysis technology in rink hockey is almost non-existent, Study 3 sought to understand how research using indoor positioning systems could contribute to a better understanding of the demands of rink hockey. It was found that most studies have focused on performance analysis, load management, injury development process, and nutrition. Still, in Study 3, it was proposed that integrated analysis of kinematic and

mechanical variables should be studied alongside their correlation or association with internal load variables to understand athletes' performance improvement strategies better. In this logic, Study 4 observed in a preparation for an international competition that training demands do not match those of the competition. High-intensity impacts followed by decelerations characterize the metrics that most impact athletes' subjective perception of effort during competition, which are underexplored during training, particularly high-intensity impacts. Therefore, in Studies 5 and 6, a proposal was developed to characterize physiological and biomechanical demands in training and competition situations, providing coaching staff with a methodological tool to optimize microcycle planning. In Study 5, it was found that no exercise category analysed has the physiological and biomechanical demands of the game. While the game is characterized by high physiological and biomechanical demands, most exercises have low physiological and biomechanical demands, except for exercises performed in midcourt and full court, which have high physiological and medium biomechanical demands. Still, in Study 5, no category of exercises with simultaneous high biomechanical and low physiological demands was found. Finally, in study 6, a misalignment between the specific demands of different positions was observed when comparing the game with the training sessions of the microcycle. That is, although the game is characterized by high physiological and biomechanical efforts, advanced players tend to achieve a lower physiological and biomechanical profile than defender-midfielder players. These differences are not considered throughout the microcycle. Finally, this approach used in Studies 5 and 6 allows us to assume that the integrated variables that best characterize the physiological demands in rink hockey are average heart rate, maximum heart rate, and distances skated at high intensity. In turn, those that best integrate biomechanical demands are high-intensity impacts, decelerations, and accelerations.

In summary, the results suggest that training does not meet the demands of the game, compromising athletes' appropriate response capacity, particularly considering the game's biomechanical demands. This is because there is a failure to replicate these demands in training in terms of training structure and player individualization, mainly due to the absence of exercises that promote high-intensity impacts associated with decelerations and accelerations. The quadrant-based classification system proposal presented in studies 5 and 6 offers coaching staff a methodology to analyse and adjust training structure and player specificity, thus promoting an environment that better replicates competition demands.

Keywords

Load monitoring, elite athletes, tracking systems, performance analysis, Team Sports

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List of Acronyms

ACC	Accelerations
AU	Arbitrary Units
ABC	Abdominal circumference
ACWR	Chronic work load
ANLT	Analytical situations
BF%	Body fat percentage
BM	Body mass
BMI	Body mass index
CA	Chronological age
CI	Confidence Intervals
CL	Competition Load
CW	Competition week
DEC	Decelerations
DEF-MID	Defenders-Midfielders
DXA	Dual-energy X-ray absorptiometry
EX.FC	Full-court exercises (20×40m)
EI	Energy intake
EL	External Load
EX.IN¾	¾ of the court exercises (15×18m)
EX.MD	Mid-court exercises (20×20m)
EX. S/I	Superiorities/inferiorities exercises
ES	Effect size
EEE	Energy Expenditure
EWMA	Exponentially weighted moving average
FFM	Fat-free mass
FM	Fat mass
FWD	Forwards
GM.EFF	Effective time of official games
GM.RUN	Runing time of official games
GPS	Global Positioning System
HMLD	High metabolic load distance
HIA	High-intensity activities
HIE	High-Intensity events
HIMPCTS	High-intensity impacts
HR	Heart rate
HR_{AVG}	Heart rate Average
HR_{MAX}	Maximum Heart rate
HR-TRIMP	Heart rate training impulse
HSS	High-speed Skating
IL	Internal Load
INT	Introductory technique - activation exercises
LPS	Local Positioning System
LSS	Low speed skated
Md	Median
MD	Match Day

MSS	Médium speed Skating
RDTC	Rigth distal-tight girth
PL	Player Load
RPE	Rate of Perceived Exertion
RCC	Right calf circumference
RDTC	Right distal-tight Circumference
RTC	Right thigh circumference
sRPE	Rate of Perceived Exertion of the session
TMD	Training match day
TEL	Total effective load
SD	Standard Deviation
TDS	Total Distance skated
TL	Training load
TW	Training week
UWB	Ultra-wideband
VO_{2max}	Maximal oxygen consumption
WBs	Well-being score
WG	Wingers

1. Introduction

Over the years, research in sports sciences has allowed the production of useful insights into physiological reactions, biomechanical patterns, anthropometric traits, and psychological elements that characterize sports training and performance (Yaman, 2020). Therefore, understanding players' traits and their sport specificity may lead to increasing knowledge in order to understand each sport and player-specific needs better (Slimani & Nikolaidis, 2019). In fact, research in team sports enables not only a better understanding of each sport but also the development of solid coaching programs suited to each sport and player (Yaman, 2020).

However, popular team sports such as football dominate research, and further investigation is required in other sports such as rink hockey to improve practitioners, coaches, and strength and conditioning coaches' understanding of performance enhancement and injury prevention specificities in athletic pursuits (Sousa et al., 2018). Thus, diversifying the scope of study according to the specificities of each sport allows researchers to uncover the unique training and competitive traits inherent in these sports, providing insights to improve athletic performance, competition readiness, and injury prevention (De Pablo et al., 2022; Ryan et al., 2017).

Based on the specific demands of distinct team sports, several approaches have been explored to understand how players' performance may be categorized based on specific metrics (Calò et al., 2009; S. Ryan et al., 2017). For example, it is known that athletes' body composition features constrain their competitive performance and training (Ackland et al., 2012), according to sports and players' positions (Calò et al., 2009). Therefore, considering the intent of the analysis is essential to increase the understanding of the relationship between each sport's demands and players' physical profile (Ryan et al., 2017). The combination of local positional systems (LPS) for the analysis of external load / time-motion variable, with monitors to measure internal load, has gained significant acceptance in the research of sports demands and players' internal responses (Helwig et al., 2023) aiming to develop proper training adjustments to increase players' readiness for competition (Ribeiro et al., 2020). Despite its potential benefits, the use of monitoring systems like LPS for research in rink hockey is still limited (Fernández et al., 2020).

Based on this scope, the general purpose of this thesis was to provide important insights into elite rink hockey players' characteristics, training, and competition demands and to replicate this knowledge to propose an additional suitable method of monitoring training and competition.

The following sections present some of the research questions that serve as the roadmap guiding our work. They support the overview of the thesis's goals and the interrelated nature of the studies in question.

1.1 An overview of rink hockey research

Rink hockey, commonly known as roller hockey or hardball hockey in the United States, is a team sport played on a 20-by-40-meter rink with a fence around its perimeter and is played by five players (one goalkeeper) (Yagüe et al., 2013). Playtime varies according to the athlete´s category; however, at the elite level, the game lasts 50 minutes (two 25-minute halves), but the overall time with interruptions is around 70-90 minutes, occasionally more (Blanco et al., 1993). Field players participate for an average of 70 to 90 minutes per match (Yagüe et al., 2013). In all of the different categories, there is a 10-minute break between the end of the first period and the start of the second one (*Worldskate - Skateboarding & Roller Sports - Regulations - Regulation*, 2020). In this indoor team sport, players move around the field in specialized four-wheeled quad roller skates while controlling a hardball by manipulating a wooden stick (Hoppe et al., 2015). Rink hockey is an indoor team sport that requires both intermittent short and long-duration efforts and is characterized by being highly specialized and physically demanding (Yagüe et al., 2013).

The research regarding the physiological demands of rink hockey is sparse. Also, few studies have been developed with the purpose of characterizing the technical and tactical game demands of rink hockey (Sousa et al., 2020). However, it is known that it is a highly demanding sport in which, in a competitive match, heart rate is between 85 to 90% of HRmax, and blood lactate content is between 4.0 and 4.6 mmol · L^{-1} (Blanco et al., 2016; Tañá, 2016). Also, rink hockey has been characterized as a high-intensity intermittent sport categorized by non-continuous activities at varying speeds and insufficient recovery periods (Calò et al., 2009). Although the particular requirements of using skating to move on the field, rink hockey demands appear to be similar to other indoor team sports (Burr et al., 2008) and may promote specific anthropometric traits in players (Coelho-E-Silva et al., 2012). However, there is still a limited understanding of enhancing performance based on players' profile, training, and game demands when compared to other team sports (Sousa et al., 2020)Based on the above overview, our first main goal was to establish a systematic search and organize the literature on rink hockey over the past two decades in order to uncover the evolutionary tendencies of player characterization and game performance in male rink hockey.

1.2 The profile of elite rink hockey players

Elite programs for sports training and development potentiate athletes' anthropometric, motor, and physiological characteristics according to the sports' requirements (Zhao et al., 2019). For example, has it already been presented in different sports, researching the physical and anthropometric profile of elite athletes is relevant because it can distinguish elite from non-elite athletes (Alejandro et al., 2015; Gómez-Campos et al., 2023; Zhao et al., 2019). Therefore, understanding the body composition and physical condition of players, in comparison to the profile of elite athletes, can be used as a benchmark strategy for the optimal development of athletic performance (Sekulic et al., 2021). For example, looking into other team sports, several studies showed that excessive body weight and body fat measurements were connected to inferior muscle strength in football (Nikolaïdis, 2012), basketball (Nikolaidis et al., 2015), handball (Gorostiaga et al., 2005) and futsal (Sekulic et al., 2021). On the other hand, besides one study with U-17 rink hockey players (Coelho-E-Silva et al., 2012b), which shows a relationship between grip strength and body composition and selected players for the U-17 national team. As far as we know, studies regarding body composition traits in adult elite rink hockey players are limited or non-existent. Thus, analyzing elite athletes' anthropometry is crucial for optimizing sports performance in such sports.

In general, muscular strength has been associated with physical fitness, bone density, functional status, and general health (Braam et al., 2013; Toong et al., 2018), while grip strength has been associated with physical level and performance, particularly in hockey disciplines such as ice hockey. Like in many hockey disciplines, rink hockey players require strong grip strength to execute complex skills while manipulating a wooden stick, differentiating top players from non-top players (Coelho-E-Silva et al., 2012).

In athletes, evaluating training adaptations through fitness testing is important for assessing physical performance levels (Ribeiro et al., 2020). Besides normative values that may suggest standard information for specific-sport elite players, it is widely recognized that evaluating training adaptations according to individual specificities, such as individual's ethnicity, is important for assessing their functional, morphological, and physiological adaptations, including strength, body fat, and cardiovascular adaptations (Papadakis et al., 2012).

Rink hockey has developed strong ruts in African countries, increasing the number of practitioners. Considering the potential biological differences in body composition between Black Africans and Caucasians, some authors suggest the need for developing population-specific prediction equations (Papadakis et al., 2012; Wagner & Heyward, 2000). There are no references to such elite athletes regarding body composition and grip strength. Thus, the second goal of this thesis was to characterize the body composition and grip strength in elite rink hockey players and identify the variables that may constrain such dimensions according to ethnicity.

1.3 Tracking devices and their applicability in elite team sports

Team sports require intense tasks based on teammates' or opponents' space and time relationships. To improve athletes' performance at this level, sports team staff must vary the training load, particularly by increasing frequency, duration, and intensity (Pyne et al., 2011). Therefore, training loads must be adjusted at various periods during the training cycle to increase or decrease fatigue, depending on the training phase (baseline or competition) (Migallón et al., 2022). Consequently, effective fatigue management is crucial for both training adaptation and competitive performance (Halson, 2014).

To develop an understanding of multi-directional sports requirements, previous research has quantified sport-specific demands in various ways (Taylor et al., 2017). According to that, tracking athletes' time motion, along with physiological measures like heart rate (Helwig et al., 2023), has become a popular method for determining their EL and IL (Hausler et al., 2016). The understanding of this relationship (EL *versus* IL) helps to track sport-specific demands during play (Chambers et al., 2015). Additionally, monitoring an athlete's workload during training is crucial for determining adaptation and reducing the danger of non-functional overreaching (long-term exhaustion), injury, and illness (Halson, 2014).

Recent research has been dedicated to finding the right balance of physical exertion during both short and long-term training (Ribeiro et al., 2022; Windt et al., 2017). One approach is the acute-chronic workload ratio, which measures the rate at which sport-specific demands, such as running or the number of accelerations/decelerations, increase over time, helping to prevent decreases in performance and the resulting injuries (Taylor et al., 2017). Also, recent studies in team sports have focused on identifying the most demanding patterns of play, analyzing the impact of various training methods, and understanding injury triggers (Migallón et al., 2022).

For the purpose of performance enhancement, it was argued that selecting the right metrics according to sports-specificity is fundamental for properly describing, monitoring, planning, and evaluating the training and competition demands of each sport (Torres-Ronda et al., 2022). Therefore, to initiate the monitoring process in elite rink hockey teams and to properly adjust the research methods in this thesis, previous research must be systematized to better understand the variables/methods of analysis that best describe the damage mechanism or performance improvement.

Based on this scope, the following goal of this thesis was to elaborate a scoping review aiming to understand the applicability of tracking systems for performance analysis in team sports in the last decade, promoting an understanding of how research strategies and performance metrics have been applied and combined according to research objectives.

1.4 Monitoring key metrics in elite rink hockey demands.

Monitoring athletes' training load (TL) and competition load (CL) is crucial in team sports like rink hockey to assess their adaptability to training regimens and competition performances (Rago et al., 2020). The load can be classified as internal or external, with the external load (EL) being the work accomplished by a player regardless of his or her internal features expressed in terms of distance, accelerations, decelerations, or sprints (Impellizzeri et al., 2019), and the internal load (IL) is associated with physiological, psychological, and biomechanical stress as a result of the adaptive responses caused by training or competition-induced adaptations (Varley & Aughey, 2013).

Nowadays, the use of tracking technology has made it possible to study the demands of elite rink hockey competition, which was previously unknown to coaches (Fernández, Varo, et al., 2020). Fernández et al., (2021) showed that high-speed skating (HSS >18km/h), ACC, and DEC were identified as the EL variables that best characterized the most demanding efforts in this sport, whereas match-day (MD)-4 [i.e., 560 ± 212(m); 122 ± 22.0(*n*) and 99.9 ± 21.7(*n*)] and MD-1 [i.e., 256 ± 103(m); 82,3 ± 17,6(*n*) and 64,4 ± 18,3(*n*)] sessions tended to present "low EL and IL" zone. In contrast, in MD-3 [i.e., 727 ± 225(m); 172 ± 33.7 (*n*) and 143 ± 31.9 (*n*)] and MD-2 [i.e., 683 ± 245 (m); 149 ± 31.9 (*n*) and 121 ± 30.1 (*n*)] sessions, as well as in MD [i.e., 739 ± 209 (m); 160 ± 26.6 (*n*) and 143 ± 25.8 (*n*)], the highest loads were observed (i.e., ACC from 3 to 10 m/s^2, DEC from -10 to -3 m/s^2, and HSS >18Km/h). In MD-3, MD-2, and MD, the majority of the players presented "high EL and IL, with a tendency to disperse towards the fitness or exhaustion zones (Fernández et al., 2021). Despite the results obtained, no research has been carried out to examine the association between the training structure, the type of work developed (EL variables), and the stress imposed on the players (IL) during competitive periods.

Under this scope, our fourth study aimed to characterize the dynamics of external and internal load during the two weeks of preparation and the competition week of the European Championship and to understand the relationship between EL and IL in training sessions and competition.

1.5 Are we training to compete? The case of the elite rink hockey

Training load (TL) monitoring assesses both the physical work an athlete does during training EL and their response to that demand (IL)(Coyne et al., 2022). It is commonly assumed that improved athlete performance involves a better understanding of training demands. Several researchers have studied EL measures (mostly kinematic and mechanical) in training and competitive circumstances (Mangan et al., 2017). Furthermore, researchers have studied athletes' performance by connecting kinematics, mechanics, metabolic metrics, and, more recently, IL variables during training and competition (Beato, Vicens-bordas, et al., 2023). In some studies, researchers combine players' techniques with EL and IL, while others categorize EL and IL based on training drills to compare their demands from competition (Coyne et al., 2022; Ohmuro et al., 2020; Principe & Vale, 2020). However, besides the importance of understanding "*how we compete*" in order to evaluate and manipulate "*how we train*," both knowledge must be linked to an adequate recovery strategy to ensure optimal physiological and biomechanical adaptations based on specific training " stimulus"(Coyne et al., 2022; T. Gabbett, 2023). Graded exposure to physiological and biomechanical (Coyne et al., 2022) stress is an essential component of evidence-based training programs but only can be properly applied in case competition demands and sport-specific metrics are well-known (Gabbett et al., 2014). To improve capacity, the training load applied should exceed the athlete's functioning capacity but not to the point of causing tissue injury (Caparrós et al., 2018). Consequently, it is important for athletes to undergo both high and low-intensity training periods to deal with the demands of competition (Coyne et al., 2022).

In rink hockey, little research comparing training to competition has been developed. However, a recent study shows that no training sessions represent the game demands (Fernández et al., 2021). Besides, the author demonstrates an attempt to fluctuate the load across the microcycle, just a broad description of the training session as a whole is given with no mention of the specificities of the training tasks (Fernández et al., 2021). As a result, it makes it difficult to understand the needs of each training assignment and its contribution to the weekly load, as well as to recreate competitive expectations (Gabbett, 2023), as previously shown in other team sports (i.e., futsal) (Rico-González et al., 2022).

The information provided by tracking systems' impact on decision-making in team sports remains unknown, perhaps representing a 'translational gap' in sports science research (Impellizzeri et al., 2019). Such gaps may be caused by coaches considering a lack of a combined purpose with their sports science departments as a barrier to using training data in coach decision-making (Nosek et al., 2023). In this sense, effective transmission of data to coaches is crucial, as poor communication might constrain data use (Nosek et al., 2021). In rink hockey, the use of tracking systems to improve decision-making may be limited due to the lack of research and data selection. Therefore, there is a need to simplify the selected metrics and their respective analysis by reducing the number of variables. Additionally, a visual tool that can aid coaches in increasing their perceptual interpretation and decision-making skills is necessary.

Based on the above approach, the 5th main goal of this thesis was to propose an approach to characterize and classify the specificity of training tasks in relation to competition for a top-level rink hockey team based on physiological and biomechanical demands. At the same time, a quadrant of efforts is proposed, allowing for better visual perception and interpretation.

In the same order of ideas, there is an additional need to build theoretical and practical knowledge to understand how technical-tactical manipulations may influence training adjustments and competitions, such as player positioning.

Sports scientists have attempted to understand the complexities of competition in order to replicate them during training. Nevertheless, there is a significant gap in research comparing training and competition (Nosek et al., 2023). Rink hockey is a perfect example of that.

Wearable technology has been employed in field sports to quantify movement demands objectively, assess the differences between practice and competition demands, and offer information on high-intensity actions (Douglas & Kennedy, 2020). Therefore, this knowledge can help experts develop valid, reliable, and practical methodologies for quantifying players' external demands during competitions (Chambers et al., 2015). Importantly, this could offer coaches information to optimize the prescription of external training load, especially during technical-tactical training (Douglas & Kennedy, 2020). Unfortunately, there is currently limited published data using LPS technology to measure rink hockey players' demands (i.e., ACC, DEC, and distances skated) (Fernández et al., 2023). Therefore, the knowledge to understand how technical-tactical variation demands, like the conditional profile of different players' positions in rink hockey, is very narrow. Also, there is a lack of information regarding the demands of the game based on tactical positions and how training sessions can provide valuable insights to adjust training objectives and promote efficient physiological and biomechanical adaptations for each position. Accordingly, individualizing players monitoring according to specific game positions is critical (Di Salvo et al., 2007). As far as we know, only two studies have been conducted in rink hockey to comprehend players' positional variations(Fernández et al., 2020; Fernández et al., 2023). In the first study, no differences were observed between players' positions (both interior and exterior players) in overall game physical demands (i.e., TDS, HSS, ACC, and DEC) (Fernández et al., 2020). However, in the second one, it was observed that high-intensity actions are position-dependent, with exterior players covering greater TDS and inside players performing a higher number of ACC (Fernández et al., 2023). In both studies, variables were measured individually, and no information was provided about the training load response. In this order of ideas, it is crucial to consider the effect of different training sessions on players' positioning during a microcycle (Rico-González et al., 2022) and relate them to game demands (Fernández et al., 2023; Lin et al., 2023).

To assemble this research thesis, our final main question was how can we describe and classify load demands in a top-level rink hockey team, considering the physiological and biomechanical requirements during training and games?

2. Objectives

Based on the need to increase the scientific knowledge in rink hockey to support elite athletes and technical staff involved in the training and competition environment, this thesis was prompted by the need to contribute to a further understanding of rink hockey game demands and the key factors required for performance enhancement. For that, three major topics were considered for the development of this thesis: i) What characterizes elite rink hockey players´ anthropometric traits and conditional profiles; ii) How to improve rink hockey monitoring load strategies? iii) How could monitoring strategies be used to clarify training and competition responses, assisting coaches and team staff members in tailoring their training sessions to the objectives? From such major topics the objectives of this thesis for each major topic were:

i) What characterizes elite rink hockey players´ anthropometric traits and conditional profiles?

- To conduct a systematic search and organization of the rink hockey literature from the previous two decades in order to understand the evolutionary tendencies of player characterization and game performance in male rink hockey.
- To characterize elite male rink hockey players' body composition and grip strength and establish the relationship between ethnicity, body composition, and grip strength.

ii) How can rink hockey monitoring load strategies be improved?

- To understand the applicability of tracking systems for physical performance analysis in team sports in the last decade by allowing an understanding of how research strategies and variables have been used and combined according to research goals.
- To understand the dynamics of external and internal load across the training sessions of the 2 weeks of preparations and the competition week of a national team for a European Championship.

iii) How could monitoring strategies be used to clarify training and competition responses?

- To propose an applied approach to characterize and classify the training task specificity in relation to competition in a top-level rink hockey team.

- To propose a new approach for characterizing and classifying the load demands, considering training and games' physiological and biomechanical demands according to playing positions in a top-level rink hockey team.

3. A Review of Players' Characterization and Game Performance on Male Rink-Hockey

Ferraz A, Valente-Dos-Santos J, Sarmento H, Duarte-Mendes P, Travassos B. A Review of Players' Characterization and Game Performance on Male Rink-Hockey. *Int J Environ Res Public Health*. 2020 Jun 15;17(12):4259.

3.1 Introduction

Rink-hockey (also known as hardball or roller hockey) is an indoor intermittent team sport that requires the combination of short and long-duration efforts and is considered a highly specialized and physiologically demanding sport (Yague, 2007). Players move themselves on the field with specialized four-wheeled quad skates, combining high-intensive effort while manipulating a wooden stick and a hard rubber ball (Hoppe et al., 2015). The game is performed on a 20 m × 40 m rink with five players (one goalkeeper) and a wall around the rink perimeter (Hoppe et al., 2015). Play time varies according to the athlete´s category—(1) 30 min, divided in two periods of 15 min (under-15s categories); (2) 40 min divided on two periods of 20 min each (senior male, senior female, under-23s male, under-19s male, under-18s female, and under-17s male); (3) international and national competitions can play a maximum of 50 min game time (two periods of 25 min each). In all the above-mentioned categories, there is a 10 min interval between the end of the first period and the start of the second period (Rossi et al., 2018). The game structure consists of intervals of different intensities, such as short, middle, and long distances (Hoppe et al., 2015).

Regardless of rink hockey being popular worldwide and played on five continents, there seems to be a lack of published scientific research (Sousa et al., 2018), with only a small amount being published in English when compared with other team sports that are intensely studied and published, such as football (Sarmento et al., 2018) or basketball (Sarmento et al., 2018).

Despite the lack of scientific literature, it is well-reported that rink hockey is a high-intensity intermittent sport in which non-continuous actions of different speed levels are followed by incomplete recovery periods (Calò, 2009; Yagüe et al., 2013), requiring a well-developed metabolism for short and long-duration efforts (Yagüe et al., 2013). Also, intra- and inter-muscular and neuromuscular coordination are determinants for skating and for ball mastery and control using the stick (Calò, 2009). In general, despite the specific requirements of the use of skating to move on the field, rink-hockey demands seem to be similar to other elite indoor team sports (Burr et al., 2008). Accordingly, the improvement of specific conditioning traits of performance as strength, power, agility, speed, and maximal oxygen uptake is of particular importance for athletic performance (Hoppe et al., 2015).

An understanding of physical and physiological demands is essential for game success. However, it is also crucial to complement athletes' fitness traits and game characterization. As in any other invasion team sport, game analysis, and more specifically, the analysis of technical and tactical behaviors of players and teams, it is fundamental to characterize the behavioral demands of the game (Travassos et al., 2013). To our knowledge, with the exception of Sousa et al. (2018), who analysed the offensive play on the performance of rink-hockey goalkeepers, no other study has been developed with the purpose of characterizing the technical and tactical game demands of rink hockey. Further research is required in rink hockey regarding performance analysis—specifically, the understanding of technical and tactical game demands (Brázio, 2006).

There are constantly new approaches to improve team sports performance, such as tactical, technique, and physical conditioning (Stølen et al., 2005). Further research should be developed to improve the understanding of several indicators from training and the game environment. Rink hockey must not be an exception.

Summarizing, in the last 10 years, an increase in the number of studies has been observed in rink-hockey (Sousa et al., 2019). However, no research has been developed in order to clearly identify the players' characterization and game performance of male rink hockey. Therefore, the purpose of this article was to develop a systematic search and organize the literature on rink hockey of the past two decades as an attempt to identify the evolutionary tendencies of the characterization of players and game performance in male rink hockey. Particularly, it was our purpose to (a) identify the physiological and functional demands of rink-hockey; (b) identify and characterize the anthropometry, body composition, and conditional profile of rink-hockey players; (c) to identify the game patterns that characterize the game; and (d) to identify the prevalent injuries in this sport.

3.2 Methods

3.2.1. Search Strategy: Databases and Inclusion Criteria

A systematic search was conducted on the electronic databases PubMed, Web of Knowledge, and Scopus, according to the recommendations from the preferred reporting items for systematic and integrative reviews and meta-analysis statement (PRISMA) (Hopia et al., 2016; Moher et al., 2015). A search by relevant publications between the 1 January 2000 and 31 January 2020 using the keywords "roller hockey" and "rink hockey," both associated with "elite," "ethnicity," "heart," "ice hockey," "internal and external load," "physiology," "sports sciences," and "youth" were performed. The publications that were retrieved had to follow the following specific criteria: the publications (1) contained relevant data regarding athletes´ morphological or physiological demands, or anthropometry or body composition characteristics; (2) were related to rink/roller hockey performers; and (3) were written in the English language. Exclusion criteria applied if they (1) contained other sports performers; (2) included females; (3) did not contain relevant data about athletes morphological and physiological demands, anthropometry, and body composition characteristics.

To increase research accuracy, two reviewers (A.F., J.V.S.) separately screened citations and abstracts to identify the articles which would potentially combine the inclusions criteria, having registered the characteristics of each study, including the name of the authors, sample, procedure and results or main outcomes. In case of disagreement regarding the eligibility of the article, a third reviewer (H.S.) was included in order to reach a final decision. After all the articles were screened, the categories of the studies were organized into specific topics according to their main research topic.

3.2.2. Quality of Studies and Data Extraction

The quality of the studies was assessed as recommended in Faber et al. (2016) using the criteria for critical review forms in Law et al. (2000) (16 items) with the purpose of identifying the studies in which the low-quality score could interfere in the results. The possible criteria for each item were 1 (meets criteria), 0 (does not meet the criteria), or NA (not applicable). Articles were assessed with regards to their purpose (item 1), relevance of background literature (item 2), appropriateness of the study design (item 3), sample included (items 4 and 5), informed consent procedure (item 6), outcome measures (item 7), validity of measures (item 8), significance of results (item 9), details of intervention (item 10), analysis (item 11), clinical importance (item 12), description of drop-outs (item 13), conclusion (item 14), practical implications (item 15), and limitations (item 16). Based on the guidelines of Faber et al. (2016) a final score was calculated allowing to classify the articles as: (1) low methodological quality (≤50%); (2) good methodological quality (50%–75%); and (3) excellent methodological quality (>75%). A data extraction sheet (from Cochrane Consumers and Communication Review Group's data extraction template) (Ryan & Hill, 2019a) was adapted to this review's study inclusion requirements and then tested on 10 randomly selected studies (pilot test). One author extracted the data, and another verified it. Disagreements were resolved in discussions between these two authors (A.F., J.V.S.). To organize the results, the studies were classified into categories established according to the major research topics.

3.3 Results

3.3.1. Search, Selection, and Inclusion of Publications

The initial search identified 815 titles. These data were then exported to reference manager software Mendeley (Thompson Reuters, San Francisco, CA, USA). Duplicates (605) were eliminated automatically or manually. The remaining 210 were then screened for relevance based on their title and abstract information, with 159 being excluded. The remaining 51 were analysed in more detail, and 32 papers were excluded according to the following criteria: (1) articles published in languages other than English (*n* = 9); (2) articles regarding other sports (*n* = 19); (3) articles including female athletes (*n* = 2); and (4) articles included others sports athletes with no relevant data (*n* = 2). Finally, 19 articles were included for the review. A flow chart of the study selection process is shown in Figure 1.

The publication target years were limited to the past two decades, from 2000 to January 2020. The remaining articles used for in-depth reading revealed that there has been a surge of research available in rink hockey. Included in this review are 63.3% of the studies published in the last five years (from 2015 to 2020), 31.5% from 2010 to 2014, and 5.2% before the year 2010.

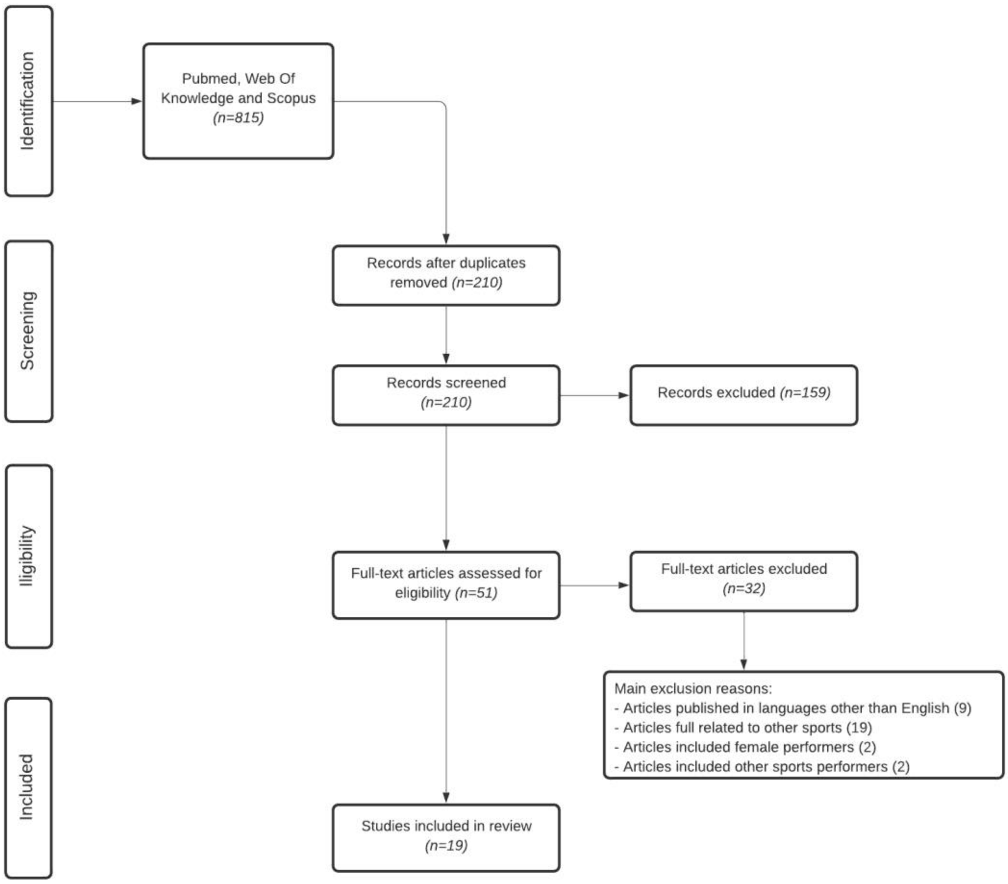

Figure 1. Flow chart of the article's selection process

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3.3.2. *Quality of the Studies*

Regarding the quality of studies, as recommended in Faber et al. (2016) and Sarmento et al. (2018), the average score of the 19 selected quantitative studies was

85.9%. Three studies achieved 100%; 14 achieved an average rating of ≥75%; and only five achieved a score between 55% and 75%; none of the studies scored below 50%.

3.3.3. General Description of the Studies

Studies were classified into the following categories established according to the main research topics that emerged from the content analysis: (1) physiological demands, (2) anthropometric, body composition and conditional profile, (3) game characterization and games patterns, and (4) injuries. See Figure 2. Studies were also identified by countries in which the studies were carried out—(1) Portugal (63.16%), (2) Spain (26.32%), (3) Germany (5,26%), and (4) Italy (5,26%).

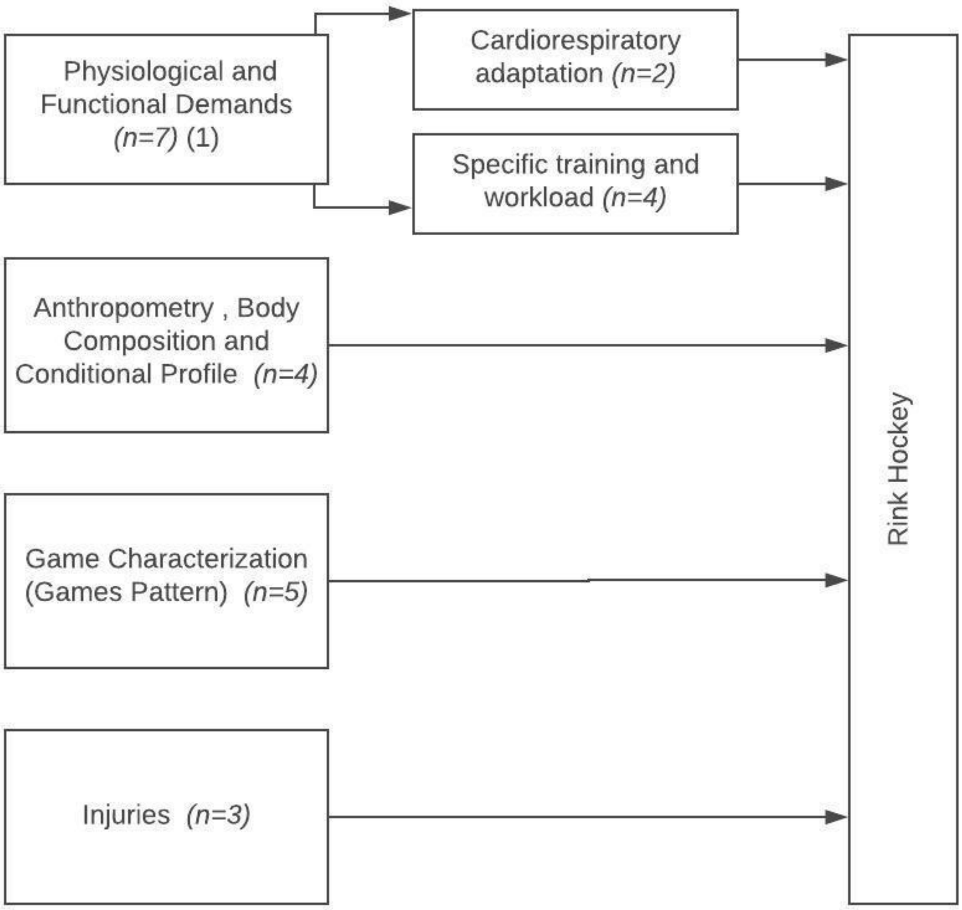

Figure 2. Flow chart of the main research topics in rink-hockey of the past two decades according to the inclusion criteria.

The analysed studies bring up information related to the characterization of specific competition level such as competitive demands of elite male rink-hockey and the influence of workload and well-being on athletes (Gonçalves et al., 2020; Yagüe et al., 2007) or functional strength and shooting biomechanics analysis (Gonçalves et al., 2020; Reverter-Masía et al., 2017; Yagüe et al., 2013)An insight of body composition, cardiac indicators, and peak oxygen uptake are described in adolescent players (Castanheira et al., 2017; Coelho-E-Silva et al., 2012; Valente-Dos-Santos et al., 2013). On the other hand, Coelho-E-Silva, et al. (2012) present an approach model of sport selection under-17s in roller hockey combining anthropometry, functional and physiological information. Nutritional and body composition assessment in young Portuguese rink-hockey players was made by Silva and Silva (2017). Regarding game characteristics, observational instruments are explored to understand game patterns (Mendo & Argilaga, 2002; Sousa et al., 2019). The high-intensity demands of the game combined with the mastery of skating and ball possession are described as potential injury risk (Reverter-Masía et al., 2017; Venâncio et al., 2016; Jacopo Antonino Vitale et al., 2019a)

3.3.4. Physiological and Functional Demands.

Based on the analysis of the selected studies, the lack of research about this thematic in comparison with other team sports is obvious. However, Yagüe (2007) in a study that involved six rink-hockey players, developed some field and laboratory tests. Also, it was possible to classify other studies in two sub-categories that allow for the characterization of physiological demands of rink-hockey—cardiorespiratory adaptations, specific training, and workload (see Table 1).

Table 1.*Articles predominantly related to physiological demands in rink-hockey.*

Study and Country in Which Study Have Been Carried	Sample	Main Outcomes Measured	Results	Quality Score (%)
Valente-dos-Santos et al. (2013) — Portugal	73 Portuguese, highly trained, male rink-hockey athletes, aged 16.4 ± 1.5	Anthropometry and peak oxygen fitness survey	The adolescents highly trained athletes chronological age (CA), 15.4 ± 0.6 years, skeletal age (SA), 16.4 ± 1.5 years; stature, 169.9 ± 6.9 cm; body mass, 63.7 ± 10.7 kg; thigh volume, 4.8 ± 1.0 L) performed and incremental maximal test on a motorized treadmill. Exponents for body size descriptors were 2.15 for stature (R^2 = 0.30, p < 0.001) and 0.55 for thigh volume (R^2 = 0.46, p < 0.001). The combination of stature or thigh volume and CA or SA, and CA^2 or SA^2, increased the explained variance in VO^{2peak} (R^2 ranged from 0.30 to 0.55)	100
Yagüe et al. (2013)— Spain	6 rink-hockey players aged 23.4 ± 3.1 years, 173.3 ± 4.7 cm and 72.3 ± 5.1 kg	Heart rate (HR), blood lactate, oxygen consumption, ventilation and respiratory exchanged ratio were recorded in a 20-metre multi-stage shuttle roller skate test, a tournament match, and a simulation test (ST)	Peak heart rate was 190.7 ± 7.2 heart.min^{-1}. No differences in peak HR between the three tests. The mean of HR was similar between the ST and the match (86% and 87% of HR_{max} respectively). Peak and mean ventilation averaged 111.0 ± 8.8 L-min^{-1} and 70.3 ± 14.0 L-min^{-1} (60% of V_{Emax}), respectively. Vo_{2max} was 56.3 ± 8.4 mL-kg^{-1}-	81.3

			min^{-1}, and mean oxygen consumption was 40.9 ± 7.9 mL-kg^{-1}-min^{-1} (70% of Vo_{2max}). Maximum blood lactate concentration was 7.2 ± 1.3 mmol/l^{-1}. St yielded an energy expenditure of 899.1 ± 232.9 kj, and energy power was 59.9 ± 15.5 kg-min^{-1}	
Hoppe et al. (2015) — Germany	10 elite rink-hockey players from the German National team (24.0 ± 1.5 years; 78.3 ± 8.2 kg; 178.6 ± 6.6 cm; 24.6 ± 1.7 IMC; 11.9 ± 2.9%$^{\text{Body Fat}}$)	Athletes were tested in time to exhaustion, maximum oxygen uptake, and running economy; one repetition maximum bench press and half squat; counter movement jump height; 5 m, 10 m, and 20 m agility; ventral, lateral-left, lateral-right, and dorsal core strength-endurance using concentric-eccentric muscle tests	The level of core strength of total and ventral strength-endurance was largely correlated with maximum oxygen uptake (r = 0.74 and r = 0.71, both *p* < 0.05). There was a large correlation between the level of ventral core strength-endurance and the time to exhaustion (r = 0.66, *p* < 0.05)	93.8
Castanheira et al. (2017)— Portugal	42 basketball players aged 15.32 ± 0.64 years, 73 rink-hockey players aged 15.29 ± 0.73 years, 28 judo athletes aged 15.23 ± 0.49 years, and 21 swimmers aged 15.35 ± 0.43 years.	Anthropometry and echocardiographic exams were assessed by an experienced technician	Basketball and roller hockey players have larger left auricle diameters in comparison with judo athletes (F = 3.865; *p* = 0.011; ES-r = 0.316). Interventricular end-diastolic septal thickness (F = 7.287; *p* < 0.001; ES-r = 0.347) and left ventricular posterior wall thickness (F = 8.038; *p* < 0.001; ES-r = 0.362) of judokas are smaller compared to the mean value of other sports participants Relative left parietal ventricular wall thickness is lower among swimmers in comparison with judokas (F = 4.127; *p* = 0.008; ES-r = 0.268)	81.3
Reverter-Masia et al. (2017)— Spain	Physical conditioning coaches from Ok Liga (*N* = 14), elite teams) and roller first division (*N* = 16).	A Survey was administered to each physical conditioning responsible by means of personal interview to determine the use of technology associated to the control of strength training	There were differences between categories in the utilization of the encoder (21.4 vs. 12.5%) and of the Optojump (35.7 vs. 25.0%). The countermovement jump (CMJ) (33.9%) and the squat jump (SJ) (20.5%) were the two vertical jump height tests further used	56.3
Casassas et al., (2018)— Spain	Physical conditioning coaches from Ok Liga (*N* = 14), elite teams) and roller first division (*N* = 16).	Survey administered to the people responsible for the physical conditioning to characterize medical staff and physical conditioning coaches.	80% of the physical conditioning coaches of the OK Liga have degrees in Physical Activity and Sports Sciences against 40% of the first division teams (*p* < 0.001). Respectively, 45% and 20% had a Master and Doctoral degree in related fields of human performance. More than 80% of the OK Liga had physiotherapist, doctor and physical trainer significantly higher (*p* < 0.001) than first division teams (<45%). The percentage of the teams with kit men is also higher on OK Liga (>83.5% vs. 62.4%, *p* < 0.001)	62.5
Gonçalves et al. (2020)— Portugal	10 elite rink-hockey players (29.3 ± 4.8 years; 178.3 ± 6.4 cm; 78.0 ± 3.9kg) from the Portuguese 1st league division	Perception of fatigue, stress, delayed onset muscle soreness, and quality of sleep were recorded; afterward, the Hopper index (1–7) was constructed with the sum of the four subjective ratings. Rating of perceived exertion (RPE) was collected approximately 30 min after each training session using Borg´s CR-10. Volume of	Players spend less time training on congested weeks (more than one game in the week) when compared with normal weeks. Similar results were identified in both congested and normal weeks concerning the training process of the days classified as MD-3 (three days before a match). There were significant differences between days classified as MD-3 and MD-2.	93.8

		training was also registered, and the session calculated	Higher values of internal load, RPE, and volume, were observed respectively

3.3.5. Cardiorespiratory Adaptations

The practice of sports offers clear opportunities to understanding cardiac remodeling (Castanheira et al., 2017). Although there is limited information about cardiac indicators of adolescent hockey players, Castanheira et al. (2017) compared 73 Portuguese players aged 16.4 ± 1.5 years old with other players with same age in other sports. Also, Valente-dos-Santos et al. (2013) analysed the importance of pulmonary function in rink-hockey players. Seventy-three Caucasian athletes were engaged on an incremental maximal test on a motorized treadmill for scaling peak oxygen uptake, while body size descriptors were also assessed (Valente-Dos-Santos et al., 2013) (see Table 1).

3.3.6. Specific Training and Workload

Concerning the training environment, several factors can be considered especially relevant—therefore, the lack of conditioning coaches and the importance of multidisciplinary teams have been analysed on both divisions in Spain (OK Liga and first division) (Casassas et al., 2018). On the other hand, rink-hockey researchers developed an investigation with 10 elite players, which were tested on (1) time to exhaustion, maximum oxygen uptake, and running economy; (2) one repetition maximum bench press and half squat; (3) counter movement jump height; (4) 5 m, 10 m, and 20 m speed; and (5) 22 m agility. With the main goal of understanding the relationship between core strength and key variables of performance, athletes were also tested for (6) ventral, lateral-left, lateral-right, and dorsal core strength endurance using concentric-eccentric muscle tests (Hoppe et al., 2015). Season training periodization is a complex process, mainly considering the implications of different training loads (Gonçalves et al., 2020). Therefore, variation of season workload and well-being among 10 professional rink-hockey players was assessed to understand the implications of load manipulation on regular (one match) and congested (two matches) weeks (Gonçalves et al., 2020) (see Table 1).

3.3.7. Anthropometry, Body Composition, and Conditional Profile

The studies that analysed anthropometry and body compositions explored athlete´s profile to establish specific conditional profiles of rink-hockey players (Coelho-E-Silva et al., 2012). Also, the dietary intake, body composition and training data of child and adolescent rink-hockey players (38 children and 34 adolescents) has been assessed in order to compare body composition and nutrient deficiencies in Portuguese rink-hockey players (Silva & Silva, 2017). Body descriptors such as body size, composition, and skeletal age seem to have a relationship between cardiac ventricular mass in under-17 players (Valente-dos-Santos et al., 2013). There is little information about elite adult athletes; however, when studying the relationship between power condition, agility, and speed performance, skinfolds and body composition information may be a determinant on the understanding of possible correlations (Ferreira et al., 2019) (see Table 2).

Table 2. *Articles mainly related to anthropometric, body composition, and conditional characterization.*

Study and Country in Which Study Have Been Carried	Sample	Main Outcomes Measured	Results	Quality Score (%)
Valente-dos-Santos et al. (2013) — Portugal	73 Portuguese male rink-hockey players aged 14.5 to 16.5 years	Anthropometry, skeletal age (SA) by Fels method, and allometric modelling of left ventricular mass (LVM) assessed in accordance with recommendations of the American Society of Echocardiography	Rink-hockey players (chronological age (CA): 15.4 ± 0.6 years; SA: 16.4 ± 1.5 years) showed an eccentric remodeling of left ventricle (LV) structure within the reference range (ie., 0.24–0.42), a dilated LV chamber, but no LVM increase. Exponents for body size descriptors were 2.69 for stature (R^2 = 27%; $p < 0.001$), 2.49 for sitting stature (R^2 = 37%; $p < 0.001$), 0.76 for FFM (R^2 = 31%; $p < 0.001$), and 0.22 for FM (R^2 = 26%; $p < 0.001$). The combination of size descriptors with CA and SA increased the explained variance in LVM slightly (26%–45%)	100
Coelho-e-Silva et al. (2012) — Portugal	32 Portuguese international and 41 local under-17 (U-17) (14.5–16.5 years) male rink-hockey players	Athletes were considered in the context of discrimination by level of competition using training history, anthropometry, skeletal maturity, and laboratory and field tests	International players had less hockey experience (years) but had more practice sessions and match time (minutes) during the season. Results revealed that international players are advanced in maturity status (42% vs. 22%). Local players are shorter and attained better performance in the 25 m dash, while international players performed better in sit-ups, ball throw and 20 m shuttle run. Fatigue index stemmed from Wingate anaerobic test was higher in local. There seems to have an interaction amongst strength, anaerobic fitness and training plus game time as a factor of discriminating international from local level players	100
Silva, Silva (2016) — Portugal	72 male rink-hockey players (38 children and 36 adolescents) and 79 male controls (43 children and 36 adolescents). Athletes spent a mean of 8.5 ± 3.5 h of physical exercise per week (training and matches), while controls spent a mean of 2.0 ± 0.5 h of physical activity per week	Evaluation of training data, medical history, body composition, and typical dietary intake	Lower body fat (BF) and higher fat-free mass (FFM) were significantly observed in Rink-Hockey players. Intakes of carbohydrate and protein were adequate in athletes, on the other hand, mean intakes of fat were above the recommended levels. Differences were found in the energy intake (EI) and energy expenditure (EEE) between athletes and controls ($p < 0.05$), impacting in some cases of low energy availability in Rink-Hockey players. Intakes of	81.3

			vitamins and mineral intakes in child and adolescents were significantly higher ($p < 0.05$) in controlled groups. Low intakes of vitamins D, E, and K; calcium; iron; boron; and magnesium were reported in athletes, with the exception of thiamine ($p = 0.449$), riboflavin ($p = 0.246$), pantothenic acid ($p = 0.065$), magnesium ($p = 0.061$), and phosphorus ($p = 0.051$) in children and for niacin ($p = 0.652$), vitamin D ($p = 0.406$) and zinc ($p = 0.783$) in adolescents	
Ferreira et al. (2019)—Portugal	10 male roller hockey players with 14.20 ± 0.57 years old involved in the Portuguese national competition of under-15	Cross-sectional study. Strength was measured with squat jump (SJ) and countermovement jump (CMJ); sprinting time at 11 m, 22 m and 33 m was determined as well as in the agility t-test in roller skating	Significant inverse correlations were observed between vertical jumps and linear velocity in skating (−0.78). It was also verified a moderate inverse correlation between agility test with strength (−0.48). Lower limbs explosive and strength looks to be a strong predictor of skating linear speed and agility amongst young elite roller hockey players	87.5

3.3.8. Games Characterization (Games Pattern)

Vaz et al. (2011) analysed the characterization of the biomechanics of the penalty stroke in rink-hockey with 15 rink-hockey players in order to measure the ball speed and the bend angle of the wooden stick at the moment of contact with the hard ball. More focused on game patterns of play, Sousa, Sarmento, Harper, and Valente-dos-Santos (2018) and Sousa, Sarmento, Marques, Field, and Vaz, (2020) developed studies focused on the analysis of the impact of goalkeeper behavior in opponent´s offensive play. Also, prominent tactical position (Oliveira et al., 2015) and determination of several combinations of possible behavior structure were analysed in other studies with the goal to link behavior chain and the consideration of possible strategical interventions to improve players´ knowledge and resources (Mendo & Argilaga, 2002)(see Table 3).

Table 3. *Articles predominantly related to the involvement of games characterization (games pattern).*

Study and Country in Which Study Have Been Carried	Sample	Main Outcomes Measured	Results	Quality Score (%)
Mendo et al. (2002)—Spain	Six observational sessions—six premier division matches involving a total of six different teams	Sessions were recorded for sequential game behavioral (technical-tactical actions, shooting actions, goalkeeper actions, other incidents) analysis	Sequential behaviors between technical-tactical actions, shooting actions were associated for definition of patterns of play. Information about game behavioral development that allow to link each behavior chain to strategies suited to improving players´ resources	68.8

Vaz et al. (2011)—Portugal	15 athletes from different positions and levels (1st division—*n* = 7) (2nd division—*n* = 8) from the Portuguese league	Each athlete comprises three shot trials. Shots were recorded with a high-speed video camera (Photron Fastcam SA 2). A Stalker ATS radar (33.4 to 36 Ghz) was used to measure ball velocity	With no approach run, the ball speed may reach 90 ± 5.2 km/h (2nd league) and 102.0 km/h ± 4.6 (1st league). A shot with an approach run from a 1st league athlete may reach 115.4 ± 7.2 km/h. During contact with the ball, the angle of bending measured was 18.5 ± 3.2	62.5
Oliveira et al. (2015) — Portugal	54 rink-hockey players from five different levels (U12 *n* = 10), (U14 *n* = 11), (U16 *n* = 10), (U18 *n* = 12) and Elite (*n* = 11)	Centrality metrics of the network of passes and analysis of the variance between competitive levels and tactical positions during three official matches.	No statistical differences in centrality levels of players between competitive levels. Tactical positions had a significant main effect on the central metrics. It was found that defender and forward position are the ones that receive the balls from the teammates more	75.0
Sousa et al. (2018) — Portugal	64 coaches and 30 goalkeepers.	Development and validation of and observational instrument using five methodological stages; (1) and (2) exploratory phase about rink-hockey; (3) and (4) development of a questionnaire and observational instrument; (5) test of the reliability of the instrument	The observational instrument was considered reliable to analyse the activity of rink-hockey goalkeepers. (Kappa of intra- and inter- observer were ≥ 0.80)	75.0
Sousa et al. (2020)—Portugal	40 matches, including 1713 shots on goal from the Portuguese rink-hockey 1st division (2016–2017)	Data were analysed by a specific notational analysis system developed and validated by Sousa et al. (2018). Additionally, a Chi-square test was performed to understand which variable was associated with the final action	Goalkeepers are more effective in the first half than the second half of matches. Goalkeepers' performance is lower in the direct free-hits and penalties when compared with indirect free-hits. To save shots at the goal the most frequent technique used by goalkeepers is the "knee on the floor." Results showed that when attacks commenced in the opposition´s defensive area, teams are 55% more likely to score and shots at the upper zones of the goal have higher probability of being successful	81.3

3.3.9. Injuries in Rink-Hockey

A sample of 23 players (10 professional and 13 amateur) were assessed during two Spanish seasons (2014–2015 and 2015–2016) to analyse the injuries of rink-hockey players by considering the level of gravity vs. the level of competition (Reverter-Masia et al., 2018), the results bring up an insight of 88 injuries and additional description according to the level of gravity vs. the level of competition (Reverter-Masía et al., 2017). In skating and during competition, sudden controlled turning and stopping can trigger the overuse of the adductor muscles and the whole surrounding region, causing groin pain (Vitale et al., 2019). The implications of groin pain were analysed during Christiania stop (a sudden and intense change of direction and stopping) in professional rink-hockey players during a simulated test (Vitale et al., 2019). The influence of the knee joint position sense in rink-hockey players was studied, relevant information about the angular errors and benefits on proprioceptive accurate have been reported (Venâncio et al., 2016) (see Table 4).

Table 4. *Articles related to injuries in rink-hockey.*

Study and Country in Which Study Have Been Carried	Sample	Main Outcomes Measured	Results	Quality Score (%)
Venâncio et al. (2016) — Portugal	21 male roller hockey players (23.2 ± 4.2 years old; 81.8 ± 9.8 kg; 180.5 ± 4.1 cm) and 43 male voluntary participants (23.7 ± 3.9 years old; 85.0 ± 6.2 kg; 181.5 ± 5.0 cm)	Cross-sectional study which evaluated the knee joint position sense of the dominant limb, using a technique of open-kinetic chain and knee positioning	The results of this study show that the group of the roller hockey players presented significantly lower absolute (2.4 ± 1.2 vs. 6.5 ± 3.2, $p \le 0.001$) and relative (1.7 ± 2.1 vs. 5.8 ± 4.4, $p \le 0.001$) angular errors, in comparison with the non-athlete group	87.5
Reverter-Masia et al. (2018) — Spain	10 professional roller hockey players (28.7 ± 6.78 years old; 74.9 ± 5.22 kg; 23.01 ± 1.57 IMC) and 13 amateur players (31.85 ± 8.81 years old; 82.69 ± 9.97 kg; 25.71 ± 2.58 IMC)	Descriptive analysis from injuries recorded during the 2014–2015 and 2015–2016 seasons	Of the 88 injuries registered, 15.4% were considered mild, 50% moderate, and 34.1% serious. The incidence of moderate injuries was higher in the professional in comparison to the amateur team players (65% vs. 37.5%), while serious injuries was superior in the amateur team (45% vs. 20%). The most frequent injury in both divisions was muscle-related by traumatic mechanism, mainly affecting the upper extremity	68.7
Vitale et al. (2019) — Italy	8 male professional rink-hockey players—4 have had previous groin pain (27.75 ± 9.60 years old; 77.75 ± 5.50 kg; 179.75 ± 6.70 cm; 24.11 ± 2.04 IMC), and 4 with no-groin pain (23.25 ± 2.36 years old; 78.5 ± 5.07 kg; 177.5 ± 5.07 cm; 24.91 ± 2.01 IMC)	Prospective case series study was performed. Athletes were asked to perform the Chistiania stop, while muscle activity patterns and lower limbs kinematics were acquired with an optoelectronic system and infrared cameras allowing a computerized three-dimensional motion recording	Athletes from the groin pain experience, when performing Christiania stop, involuntary attempt to preserve the groin area. They showed lower peak values in kinematics parameters. The most frequent pattern of surface electromyography amplitude referred to adductor longus muscle, vastus medialis, tensor fascia latae and transversus abdominals. No-groin-pain group, the most frequent pattern of surface electromyography amplitude referred to transversus abdominis, adductor, vastus medialis and tensor fascia latae	87.5

3.4 Discussion

3.4.1. Physiological and Functional Demands

The match demands of “multiple-sports” include periods of strenuous physical activity and recovery interspersed with brief periods of sprinting (Blanco et al., 1993), but information about the impact of the external load is still sparse. Previous research has monitored the physiological indicators during rink-hockey competition, observing that the heart rate flows between 85% and 95% of the HR_{max} and blood lactate performance is between 4.0 mmol/l^{-1} and 4.6 mmol/l^{-1} (Boyle et al., 1994). In rink-hockey, there is not much research that includes the replication of match demands and the evaluation of player´s physiological profile. In other multiple-sprints sports, investigators have tried to replicate the demands by means of laboratory and field tests (Pelliccia et al., 1999). Our results showed that Yagüe et al. (2013) tried to replicate the physiological demands designing a simulating skate test to describe the energy to extrapolate the results for the competition. Results obtained demonstrate that physiological and metabolic demands can be achieved in laboratory settings. No significant differences were obtained in heart rate mean between stimulation tests and competition (189 ± 6.2 vs. 188 ± 5.6) (Yagüe et al., 2013). In line with other studies, the authors revealed that the heart rate stays between 85% and 88% of HR_{max} during the whole game, remaining constant throughout the entire game (Blanco et al., 1993; Te Wierike et al., 2013). Blood lactate during rink-hockey matches achieves values around 4.5–5.5 mmol/l^{-1} and 5.5–6.5 mmol/l^{-1} at the end of game, slightly lower than levels obtained during Yagüe et al. (2013) in their simulated test (5.2 ± 01.0 mmol/l^{-1} in the middle and 7.2 ± 1.0 mmol/l^{-1} at the end). Maximal effort and maximum heart rate are frequently reached in matches, therefore Yagüe (2013)mention that lactate levels during matches could be similar to those obtained in simulation tests. These reports are useful for monitoring and improving training by proposing the necessary changes. Nevertheless, new studies in rink-hockey matches are necessary, particularly those pertaining to blood lactate concentration immediately after high-intensity phases (Yagüe et al., 2013).

3.4.2. Cardiorespiratory Adaptations

It is recognized that sports training is related to the occurrence of concentric and eccentric cardiac hypertrophy (Madeira et al., 2008). Long-term intensive training promotes cardiac changes such as increased cavity diameter, wall thickness, and left ventricular mass (LVM) (Pelliccia et al., 1999). Although rink-hockey is not an endurance sport per se, it has been suggested, however that high values of cardiopulmonary function may be important to maintain a high level of activity during the entire game (Hoppe et al., 2015) and for efficient recovery from high-intensity short movements (Wierike et al., 2013). Regarding cardiac remodeling indicators in adolescent athletes, when compared with judo athletes, hockey players under-17 showed lager left auricle diameter (36.4 vs. 34.4 mm), interventricular end-diastolic septal thickness (8.1 mm vs. 7.5 mm) and left ventricular posterior wall thickness (7.7 mm vs. 7.1 mm) (Castanheira et al., 2017). Regarding the scaling of peak oxygen uptake, male Rink-Hockey players aged 15.4 ± 0.6 years reached 3.89 L-min^{-1} (Valente-Dos-Santos et al., 2013). Results suggest that variability of aerobic fitness in adolescent players may be influenced by tight volume (4.8 ± 1.0) and skeletal age (SA) (16.4 ± 0.6 years) (Valente-Dos-Santos et al., 2013). There are few studies regarding maximal oxygen uptake in male elite players, but simulation tests and laboratory tests reports values between 50 and 60 mL/Kg/min (Hoppe et al., 2015; Rodríguez et al., 1991). Further research regarding cardiac morphophysiological traits and adaptations is required to better understand the maximal oxygen uptake in elite rink-hockey players.

3.4.3. Specific Training and Workload

Although few studies have addressed research focused on the characterization of morphological and physiological demands of roller hockey, it seems clear that in elite rink-hockey, as in other indoor team sports (Burr et al., 2008), enhancing specific variables of endurance like strength, power, speed, and agility seem to contribute to the increase in the players performance. Such results can be measured by time to exhaustion, maximum oxygen uptake, running economy during incremental testing (Grieco et al., 2012), one repetition maximum in half squat and bench press exercises (Nesser et al., 2008), vertical jump height in counter movement jump (Ziv & Lidor, 2010), and sprint times from speed and agility tests (Sheppard & Young, 2006), which are important for athletic performance (Hoppe et al., 2015). However, as in other sports, a relationship between core training and athletic performance is not consensual (Hoppe et al., 2015). Nonetheless, similarly to results obtained in football (Nesser et al., 2008), the level of total and ventral core strength-endurance was largely correlated with maximum oxygen uptake (r = 0,74 and r = 0.71, both $p < 0.05$) in elite male rink-hockey players, with a large correlation between the level of ventral core strength-endurance and the time to exhaustion (r = 0.66, $p < 0.05$) (Hoppe et al., 2015).

Monitoring athletes´ training loads is important to understand whether they adapt to the training program and to determine their feedback through fatigue (Gonçalves et al., 2020). The combination of different endurance determinants, such as internal load, fitness status, and wellness, seem to have an important role in improving athletes´ global performance (Bourdon et al., 2017). Coaches should periodize regular and congested weeks with different approaches to improve an athlete's recovery (Beachle & Earl, 2008). Unfortunately, there is a lack of literature about elite rink-hockey athletes. Given this fact, we believe that more research involving athletes' physiological traits and game load may be crucial to updating new training environments. According to Cassassas et al. (2018), coaches should take advantage of recent scientific knowledge concerning the implication of conditioning to improve training environment.

In rink-hockey athletes, training sessions during normal weeks (one game) are associated with higher loads than sessions during congested weeks (two games) as indicated by differences in volume, rated of perceived exertions (RPE), and internal training load (Gonçalves et al., 2020). In terms of within-weeks variation, the day that is determined for more loads on normal weeks corresponds to the game day on congested weeks (Gonçalves et al., 2020). Therefore, it is suggested that there be an adjustment to the training load by decreasing the volume, intensity, and, consequently, internal and external load of training tasks in congested weeks (Gonçalves et al., 2020). The characterization of external and internal load demands of elite rink-hockey players during competition and training is required to best characterize game demands of competition and consequent comparison with training sessions using indoor tracking system devices.

3.4.4. Anthropometry, Body Composition, and Conditional Profile

In the few last decades, several studies in different sports have focused their attention on the anthropometric characteristics of elite athletes (Carter & Heat, 1991; Gualdi & Zaccagni, 2001)with the goal of identifying key determinants of performance that characterize specific sports and/or specific positional groups of players (Calò et. al., 2009). Therefore, the analysis of an athlete's body composition is actually an important tool to characterize and improve sports performance (Calò et. al., 2009). Regarding the anthropometry methodology used in the reviewed articles, in all studies, body mass (BM) and stature were assessed. Additionally, in order to calculate the percentage of fat mass (FM) in two studies was used the sum of two skinfolds (triceps and subscapular) (Silva & Silva, 2017a; Valente-dos-Santos et al., 2013). However, Silva and Silva (2017) used the protocols of Frisancho (2011), Valente-dos-Santos et al. (2013), and the Slaugther et al. (1988). On the other hand, in the research of Coelho-e-Silva (2012), the sum of four skinfolds (triceps, subscapular, suprailiac, and medial calf) was used following the standard procedures of Lohman et al., (1988). In all studies, a single observer completed all anthropometric procedures. Fat-free mass (FFM) was calculated as the difference between BM and body fat (BF) (Valente-Dos-Santos et al., 2013).

For example, the analysis of the energy intakes according to the demands of the competition in each sport allows for an analysis of the necessary energy levels required by athletes for sports performance and especially for growth (Casassas et al., 2018; Hoppe et al., 2015). With this concern, Silva and Silva (2017) characterized and compared the body composition and nutrient deficiencies between rink-hockey athletes and non-athletes. Results revealed that body mass index (BMI) was significantly lower in athletes than in non-athletes, mainly because of lower body mass. Similar results were observed in the analysis of 50 ice hockey players and controls (Fogelholm et al., 2000), which corroborates that BMI is an indicator of body composition in athletes (athletes vs. non-athletes). Data revealed that mean intakes of carbohydrates and protein were adequate in both groups, but mean intakes of fat were above the recommended levels in athletes (Silva & Silva, 2017). Significant differences were found in energy intake (EI) and exercise energy expenditure (EEE) between athletes and controls ($p < 0.05$), resulting in some cases of low energy availability in rink-hockey players (Silva & Silva, 2017). On the other hand, significant group differences ($p < 0.05$) were also observed for vitamin and mineral intakes in child and adolescent rink-hockey players due to higher mean intakes in control groups (Silva & Silva, 2017). This fact may suggest that nutritional deficiencies in macronutrients and micronutrients may impair athletes´ growth and development promoting negative impact on their athletic performance. It has been reported that high body mass in athletes from contact sports may help in generating power and force, which in rink-hockey may be important for effective skating and physical contact, however, collision sports (where rink-hockey is also included) are likely to be favorable to athletes with greater levels of fat free mass rather than a greater total body mass (Delaney et al., 2016). The importance of body composition analysis extends to cardiac structure and performance (Valente-Dos-Santos et al., 2013). Among adults, there has been a variety of methods to normalize left ventricular mass to body size, such as dividing left ventricular mass by body size variable namely stature (Lauer et al., 1991). However, body proportion changes with growth and maturation, therefore, the relationship between cardiac size and stature may differ at different stages of development (Dewey et al., 2008). Well-trained adolescent rink-hockey players aged 15.4 ± 0.6 presented 55.6 ± 7.9 kg of fat-free mass (FFM), and 11.8 ± 6.2 kg of fat mass (FM) (Valente-Dos-Santos et al., 2013). Such results are in line with previous studies (Chinali et al., 2006; Rowland & Roti, 2010) and may be an important indicator of athletes' body composition at this age.

The indicators of FFM and FM, were simultaneous robust determinants of left ventricular mass (LVM) (Chinali et al., 2006; Rowland & Roti, 2010) However, in the study by Valente-dos-Santos et al. (2013), skeletal age was the variable that better relates to the left ventricular mass of roller hockey players. Upper body length measured by sitting stature was the most robust individual determinant of LVM. Sitting stature and fat mass was the most robust individual determinant of LVM normalized (Valente-Dos-Santos et al., 2013).

According to Coelho-E-Silva et al. (2012), the comparison between under-17 male rink-hockey players selected for the Portuguese national team and athletes from regional level of the same age revealed advanced skeletal maturation and taller values with less subcutaneous adiposity of players selected for the Portuguese national team (Coelho-E-Silva et al., 2012). Data shows that international players are on average, 4.4 cm taller and 4.3 kg heavier than the local players; however, the body mass was not statistically significant (Coelho-E-Silva et al., 2012). In the end, the results revealed that differences in body size influence the performance by international players in hand-grip strength (Coelho-E-Silva et al., 2012) . Authors concluded that young athletes who possess superior skills and functional abilities are nearest to becoming elite athletes (Buekers et al., 2015). Furthermore, when they present advanced biological maturity based on anthropometric determinants, they suggest an obvious motivation of sport performance (Reilly et al., 2000).

Studies of adult male rink hockey players are limited, and thus, those that exist consist of a small number of participants.

In rink hockey, power, strength, speed, and agility are physical qualities of extreme relevance for the physical performance of the players, as in ice hockey (Stastny et al., 2018). Agility is described as a rapid movement of the whole body with the change of speed or direction in response to a stimulus (Sheppard & Young, 2006). A study conducted among 10 male rink-hockey players aged 14.20 ± 0.57 years with 58.62 ± 8.78 kg (body mass), 165.72 ± 8.45 cm (height), 21.26 ± 1.52 kg/m^2) (BMI), and a sum six skinfolds of 51.80 ± 14.91 mm described that a significant inverse correlation exists between vertical jumps, and linear velocity in skating (countermovement jump vs. speed, r = −0.78) (Ferreira et al., 2019). The same type of correlation exists between countermovement jump and agility teste (T-Shape tests) (Ferreira et al., 2019). The results suggest that rink-hockey athletes who jump more tend to have better agility traits (Ferreira et al., 2019). Additionally, the vertical jump test looks to be a good predictor of linear speed and agility among talented young rink-hockey players (Ferreira et al., 2019). Consequently, we believe that plyometric training may have an important role concerning the improvement of athletes´ speed and agility.

3.4.5. Games Characterization (Games Pattern)

Rink hockey is a particular invasion team sport (Brázio, 2006) because it is possible to play behind the goals (Oliveira et al., 2015). Cooperation between teammates is a dependent factor for success, which characterizes the internal logic and tactical behavior of players and teams (Griffin & Butler, 2005). It has been observed that the above-mentioned topics lack literature pertaining to match analysis (Clemente et al., 2015). As an exception, the analysis of the offensive process of an international U-20s team in five matches revealed 408 units of attacks (in circulation—indirect attack) followed by counterattack and quick transition (Ferreira, 2009). During the offensive process, major units of attack cover both lateral sides of the field and the central zone (Ferreira, 2009). According to this match analysis, the central zone seems to be a determinant for the attacking movement, generating a greater number of shootings (Ferreira, 2009). Per unit of attack a mean value of 2.73 passes were registered, showing how fast the offensive unit can be (Brázio, 2006). Regarding prominent tactical position, other research revealed that elite players actions are dependent of their positions (Oliveira et al., 2015). Defenders and forwards received more balls from teammates and at the same time performed more passes (Oliveira et al., 2015) to other players´ positions. In opposition, wing players revealed the lower number of passes over competition (Oliveira et al., 2015). It appears that players 'positioning influences ball circulation across different game zones. The identification of patterns of play (Mendo & Argilaga, 2002) supporting the following game actions—(1) shooting actions, (2) technical-tactical actions, (3) goalkeeper actions, and (4) other incidents—were assessed (Ferreira et al., 2019; Gonçalves et al., 2020). Results revealed that technical and tactical actions are involved in longer patterns of play in which behaviors do not have more than three links between the above-mentioned possible actions (Mendo & Argilaga, 2002). Regarding the offensive process, the shooting pattern is initiated with muscular power movement demanding a huge amount of muscle energy in which the athlete reaches a specific momentum while trying to stand completely balanced just on one foot (Vaz et al., 2011). As opposed to a shot (that can easily reach 100 km/h) (Vaz et al., 2011), it is the goalkeeper who is usually the last line of the defense, wearing a protective gear in a crouched position (Sousa et al., 2018). The rink-hockey goalkeeper has an important role on his teams' success. Concerning their influence on the fine line between winning and losing, Sousa et al. (2018) developed an observational instrument tool that could help coaches to analyse the activity of rink-hockey goalkeepers. It is suggested that this type of tool may influence goalkeeper performance.

As in futsal, rink hockey is predominantly offensive, and of finishing actions, players may reach 408–422 displacements during a game (Blanco et al., 1993; Tantiña et al., 2014). Nearly 50% of offensive actions lead to an attempt to score, however just 3% of attempts end in a goal (Ferreia, 2009). It is known that opponents attacking impacts the goalkeeper´s performance (Sousa et al., 2019). The variation of shooting zones influences the performance of the goalkeeper such as; (1) shots performed in the opposition defensive area, goalkeepers are 66% less likely to save the shot, in comparison with (2) shots performed in the intermediate area (Sousa et al., 2019). In addition, the variable "match status," also seems to influence goalkeeper performance as they are more effective during the first half rather than the second, suggesting that this may be related with their lower physical conditioning (Sousa et al., 2019). The understanding of patterns may be crucial to develop new training strategies regarding the improvement of goalkeeper's performance and field players. Future studies should characterize, by using specific technology, the internal and external load of different players position and different players behavior during an entire game.

3.4.6. Injuries in Rink-Hockey

Rink hockey is an intense collision and contact sport between players; in addition to the weight and speed of the hard ball and the stick, the risk of moderate and severe injuries can be considerable (Reverter-Masia et al., 2018). Few studies have been developed to show the incidence of rink-hockey injuries. Previous studies have been focused only on the number and severity of injuries (Hootman et al., 2007; Paleaz, 2008). According to some authors the type of injury which is more frequent seems to be head injuries (Paleaz, 2008; Reverter-Masia et al., 2018). In the Spanish league, 88 injuries were analysed (professional vs. amateur), and the results reported a severity of mild 15.9%, moderate 50% and serious 30% (Reverter-Masia et al., 2018), yet, the most frequent injuries were muscular by traumatic mechanism affecting the upper extremities as well as the head (Reverter-Masia et al., 2018). The mechanism of injury coincides with the demands of a contact sport (Paleaz, 2008). Also, it seems that the level of competition influences the level of injury. In professional competitions injuries, are mainly moderate (65% vs. 37.5%), while in amateur play, these are much more serious (45% vs. 20%) (Reverter-Masia et al., 2018). This context may be associated with the lack of specific training regarding injury prevention at amateur level (Casassas et al., 2018). On the other hand, the use of helmets for field players may significantly decrease head injuries and should be recommended as a preventative strategy. One of the most common chronic injuries is promoted by the impact of the Christiania stop, which induces groin pain. (Vitale et al., 2019). Kinematics data refers that during the repetition of Christiania stop, athletes with no-groin pain show higher hip flexion, hip rotation, pelvis rotation, and knee flexion when compared with the groin pain group (Vitale et al., 2019). Players with previous groin pain tend to activate adductors the most, therefore the pain perception may lead to an adjust of task to avoid fear, leading to dysfunction of tasks (Vitale et al., 2019). On the other hand, results from the study of knee joint position of rink hockey players, suggest that athletes have higher proprioception indicators than non-athletes which contribute to injury prevention and enhanced performance (Venâncio et al., 2016). This biomechanical information may lead to specific training strategies (from conditioning-strength coaches and physiotherapists) to reduce pain, injury prevention, and improved physical performance (Casassas et al., 2018). A more systematic study is required to link the type and occurrence of injuries with players' characteristics, training, and competition load, type of competition, or even time between matches (congested vs. non-congested periods)

3.5 Conclusions

In general, the results revealed that high values of adapted cardiorespiratory function of players may be important to keep elevated levels of activity during the entire game and for efficient recovery from high-intensity short movements. As expected, it seems that the development of performance, such as strength, power, speed, agility, flexibility, and maximum oxygen uptake, may increase athlete's conditional performance profile. Characterization and comparison of body composition reveals to be an important monitoring tool of players' development and energy intakes. Further research is required to understand the relationship between players' characterization and performance over the rink-hockey game. The analysis of external and internal load of players as well as the analysis of technical and tactical actions should be promoted in order to identify reliable key performance indicators that help researchers and coaches to improve preparedness of players to the demands of the game.

The analysis of game patterns, shows a combination of specific game momentums with different outcomes according to the game zone. Their understanding may be crucial to develop new training strategies regarding the improvement of the goalkeeper and field players' performance. In line with previous comments, further research is required to improve the understanding of game dynamics linking technical and tactical behaviors of players and teams.

Regarding injuries, the intense short-term movements, collision, and contact between players, in addition to the weight and speed of the hard ball and the stick, can considerably increase the risk of moderate and severe injuries. Finally, there is a need for more research at elite levels regarding patterns of conditional profiles and physiological adaptation while, at the same time, understanding how demanding a top-level competition game can be. Therefore, we believe that it is important to understand what external load challenges the rink hockey athletes are subject to, aiming for the improvement of the training environment.

Finally, only English articles searched in Scopus, Web of Knowledge, and PubMed were included in this study. Therefore, the lack of potentially relevant articles in other languages may be a limitation per se. Future steps should allow to focus the inclusion criteria in specific research topic. Additionally, we believe that the lack of international publications regarding the major topics reviewed in this paper may influence the actual reality of sport performance in rink-hockey. Therefore, there is a need to clarify the elite athletes' traits and game demands in order to develop new evaluation and monitoring tools, which will improve rink-hockey training environments.

4. Body composition and grip strength constraints in elite male rink-hockey players of contrasting ethnicity

Ferraz, A., Valente-Dos-Santos, J., Duarte-Mendes, P., Nunes, C., Victorino, S., Coelho E-Silva, M. J., & Travassos, B. (2022). Body composition and grip strength constraints in elite male rink-hockey players of contrasting ethnicity. *PloS One*, *17*(9), e0274894.

4.1 Introduction

Rink hockey is an indoor intermittent team sport that requires both short- and long-duration efforts, followed by incomplete recovery periods (Calò, 2009; Yagüe et al., 2013), which require highly specialized and physiological demands (Yagüe, 2007). Players' performance is highly dependent on different interacting factors such as health status, genetic endowment, physical training, fitness levels and body composition (Williams, 2013). In line with previous studies, there are similarities between rink hockey and other hockey modalities such as ice hockey: (1) high-intensity intermittent skating and physical contact requiring a well-developed metabolism for short and long-duration efforts; and (2) multidirectional skating and the need to continually perform complex skills while gripping a stick (Yagüe, 2007; Toong et al., 2018).

It is known that the body composition characteristics of athletes constrain their competitive performance as well as their training, which is especially relevant for sports professionals (Ackland et al., 2012; Malina, 2007). Anthropometry is defined as the study of body dimensions and composition and is among the biological variables related to sports performance (Malina, 1996). In the last decades, several researchers in different sports have focused their attention on the anthropometric characteristics of elite athletes (Carter, 1990; Russo, 2001) aiming to identify key determinants that characterize specific sports and/or specific positional groups of players (Calò, 2009). Therefore, the analysis of an athlete's anthropometry is an important tool to characterize and improve sports performance (Calò, 2009).

Grip strength is an important variable used to measure muscular strength, which is a vital component of physical fitness (Caspersen et al., 1985), as it can be used to gain relevant insights regarding bone health (Saint-Maurice et al., 2015) and functional status (De Smet, 2001). Upper strength assessment has been shown to correlate to an individual's general muscular strength (Wind et al., 2010), and the hand-grip strength test seems to be influenced by the level of physical activity and training (Nevill & Holder, 2000). Grip strength is mandatory in most hockey-specific movements with players continually performing complex skills while gripping a stick (Toong et al., 2018). According to Coelho-e-Silva et al. (2014) under-17 international male rink hockey players revealed particular body composition characteristics and high hand-grip strength when compared with local players, arguing that players with high hand-grip strength have a greater propensity towards becoming elite athletes.

Regarding ice hockey, a previous study emphasized that the grip hand is influenced by age (Toong et al., 2018). Adult athletes revealed higher values (right = 67.34 ± 7.75kg; left = 67.03 ± 8.16kg) when compared to younger athletes (Chiarlitti et al., 2018). However, there is no information or standard references regarding this relationship in adult elite athletes in this sport. To the best of our knowledge, the existing research regarding body composition with adult elite athletes was only assessed with small sample sizes. Furthermore, anyone has been conducted exploring normative grip strength performance in adult elite male rink-hockey players.

Fitness testing for monitoring and evaluating training adaptations is important for assessing the level of physical performance in athletes (Vaara et al., 2012). According to previous research, ethnicity also seems to be an important determinant factor for functional, morphological, and physiological adaptations such as strength, body fat and cardiovascular adaptations (Papadakis et al., 2012). In the past few years, a relevant number of African athletes playing abroad prompted researchers to investigate the effect of exercise and sports training on those ethnicities. Generally, several researchers have shown that ethnic differences in body proportions can have a significant influence on the estimation of BF% derived using field methods (Wagner & Heyward, 2000). Some authors suggest that the biological differences in the body composition between Black Africans and Caucasians may necessitate the need to develop prediction equations based on the specific population (Wagner & Heyward, 2000). However, to our best knowledge, there is no information regarding this characterization of Black elite male rink hockey players.

Therefore, the aim of the present research was to characterize and underline possible differences in body composition and grip strength between Black African and Caucasian ethnicities. Particularly, it was our intention to identify the variables that constrain body composition and grip strength values according to ethnicity.

4.2 Material and Methods

4.2.1 Ethics statement

Data collection was carried out according to the international ethical standards with humans (Harriss & Atkinson, 2015) after approval by the Ethics Committee of the Universidade da Beira Interior (CE-UBI-Pj-2019-053:ID1519). All participants were informed about the aims, the protocol and procedures, and signed written informed consent. Participation was voluntary and each participant could withdraw at any time. Data was measured in Angola and Portugal between December 2019 and the end of February 2020.

4.2.2 Sample

One hundred (100) elite rink-hockey athletes aged 26.59 ± 6.02 participated in the study. The sample comprised 69 Caucasian elite male rink-hockey players aged 27.58 ± 6.44 years, from the Portuguese first league, which was comprised of six (6) teams and six (6) nationalities (Portuguese n=47; Spanish n=11; Argentines n=7; French n=2; Italian n=1;

English n=1) and 31 Black African elite male rink-hockey players aged 24.39 ± 4,27 from the Angolan first league, consisting of three (3) teams and (1) nationality (Angolan n=31). The selection process of the sample was convenient considering the level of the clubs, and their availability to participate in this study. The inclusion criteria of the players were as follows: (1) must be between 18 and 43 years old, (2) must be continuously competing for at least 5 full years without having played any other sport in the past, and (3) attend at least four weekly training sessions in clubs registered at Federação Portuguesa de Patinagem and Federação Angolana de Patinagem (McAuley et al., 2022).

4.2.3 Anthropometric measurements

Height was measured with no shoes using a stadiometer (Seca 700: Seca, Hamburg Germany) to the nearest 0.1 cm. Body weight was measured in light clothing with no shoes using the Tanita (RD-953) digital weight scale. All skinfolds and circumferences were measured using an anthropometric tape (Harpenden, Holtain LTD, Germany) to the nearest 0.1cm (ISO, 1989) while the participants were in a standing position. Waist circumference was measured midway between the lower costal margin and the iliac crest and at minimal respiration. Hip girth circumference was measured round the buttocks at the level of the greatest trochanteric projections. Thigh girth circumference was measured at the highest tight position, while mid-thigh girth circumference was measured midway between the hip level and the knee. Lower-thigh girth circumference was measured 5cm from the top of the patella, and calf girth circunference was measured with legs slightly apart with body mass equally distributed on both legs. All circumferences assessed were as follow: *(1)* WC (Waist Circumference); *(2)* ABC (Abdominal Circumference); *(3)* HC (Hip Circumference); *(4)* RTC (Right Thigh Circumference); *(5)* RMTC; *(6)* Right mid-thigh Circumference); *(7)* RDTC (Right distal-tight Circumference); *(8)* RCC (Right Calf Circumference); *(9)* LTC (Left Tight Circumference); *(10)* LMTC (Left mid-tight Circumference); *(11)* LDTC (Left distal-tight Circumference); *(12)* LCC (Left Calf Circumference); Body fat percentage was derived from the three skinfolds Body Density (BD) formula of Jackson and Pollock (1978), additionally, the BF% was calculated by using the Siri (1956) formula. The thickness of the nine skinfolds (*triceps, subscapular, biceps, supra iliac, abdominal, pectoral, medium axillar, front-thigh*, and *media calf*) was measured using a Harpenden skinfold calliper (British Indicators, Burgess Hill, UK) and calculated according to Durnin and Womersley (Durnin & Womersley, 1974). The summary of skinfolds (SUMSK) was also calculated. Body surface area (BSA) was derived from the Dubois formula (DuBois, 1989).

4.2.4 Reliability of anthropometric measurements

All measurements were taken by an experienced observer during both competition seasons. Body Mass Index (BMI) was calculated as [weight (kg)]/ [height (m)]^2 and was classified according to WHO standards. To calculate the precision of measurements, intra-observer technical error of measurement (TEM) was calculated for skinfolds and circumferences (Note. TEM =PD2/2N, where D is the difference between pre- and post-measures and N is the sample size, and TEM% = 100 * TEM/X, where X is the grand mean of the pre- and post-measures) (Ulijaszek & Kerr, 1999). Ten rink hockey athletes were measured by the same observer. Skinfolds and circumferences were registered twice to calculate deviations between both measures. The mean TEM% for the 9 skinfolds was 5.8% and 1.8% for the 11 circumferences. The absolute TEM was acceptable for both measurements (Ulijaszek & Kerr, 1999).

4.2.5 Handgrip upper static strength

Grip strength was conducted to assess musculoskeletal fitness. Athletes used a handgrip dynamometer (T.K.K. 5401) adjustable to the hand size by an experienced observer. Maximal handgrip strength (recorded to the nearest tenth of a kg) was measured bilaterally with limbs unsupported and with the elbow in the extended position. Athletes were asked to squeeze the dynamometer as tight as possible. Each hand was measured twice, and the peak value obtained over the 2 trials was considered for the analysis (Burr et al., 2008).

4.2.6 Statistical Analysis

An inspection of the data revealed no missing values, nor were any univariate outliers found. A priori power analysis through G*Power (3.1.9.2) (Faul et al., 2007a) was used to determine the required sample size considering the following input parameters: effect size d = 0.8; α =0.05; statistical power = 0.9. The required minimum sample size was 58 (28 for each group), which was respected in the present study. Regarding to the multiple regression analysis, the required minimum sample size was considered based on the following input parameters: effect size f^2 = 0.1; α =0.05; statistical power = 0.9. was 88 (total sample), which was also respected.

Descriptive statistics (range, mean, standard error of the mean, and standard deviation) were calculated for the overall sample. Players were classified according to ethnicity, and body composition and maximal grip strength were compared between groups. Data normality was tested by the Kolmogorov-Smirnov test. A *t*-test for independent samples (variables with normal distribution) and Mann-Whitney (variables with non-normal distribution) were used to verify differences between ethnic groups (Black Africans and

Caucasians). Additionally, an effect size analysis was used to determine the magnitude of the effect (Cohen, 1988). Cohen's *d* was considered, whenever the *t*-test was used, and interpreted based on the following cut-off values: 0.0-2.0, trivial; 0.21-0.60, small; 0.61-1.20, moderate; 1.21-2.00, large; > 2.00, very large (Hopkins et al., 2009a). In cases where the Mann-Whitney test was used, η^2 was obtained and the interpretation of the effect size was based on the following criteria: <0.01 no effect, 0.01–0.05 small effect, 0.06–0.13 moderate effect and ≥0.14 large effect (Fritz et al., 2012a).

In addition, a multiple linear regression analysis was performed to explore the predictors of the variables; BF% and Grip Strength. For BF% the independent variables included in the model were the following: Hours of training, Chronological Age (CA), Body Mass (BM), Height, Body Mass Index (BMI), Body Surface (BSA), Ethnicity and the circumferences (as previously described). Skinfolds were not included in the model to avoid multicollinearity situations. Regarding the Grip Strength, the independent variables included in the model were the following: Hours of training, Chronological Age (CA), Body Mass (BM), Height, Body Mass Index (BMI), Body Surface (BSA), Ethnicity, the 9 skinfolds and the 11 circumferences. The Stepwise method was applied in the multiple linear regression analysis. Ethnicity was considered as Black or Caucasian for comparison purposes in the model. The value of the ANOVA test was used to assess whether the model is a significant predictor. The adjusted R^2 was used to evaluate the model's power of explanation, and interpretation of R^2 as an effect size measure was made based on the following criteria: 0.02–0.13 small, 0.13–0.26 medium, and >0.26 large effect size (Kotrlik et al., 2011). The assumptions underlying the use of the multiple linear regression model (normality, independence and homoscedasticity of the error and no situations of multicollinearity) were all met. The assumption of no extreme values was also verified.

Statistical analyses were performed using IBM Statistical Package for Social Science (SPSS) version 22.0 (SPSS, Inc., Chicago, Ilinois, USA) with the threshold for statistical significance set to $p \leq 0.05$.

4.3 Results

Descriptive statistics for variables measured regarding weekly training volumes, anthropometrics measures (Body mass, skinfolds, circumferences) and parameters extracted from the handgrip tests are presented in Table 1.

Table 5. *Descriptive statistics combined for both ethnic groups.*

Variable	Range (min-max)	Mean			(Kolmogorov-Smirnov)
		Value	Standard error	Standard deviation	p
Training, hours per week	7.50-12	10. 50	0.20	1,55	0.000
Chronological age, years	18-43	26.59	0.60	6.02	0.001
Body mass, kg	51.4-120.80	76.36	0.90	9.18	0.092
Height, cm	163.80-189.30	175.80	0.60	5.87	0.200
Body mass index, kg/m²	18.25-38.13	24.68	0.25	2.56	0.001
Body Surface Area, cm²	1.57-2.36	1.92	0.01	0.12	0.200
Abdominal skinfold, mm	5-52	16.20	0.81	8.33	0.002
Pectoral skinfold, mm	4-34	8.80	0.46	4.83	0.000
Front thigh skinfold, mm	5-36	12.45	0.55	5.80	0.000
Sum of skinfolds, mm	47-270	89.49	3.58	37.88	0.000
Body density, g/cm3	1.03-1.09	1.07	0.01	0.01	0.026
Body fat mass, %	3.86-31.93	10.82	0.48	5.07	0.021
Waist circumference, cm	71.5-111.5	84.81	0.58	5.98	0.020
Abdominal circumference, cm	68.2-118	82.79	0.65	6.74	0.003
Hip circumference, cm	78.6-117.8	99.07	0.53	5.55	0.042
Right thigh circumference, cm	50.5-75	60.98	0.43	4.47	0.200
Right mid-thigh circumference, cm	48.3-66	54.88	0.31	3.32	0.000
Right distal-tight circumference, cm	35-55	42.44	0.28	2.86	0.200
Right calf circumference, cm	32-44	36.96	0.22	2.30	0.200
Left thigh circumference, cm	50-73	60.06	0.40	4.15	0.200
Left mid-thigh circumference, cm	46.60-63	54.02	0.28	2.89	0.200
Left distal-tight circumference, cm	34.30-55.50	42.17	0.29	2.90	0.006
Left calf circumference, cm	31.30-46	36.76	0.23	2.42	0.071
Right grip strength, N	37.70-73.80	50.91	0.62	6.26	0.200
Left grip strength, N	37.30-79-91	50.27	0.63	6.23	0.082

Results presented as range, mean, standard error of the mean, 95% confidence limits of the mean, and standard deviation.

4.3.1 Body Composition and Grip Strength of elite rink hockey athletes

The results of Table 1 display the body composition traits and grip strength references of rink hockey athletes with a regular weekly training volume of 10.50 ± 1.55 hours. BM showed an average of 76.36 ± 9.18 kg, and an average of 175.8 ± 5.87 cm was assessed for height. BMI reveals a high limit for normal weight (24.68 ± 2.56 kg/m2). The summary of the 9 skinfolds (89.49 ± 37.88 cm) reflects a BF% of 10.82 ± 5.07 %. The BSA is set at 1.92 ± 0.12 m^2. Hand grip strength was tested, with 88% of the sample referenced as right-hand dominant and 12% left-hand dominant. For maximal RGST it was obtained at 50.91 ± 6.26 kg and 50.27 ± 6.23 kg for LGST.

Table 2 summarized the comparison between ethnicity group results. There were significant differences in several variables between players' ethnicities. Caucasian athletes revealed significantly higher BM (77.97 ± 8.65 kg) than Black athletes (72.78 ± 9.47 kg). There were also significant differences in BMI and BSA between groups, 23.78 ± 3.08 kg/m^2 and 1.87 ± 0.13 m^2 for Black athletes, while 25.0 ± 2.19 kg/m^2 and 1.94 ± 0.12 m^2 for Caucasians athletes. Body density is significantly higher for Black athletes (1.076 ± 0.015) than for Caucasians (1.073 ± 0.009). Regarding the BF%, significantly higher results were observed for Caucasian rink hockey athletes (11.21 ± 4.13) than for Black athletes (9.94 ± 6.72).

In regards to the circumference measurements, elite male Black rink hockey athletes had significantly lower values than Caucasian athletes in almost all variables, respectively; WC (-6%), ABC (-6.8%), HC (-3.7%), RTC (-4.8%), RCC (-4.6%), LTC (-4.6%), LDTC (-5.1%) and LCC (-5.2%).

There were no significant differences in grip strength between both ethnicities, however, mean values in black athletes were higher in both hands (52.26 ± 6.34 N; 51.57 ± 5.30 N), than in Caucasian athletes (50.30 ± 6.17 N; 49.69 ± 6.56 N).

Table 6. *Descriptive statistics (mean ± standard deviation) by group and mean differences in anthropometry and strength variables*

Variable	Black African (*n*=31)	Caucasian (*n*=69)	Statistic's value	*p*-value	Effect Size		
					Value	Qualitative	ICC (IC 95%)
Training, hours per week	8.7±1.30	11.3±0.93	149.50	<0.001#2	0.47§2	Large	
Chronological age, years	24.39±4.27	27.58±6.44	769.50	0.025#2	0.05§2	Small	
Body mass, kg	72.8±9.50	78.0±8.70	765	0.023#2	0.05§2	Small	
Height, cm	175.0±6.50	176.2±5.60	923	0.348#1	0.20§1	Trivial	-0.220–0.629
Body mass index, kg/m²	23.78±3.08	25.0±2.19	782	0.032#2	0.05§2	Small	
Body Surface Area, cm²	1.87±0.13	1.94±0.12	775.50	0.014#1	0.57§1	Small	0.137-0.999
Sum skinfold, mm	88.6±52.20	89.9±29.70	764.50	0.023#2	0.05§2	Small	
Body density, g/cm³	1.076±0.02	1.073±0.01	711.50	0.008#2	0.07§2	Moderate	
Body fat mass, %	9.9±6.70	11.2±4.10	711.50	0.008#2	0.07§2	Moderate	
Waist circumference, cm	81.27±6.45	86.40±5.05	445.50	<0.001#2	0.22§2	Large	
Abdominal circumference, cm	78.82±7.14	84.57±5.77	461.50	<0.001#2	0.21§2	Large	
Hip circumference, cm	96.54±6.85	100.20±4.46	643.50	0.001#2	0.10§2	Moderate	
Right thigh circumference, cm	58.91±5.40	61.90±3.66	636	0.008#1	0.70§1	Moderate	0.266-1.135
Right mid-thigh circumference, cm	54.57±4.37	55.02±2.76	931.50	0.303#2	0.01§2	Small	
Right distal-tight circumference, cm	41.65±2.95	42.79±2.77	897	0.198#2	0.02§2	Small	
Right calf circumference, cm	35.78±2.48	37.50±2.02	587	<0.001#1	0.79§1	Moderate	0.354-1.23
Left thigh circumference, cm	58.11±4.83	60.93±3.49	671	0.005#1	0.71§1	Moderate	0.279-1.149
Left mid-thigh circumference, cm	53.49±3.44	54.25±2.59	903	0.220#1	0.26§1	Small	-0.161-0.689
Left distal-tight circumference, cm	40.67±2.99	42.84±2.60	652.50	0.002#2	0.10§2	Moderate	
Left calf circumference, cm	35.43±2.56	37.36±2.11	554.50	<0.001#2	0.15§2	Large	
Right grip strength, kg	52.26±6.3	50.30±6.2	870.50	0.148#1	0.31§1	Small	-0.741-0.111
Left grip strength, kg	51.57±5.3	49.69±6.6	849.00	0.165#1	0.30§1	Small	-0.729-0.123

Note: #1- Independent samples t-test; #2- Mann-Whitney test; §1 – Cohen's d; §2 - η^2

Results of the multiple regression analysis in Tables 3 and 4 showed an overall significant model for BF% ($p_{ANOVA} \leq 0.05$) and grip strength ($p_{ANOVA} \leq 0.05$). Once the percentage of the dominant hand is near 90% of the right hand, the right grip strength was considered for the regression model. Moreover, there were no significant differences between right and left grip strength between the ethnic groups.

Regarding to the BF%, four predictors accounted for 70.1% (R^2adj = 0.701) of its variance (ABC, RTC, RCC and ethnicity). According to the results, the following regression equations were obtained for BF%, for each ethnicity: Black Athletes = -43.658 + 0.425×ABC + 0.609×RTC - 0.440×RCC; Caucasian Athletes = -45.891 + 0.425×ABC + 0.609×RTC - 0.440×RCC.

Regarding the upper strength, three predictors accounted for 13,1% ($R^2adj = 0.131$, medium) of the variance of RGST (Ethnicity, CA and RDTC). Despite the low value of R^2, the analysis revealed a significant effect size, with a clear tendency of variance for the RGST. Based on this, the following regression equations were observed for RGST, for each ethnicity: Black Athletes = 24.018 + 0.239×CA + 0.538×RDTC; Caucasian Athletes = 20.683 + 0.239×CA + 0.538×RDTC.

Table 7. *Multiple linear regression model for BF% in elite male rink hockey athletes.*

Model 1	**Coefficients**			**ANOVA *p*-value**	**Adj. R^2**
	Estimates	**p-value**	**$CI_{95\%}$**		
Constant	-43.658	<0.001	(-53.124; -34.193)		
Abdominal circumference	0.425	<0.001	(0.292;0.558)	<0.001	
Right thigh circumference	0.609	<0.001	(0.398;0.820)		0.701
Right calf circumference	-0.440	0.001	(-0.797; -0.083)		
Ethnicity	-2.233	0.016	(-3.541; -0.925)		

Table 8. *Multiple linear regression model for right grip strength in elite male rink hockey athletes.*

Model 1	**Coefficients**			**ANOVA *p*-value**	**Adj. R^2**
	Estimates	**p-value**	**$CI_{95\%}$**		
Constant	24.018	0.007	(6.684;41.352)		
Ethnicity	-3.335	0.013	(-5.939; -0.732)		
Chronological Age	0.239	0.024	(0.033;0.446)	0.001	0.131
Right distal-tight girth	0.538	0.014	(0.110;0.966)		

4.4 Discussion

The aim of the present research was to characterize the body composition and grip strength of elite male rink hockey players and to underline the possible relationships between ethnicity, body composition and grip strength. In line with our expectations, results revealed that there are significant differences between body composition and grip strength Black Africans and Caucasian elite rink hockey players.

To the best of our knowledge, this is the first study with a relatively large sample size (n=100) of male rink hockey athletes comprising elite international Black African and Caucasian players. There are currently a limited number of studies published regarding body composition and grip strength, as well as other conditioning and physiological characterizations, of such athletes. The existing research is mainly focused on children and adolescent players (Ferraz et al., 2020). Furthermore, research with elite adult athletes was assessed with a small sample size (Ferraz et al., 2020) and only with Caucasians. We believe that the standards presented in the current study may provide a target that coaches, physical conditioning and strength coaches, researchers, and clinicians can use to evaluate elite rink hockey players during an entire season. The assessment of body composition analysis seems to be an important monitoring tool which complements the understanding of the athlete's performance and cardiac adaptation (Coelho-E-Silva et al., 2012). On the other hand, grip strength also plays a role in performance, strength, and injury prevention (Coelho-E-Silva et al., 2012; Gerodimos, 2012). There is a limited number of studies regarding the general characterization of rink hockey demands (Ferraz et al., 2020). Moreover, the understanding of physical and physiological requirements is essential for game performance. Additionally, it is also crucial to complement athletes' fitness traits and game characterization (Travassos et al., 2013).

On the descriptive values of the sample, our results demonstrate that some body composition indicators, such as height, weight, and BF%, were lower than previously reported in research with 41 Spanish elite male rink hockey players (Martín et al., 2020). However, in our study, BMI was similar to values reported in previous research (Martín et al., 2020). Our results are also in line with the results of Santos et al., (2014) with 49 rink hockey athletes. However, the overall value of BF% was slightly lower (-1%). This difference may be suggested by the technique of assessment. Dual-energy X-ray absorptiometry (DXA) is a convenient and useful tool for body composition valuation (Toombs et al., 2012), due to the speed and reliability of analysis and at the same time, due to its minimal measurement discrepancy in the water factor (Ackland et al., 2012; Pietrobelli et al., 1998). Regarding the summary of skinfolds (SUMSK) and DXA, the research of Santos et al. (2014) suggests an alignment between both methods. As reported in other sports, these results indicate the existence of an anthropometric identity of elite rink hockey, which may be considered as a reference to achieving greater performance (Ackland et al., 2012; Malina, 2007).

In research involving young men, maximal grip strength and BF% were higher than that registered in this study (Vaara et al., 2012). Similar BF% was also observed in active young men with regular practice of cycling (Marra et al., 2018). Moreover, elite rink hockey players seem to have lower BF% when compared with elite ice hockey players (Ashley et al., 2018). Besides suggestions of similarities in internal and external load between both modalities, these differences may be based on the evolutionary adaptation of elite ice hockey athletes, as reported by Ashley et al. (2018). The author suggests that the increase in physical size and fitness parameters of National Hockey League (NHL) players, such as stature, body mass, aerobic fitness, peak power output, and grip strength may be a result of the professional competition and its rigorous schedule which demands greater physical and physiological requirements on players (Cox et al., 1995; Quinney et al., 2008; Ashley et al., 2018). On the other hand, when compared with other hockey modalities, the size of the rink hockey field may influence the volume of requirements of short and long-duration efforts, its incomplete recovery periods and consequently, its metabolic demands (Calò, 2009; Yagüe et al., 2013). Additionally, the lack of information regarding external load during competition may impact a greater interpretation of players' adaptations to the game demands.

Strength training is an essential part of a physical training program (Kolej et al., 2009). Thus, the measurement of grip strength can be an important part of muscular strength assessment by providing a fast estimation of athletes' upper body strength (Coelho-E-Silva et al., 2012; Kolej et al., 2009). Besides its relevant insights into an individual´s bone density (Nevill & Holder, 2000; Saint-Maurice et al., 2015) and functional status (De Smet, 2001), grip strength is mandatory in most hockey-specific movements with players continually performing complex skills while gripping a stick (Toong et al., 2018). It is therefore probable that rink-hockey players may have higher grip strength, given these neuromuscular adaptations from training (Coelho-E-Silva et al., 2012). In fact, our results reveal that elite hockey players have noticeable higher values than active adults and amateur soccer players (Tavares et al., 2019). However, when compared with elite ice hockey athletes, the values of elite rink hockey grip strength are lower and differences within both hands are greatly evident (Chiarlitti et al., 2018). Research regarding the association of maximal strength and muscular endurance test scores with cardiorespiratory fitness and body composition of 846 young men, revealed greater grip strength and BF% than our elite rink hockey athletes (Vaara et al., 2012). Grater grip strength values were also observed in other elite athletes such as in handball, water polo, tennis, or gymnastics (Cronin et al., 2017). These differences may open new perspectives concerning the need to understand the importance of strength training for elite rink hockey athletes and its implication on their performance. Several studies associate body composition and strength scores with cardiorespiratory fitness. In our research that association was not possible. Additionally, the lack of information regarding the training and competition loads of the teams who participated in this research may have impacted the discussion of the results of the measured variables. It has been already suggested that there is a need to clarify the elite athletes' traits and game demands to develop new evaluation and monitoring tools which will improve rink hockey training environments and consequently performance levels (Ferraz et al., 2020).

Biological differences exist in the body composition of Black and Caucasians (Wagner & Heyward, 2000). The differences and similarities which have been investigated between the two ethnicities are related to fat-free body mass and fat patterning body dimensions, and proportions (Malina, 1996;Wagner & Heyward, 2000). In our research, several differences were reported in the body composition variables of the elite rink hockey athletes. In all variables, values were significantly lower in black athletes except for body density. Therefore, we believe that the results of our research are in line with previous studies. In general, elite male Black rink hockey athletes have a greater bone mineral density and body protein content than their Caucasian counterparts, resulting in a greater fat-free body density (Malina, 1996;Wagner & Heyward, 2000). For example, Vickery et al. (1988) reported that the mean value of measured body density was significantly higher in Black athletes than in Caucasians. Regarding athletes, in research with Olympic athletes, (Malina et al., (1982) reported that BF% is influenced primarily by sports and training, whereas fat patterning is more dependent on biological factors. In this study, Black athletes have significantly lower weekly training hours than their Caucasian peers, even though, significantly lower BF% and SUMSK, and significantly higher BD have been reported. Consequently, we suggest that these differences in elite rink hockey athletes are greater related to genetic factors than within training volumes. In the same line, there are no significant differences in both grip strength, as Black athletes reveal higher mean values than Caucasians. Regarding this result, it is not possible to underline if the volume and/or typification of strength work in both championships impact the existence of significant statistical differences.

In general, our results were in accordance with previous studies. The literature shows reliable differences in fat patterning between Blacks and Caucasians (Malina, 1996; Wagner & Heyward, 2000). Additionally, these differences in fat deposition could produce systematic errors in the estimates of BF% using field methods that assume a consistent fat patterning between the two ethnicities (Wagner & Heyward, 2000). Following that most equations that predict relative body fat were derived from predominantly Caucasian populations, some researchers emphasize that generalized equations need to be cross validated in Black populations (Wagner & Heyward, 2000; Cote & Adams, 1993).

Our results of the multiple regression analysis showed an overall significant model for BF% and grip strength for each ethnicity. ABC, RTC, RCC and ethnicity demonstrated a significant interaction effect on BF%. Therefore, it seems that between other variables, the effect of ethnicity was presented on both estimated equations of BF% and grip strength for rink hockey athletes. Regarding the other predictors of BF%, abdominal circumference results were in line with the literature. Several researchers have shown lower abdominal, abdominal subcutaneous, and visceral fat during regular and progressive intense training such as in rink hockey in comparison with people without intense practice (Coelho-E-Silva et al., 2012; Petrofsky et al., 2007; Martín et al., 2020).

In previous studies, prediction models used the circumference of arms, thigh, and calf, skinfolds, and body height as independent variables (Takai et al., 2018). These anthropometric variables derived from body mass are related to fat mass and fat-free mass in athletes (Quiterio et al., 2009). In this study, right thigh and right calf circumferences demonstrated a significant interaction effect on the BF% of elite male rink hockey athletes. It has been suggested that proportions of segment fat mass and fat-free mass within the whole body for athletes are event specific (Hoshikawa et al., 2010; Kanehisa et al., 1998). Therefore, we believe that such predictors may be justified by the existence of specific movements and energy requirements or even habitual training adaptations of this sport (Takai et al., 2018). On the other hand, the lack of information regarding the external load may be a limitation in better explaining these results. Further studies should be developed to extend this research to include more conditioning data and the understanding of how external game demands may be related or influenced by an athlete's conditioning profile.

Regarding the upper strength, three predictors showed an overall significant model for the variance of right grip strength. Ethnicity, age, and right distal thigh circumference were included in the model. As in BF%, ethnicity seems to be a predictor of this variable. On the other hand, as reported in research with ice hockey athletes, grip strength increases with age (Toong et al., 2018). Therefore, regarding the neuromuscular adaptation of griping the stick (Coelho-E-Silva et al., 2012) like in ice hockey (Toong et al., 2018). and according to our multiple regression, we believe that the importance of age predicting grip strength is in accordance with this previous result. Finally, in line with the third predictor (RDTC) of grip strength, the literature shows a previous relationship between the recovery after total knee arthroplasty and hand-grip strength (Hashimoto et al., 2020). However, we suggest that this variable predictor may be influenced by players' adaptations to the continuous high intense intermittent game requirements such as accelerations, decelerations, and multidirectional speed (Ferraz et al., 2020). As previously mentioned, further research should be taken regarding the characterizations of training and competition external load, and consequently athletes' adaptations.

4.5 Practical applications

Body composition and grip strength assessments may be important for coaches, strength and conditioning trainers and clinicians working with elite rink-hockey players, to facilitate comparison of performance and players' traits, allowing to establish a reference standard. We believe that such information is useful to assess and monitor changes in standards of performance, injury management, and strength/skill developments in elite rink-hockey players. Regarding the training monitoring, we believe that these results may establish reference information that might help to shed light on elite rink hockey athletes' performance and training adaptations. Consequently, the need to understand athletes' traits may open a new era in rink hockey by improving training methods and increasing players' performance, as has been observed in other sports modalities and their athletes since they have taken part in intended and longitudinal research (Ackland et al., 2012; Pietrobelli et al., 1998). Consequently, these results hope to provide new insight into information and technical monitoring regarding elite rink hockey traits and performance.

4.6 Conclusions

Rink hockey at an elite level may lead to reduced BF% and greater handgrip strength. Abdominal circumference, right circumference, right calf circumference and ethnicity seem to demonstrate a significant interaction effect on BF%. Additionally, ethnicity, chronological age, and right distal thigh circumference constrain the variance of handgrip strength in elite male rink hockey athletes.

5. Tracking Devices and Physical Performance Analysis in Team Sports: A Comprehensive Framework for Research. Trends and Future Directions.

Ferraz A, Duarte-Mendes P, Sarmento H, Valente-Dos-Santos J, Travassos B. Tracking devices and physical performance analysis in team sports: a comprehensive framework for research-trends and future directions. *Front Sports Act Living*. 2023 Nov 23;5:1284086. doi: 10.3389/fspor.2023.1284086. PMID: 38077284; PMCID: PMC10708914.

5.1 Introduction

It is commonly recognized that team sports necessitate the development of various intense activities based on the space and time relationship between teammates and opponents, implying that movement production requires a perception-action relationship in which short and long-duration efforts are needed to achieve the most functional individual tactical actions (Taylor et al., 2017). To achieve this, players must persistently adapt their field placement and enhance their preparedness to undertake actions with or without the ball by producing physical patterns such as accelerations, decelerations, changes of direction, short-term movements, and high impacts (Taylor et al., 2017). Thus, a precise and appropriate assessment of both internal load (IL) and external load (EL) considering the purpose of the analysis is required to improve the understanding of players' physical efforts and performance (Ryan et al., 2017).

Regardless of some reservations about the quality, reliability, and validity of Global Positioning System (GPS) and Local Positioning System (LPS) measures (Hausler et al., 2016), tracking athletes' time motion combined with physiological measures such as heart rate has become a usual method for characterizing athletes' EL and IL (Helwig et al., 2023; Lovell et al., 2013). The analysis of EL refers to quantifying players' movement demands regarding volume and intensity (Wallace et al., 2009). According to the literature (Rossi et al., 2018), EL can be divided into different categories, namely; (1) Kinematics, which calculates overall movement during exercise; (2) Mechanical, which describes the player's overall load during exercise; and (3) Metabolic, which measures overall movement energy expenditure during exercise. In addition to the information provided by EL, athletes may experience varied physiological (IL) reactions (Rago et al., 2021). In this setting, the IL is the individual athlete´s response induced by the EL stimulus, which is commonly determined by heart rate (HR) parameters (Achten & Jeukendrup, 2003). Thus, the investigation of the relationship between EL and IL units might be considered one of the most critical elements to monitor the dynamics of players' fatigue over the microcycle and their preparedness for the competition context (Halson, 2014).

Much research has been developed in team sports over the last few years in order to characterize game demands and identify the most demanding passages of play, to understand the influence of different training manipulations during training sessions, or even to better understand injury mechanisms (Li et al., 2020; Migallón et al., 2022). Also, some systematic reviews have been published in the last two years (Helwig et al., 2023; Inoue et al., 2022; Lima-Alves et al., 2022) with specific goals to understand the relationship between IL and EL or to characterize methods to collect and interpret EL

(Rago et al., 2020). According to the literature, combining both information (IL and EL) allows one to perceive how workload promotes physiological impacts on the players or compare match/training sessions (Lovell et al., 2013). As a result, the distinction between EL and IL units may reveal an athlete's level of exhaustion or enable the identification of the training plan. For example, it has already been reported that the efficiency index (Effindex), which combines IL and EL, is a powerful tool for the evaluation of fitness status in team sports (Lima-Alves et al., 2022). Additionally, it has been emphasized that selecting appropriate metrics is crucial in accurately describing, planning, monitoring, and evaluating each sport's training and competition aspects (Russell et al., 2021; Torres-Ronda et al., 2022). This information may aid in the management of training loads, lowering the risk of injury (Helwig et al., 2023; Hulin et al., 2016) and increasing athletic performance (Gabbett et al., 2014; Helwig et al., 2023). Systematization of prior research is essential to understand better the variables/forms of analysis that better explain the damage mechanism or performance increase. However, to the best of our knowledge, no research has provided the relationship between different metrics, the purpose of analysis, and their applicability for coaching and science purposes. An understanding of how the information from tracking technology devices has been used in previous research and what are the main issues that have been studied are required to improve further research and practice. Thus, this scoping review aimed to understand the applicability of tracking systems for physical performance analysis in team sports in the last decade by allowing an understanding of how research strategies and variables have been used and combined according to research goals. Based on this systematization, a comprehensive framework of physical performance analysis in team sports and athlete´s well-being was proposed.

5.2 Methods

Preferred Reporting Items for Systematic and Integrative Reviews and Meta-analysis Statements (PRISMA) were used to conduct a scoping review (Page et al., 2021).

5.2.1 Search Strategy; Database and Inclusion Criteria

According to the PRISMA Statement recommendations, a systematic search was undertaken on the electronic databases PubMed, Web of Knowledge (all databases), and Scopus (Page et al., 2021). A search of relevant articles published between January 2011 and July 2023 was conducted using the keywords ("global position system" OR GPS OR "local position system" OR LPS) AND ("team sports*," Indoor team sports**") AND (performance* OR "external load" OR "internal load")). The publications that were retrieved had to meet the following requirements: (1) provided relevant statistics and research strategies about elite athletes' performance; (2) athletes' EL and IL; (3) were published in English; and (4) were only about team sports. Exclusion criteria applied: If they *(1)* were specifically regarding the reliability, validity, or precision of global positions system equipment; *(2)* were regarding systematic reviews, *(3)* were published before 2011.

To improve research accuracy, two reviewers (AF and BT) independently screened titles and abstracts to identify articles that would potentially combine the inclusion criteria after noting the features of each study, such as the authors' names, sample, procedure, and results or main outcomes. In the event of disagreement about the article's eligibility, a third reviewer (HS) was brought in to make a final judgment. Following a review of all papers, the study categories were divided into multiple sports depending on the primary research topic.

5.2.2 Quality of Studies and Data Extraction

The quality of the studies was assessed in the way that is indicated by Faber et al. (2016) using the criteria for critical review forms recommended by Law et al.(Law et al., 2000) (16 items) with the goal of finding studies in which the low-quality score could interfere with the results. Both researchers (AF, BT) separately assessed the quality of each eligible article. The inter-rater agreement was moderate (k=0.43) (Landis & Koch 1977). The possible criteria for each item were 1 (meets criteria), 0 (does not meet the criteria), or NA (not applicable). According to the methodology assessment, articles were evaluated with regard to their purpose (item 1), relevance of background literature (item 2), appropriateness of the study design (item 3), sample included (items 4 and 5), informed consent procedure (item 6), outcome measures (item 7), validity of measures (item 8), significance of results (item 9), details of intervention (item 10), analysis (item 11), clinical importance (item 12), description of drop-outs (item 13), conclusion (item 14), practical implications (item 15), and limitation (item 16). According to the guidelines of Faber et al. (2016), a final score was determined, allowing the publications to be classified as (1) low methodological quality (50%), (2) good methodology quality (50%-75%), or (3) exceptional methodology quality (>75%). A data extraction sheet (based on the Cochrane Consumers and Communication Review Group's data extraction template) (R. Ryan & Hill, 2019b) was adjusted to meet the research inclusion criteria for this analysis and then evaluated on 10 randomly chosen studies (pilot test). The data was extracted by one author and validated by another. Disagreements were settled by discussions between these two authors (first and last). To organize the findings, the studies were divided into categories based on the major study issues.

5.3 Results

5.3.1 Search, selection, and Inclusion of Studies

The first search generated 772 titles. These data were then exported to Mendeley (Elsevier, San Francisco, CA, USA), a reference manager software. Duplicates (n=430) were either automatically or manually removed. The remaining 342 were then evaluated for relevance using information from their title and abstracts, with 164 being eliminated. The remaining 178 papers were examined further, and 99 were excluded based on the following criteria: (1) articles published in languages other than English (n=5); (2) articles unrelated to team sports (n=4); (3) articles unrelated to elite athletes (n=10); (4) systematic reviews (n=14); (5) articles unrelated to the analysis of athletes' performance by technology (n=22); and (6) articles concerning the reliability and validation of tracking technology (n=44). The review comprised 79 studies in total. (Figure 1).

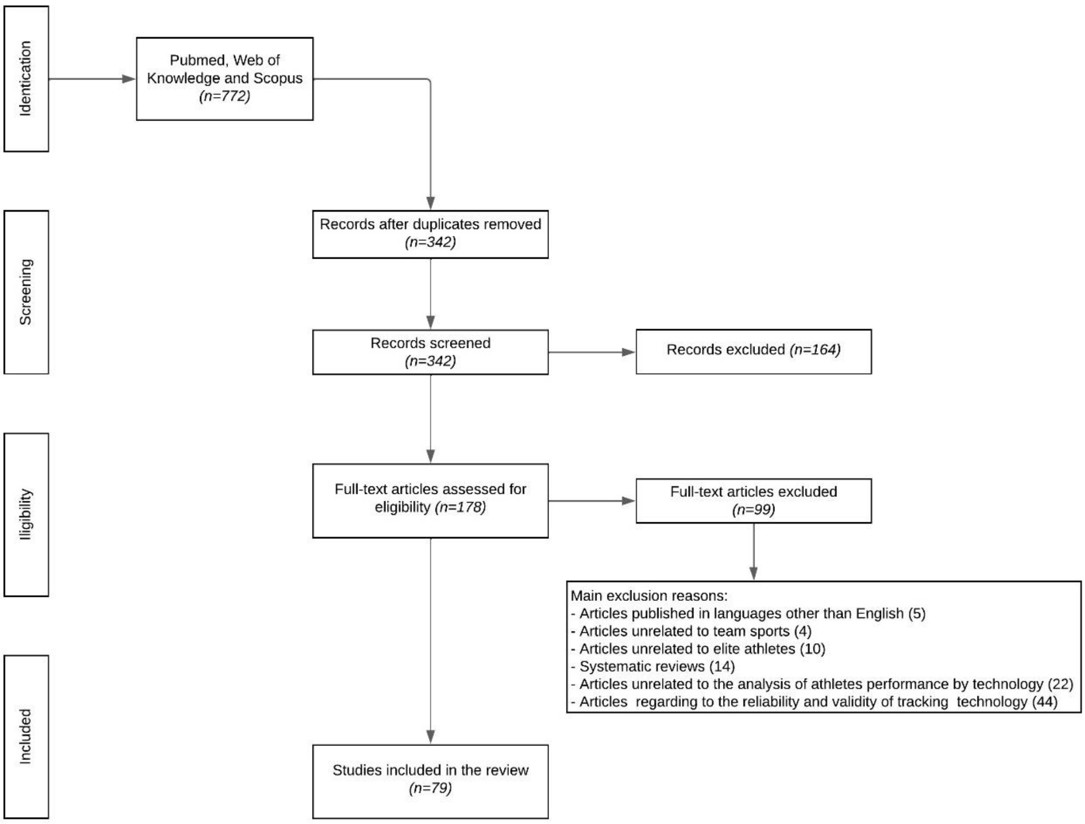

***Figure 3**. Flow chart of the article´s selection process.*

To understand the scope of the development of research methodologies in physical performance evaluation in team sports during the last decade, the publication target years were restricted from January 2011 to July 2023. The articles used for in-depth reading revealed that there had been an increase in GPS and LPS research. In this review, 84,8% of the studies were published in the last five years (from 2017 to 2023) and 15,2% from 2011 to 2016. On average, 6.3 studies were published per year.

5.3.2 Quality of the Studies

Regarding the quality of studies, following the proposal of Faber et al. (2016), the average score of the 79 selected studies was 89.2%. Fourteen studies achieved 100%; 52 achieved an average rating of ≥ 75%; 12 achieved a score between 50% and 75%.

5.3.3 General Description of the Studies

Studies were categorized by sport in which the studies were carried out: (1) football (FTB) (41.8%), (2) futsal (FTS) (15.2%), (3) rugby (RG) (11.4%), (4) Australian football (AUF) (7.6%), (5) field hockey (FH) (6.3%), (6) Gaelic football (GF) (6.3%), (7) basketball (BK) (3.8%), (8) American football (AMF) (2.5%), (9) ice hockey (IH) (2.5%), and (10) rink hockey (RH) (2.5%).

5.3.4 Variables and goals of the studies

The studies were classified based on the criteria used in the study. Most of the team sports research employing tracking technology: (1) combined kinematics and mechanical variables (35.4%); (2) only considered kinematics (21.0%); and (3) included kinematics, mechanical, and metabolic variables (16.5%). On the other hand, the analysis of IL or the relationship between mechanical variables and IL variables is less explored (Figure 2).

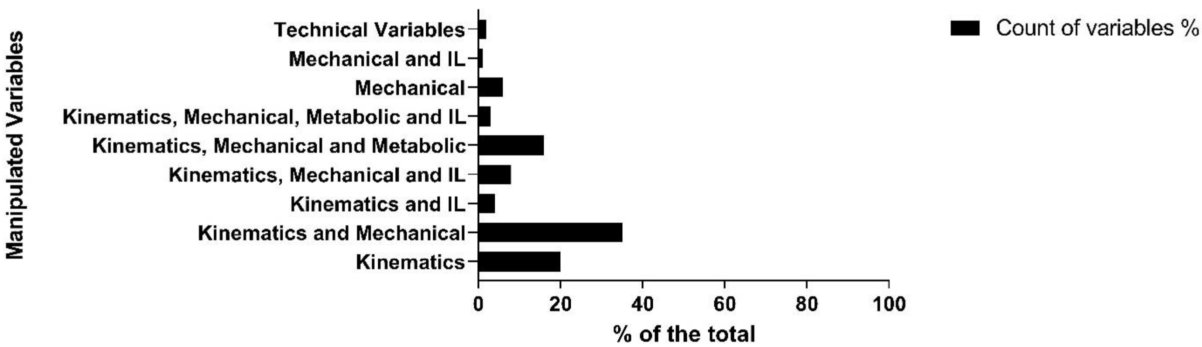

Figure 4. *Distribution of grouping variables monitored by study.*

Studies were also grouped according to the type of analysis used. Results revealed that the studies were distributed by the following analysis: (1) characterization and comparison of drills, training, and matches sessions (62.0%), (2) correlation of variables to understand its relationship in training and competition (26.6%), and (3) predicting performance, fatigue, and injuries (8.7%), and finally, (4) experimental studies to determine greater training and team management approach (2.7%). (Figure 3).

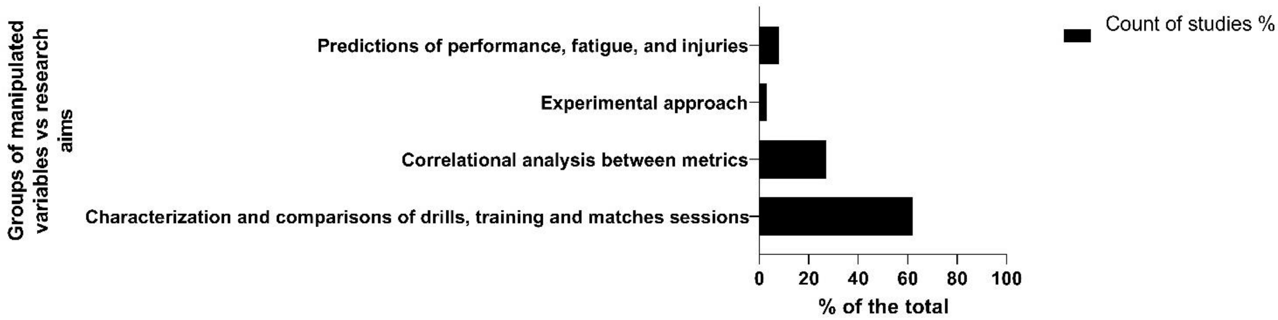

Figure 5. *Distribution of studies according to studies' results*

Regarding the main research topics from the studies in analysis, it was observed: (1) performance analysis in match demands, (2) performance analysis of training *versus* match demands (3) Injuries, and (4) nutrition (figure 4).

The studies reviewed provide information on the use of tracking systems in various domains of sports sciences, such as the importance of technology in better understanding the physical requirements for co-adaptations between match demands, in which players establish interactions with teammates and opponents to manipulate training sessions and, as a result, improve athletes' awareness and physical performance. (Corbett et al., 2017; Pizarro et al., 2021). Additionally, studies were used to determine whether specialized nutritional intake could improve players' responses to the demands of an indoor team sport. (López-Samanes et al., 2020, 2021). Also, in recent years, multiple sports have used varied methods to track injuries by understanding the external information that better characterizes sporting activities (Caparrós et al., 2018; Kim et al., 2016; Rossi et al., 2018).

Regarding the understanding of training and match demands in performance and analysis of team sports, several studies have been developed in order to compare and understand positional (Sweeting et al., 2017), tactical and technical differences (Mangan et al., 2017), intra-game information (Pino-Ortega et al., 2019)(Conte et al., 2021), comparisons of levels of competitions (Beard et al., 2019), predictors of intensity, fatigue and match performance (Barron et al., 2020; Ribeiro et al., 2020; Wiig et al., 2020; Ryan et al., 2021) and more recently, to understand the games most high-intensity activities (HIA) and periods (MIPs) (Ribeiro et al., 2022). (Figure 4)

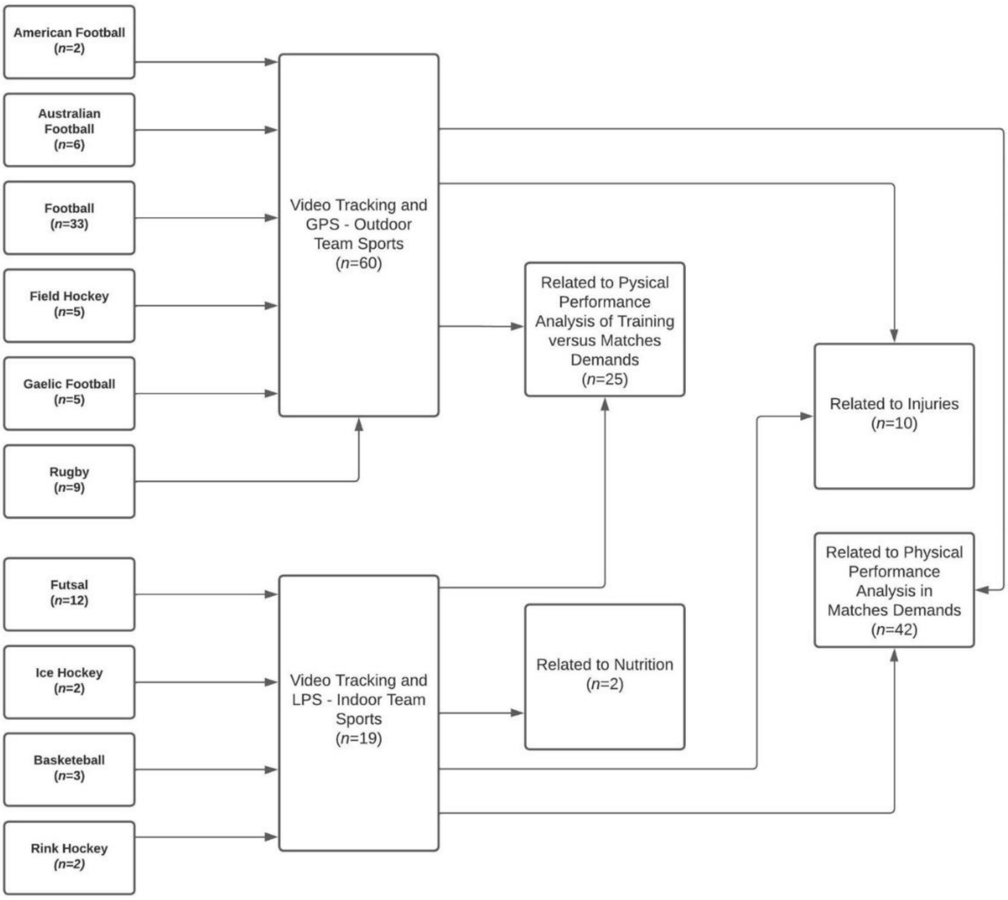

Figure 6. Flow chart of the related sports and leading GPS and LPS research topics in the past years.

5.3.5 Applicability of tracking system related to Performance Analysis in Match Demands.

Concerning the performance analysis of match demands, there are several studies involving the characterization and understanding of EL metrics in various team sports (Fernández et al., 2016; Malone et al., 2015; Mangan et al., 2017; Owen et al., 2015; Pettersen et al., 2018; Polglaze et al., 2015; Tierney et al., 2016) as well as its impact on athlete's IL (Barron et al., 2020; Fernández et al., 2021; Ritchie et al., 2015; Li et al., 2022; Rossi et al., 2019; Scott & Lovell, 2018). Some studies described moderate to high correlation observed between EL and IL (Ritchie et al., 2015; Wiig et al., 2020). Additionally, there are studies using tracking systems in which the main goal is to find correlations between metrics; (1) Kinematics vs Mechanical; (Barron et al., 2020; Carling et al., 2017; Owen et al., 2015) (2) Kinematics vs Mechanical and Metabolic (Fernández et al., 2016; Ribeiro et al., 2020).

A study with 118 elite male ruby league players shows significant increases in the offensive and defensive tackles between senior and junior players, and forwards and backs (Dempsey et al., 2018). In the same study, independently of the playing level, running demands (HSR, ACC, DEC) were significantly greater in backs than forwards

(Dempsey et al., 2018). There is a high prevalence of studies in which EL metrics are classified based on player level and player position; positioning is often related to an event or to the magnitude of EL metrics. (Delaney et al., 2018; Izzo et al., 2018; Neville et al., 2012; Oran, 2016; Pino-Ortega et al., 2019; Tierney et al., 2016; Dempsey et al., 2018). However, positioning associations are not always found in team sports. In a study of 9 elite RH players, there were no significant differences throughout all observed metrics during competition between players' positions (D. Fernández, Fernández, et al., 2020). Furthermore, variable load distribution (Total PL) based on the axis of movement was not verified based on playing position. (Oliva-Lozano et al., 2023). However, total PL appears suitable for monitoring locomotor demands or accelerometer-derived load in FTB (Oliva-Lozano et al., 2023).

Finally, and more recently, studies seems to aim for the prediction and proposal of models of fatigue (Rossi et al., 2017), and match performance according to match demands information (Grünbichler et al., 2020; Illa et al., 2020; Milanez et al., 2020; Oliva-Lozano et al., 2021; Pettersen et al., 2018) . (Table 1)

Table 9.Articles predominantly related to Match Physical Performance Analysis

Study and Sport in which study has been carried	Sample	Main Outcomes Measured	Results	Quality Score (%)
(Suarez-arrones, 2013) - Rugby	8 elite female players (1) - Backs (n=4) age, 27.0±2.6; (2) Forwards (n=4), age 26.6±1.9	Heart Rate (HR), time, speed (SP), distance (DT), location, and number and intensity of impacts (Himpts) and accelerations (ACC) expressed as g forces). GPS units were used.	The players covered 5,820±512 meters and showed positional cinematic and mechanical differences. They exerted themselves at 91-100% heart rate for 46.9±28.9% of the match.	96.7
Reilly et al., (2015) – Gaelic Football	56 elite male players (age, 15±0.66 years; height, 176.8±6.5 cm; weight, 69.08±6.72 kg and VO2max 50.77 ml-kg^{-1}min^{-1})	Predicted VO_2max was assessed using the Yo-Yo Intermittent Recovery Test. Players HR, Speed zones, total DT, and the number of sprints were recorded by GPS units.	Players' intensity levels peaked at 85% of match maximum HR. The distance covered in the second half was less than the first, and midfielders covered the most ground at 6740±384 meters.	90.0
(Owen et al., 2015) Rugby	33 elite male players (age: 25.2±3.5 y.; weight: 101.2±13.2 kg; height: 79.8±33.0 cm	ACC, DEC, and body impacts during match-play were recorded using GPS units.	Forwards had intense impacts and greater physical demands, while backs had frequent moderate to heavy accelerations and decelerations.	93.3
(Malone et al., 2015) – Gaelic Footbal	50 elite male players: age (24±4 years), height (180±7 cm), weight (81±7 kg), and years on squad (5±3 years)	The match's performance was tracked using GPS, measuring distance covered, speed, ACCs, and peak velocity.	Players completed an average of 2.6±0.5 ACC per minute. Midfielders covered more total and high-speed running distance. Running performance reductions varied by player position.	90.0
(Tierney et al., 2016) - Football	46 Elite players (age 20±3 years, height of 179±5 cm, body mass of 79.5±6.3 kg)	GPS units were used to assess total distance (TD), high-speed running (HSR), high metabolic load distance (HMLD), ACC and DEC	Different formations affect player performance. The 3-5-2 has high TD and HMLD, while the 4-2-3-1 has high ACC and DEC.	80
(Fernandez et al., 2016) - Football	A total of 2951 rows from training and official matches of 42 elite players	GPS devices were used to collect (1) Locomotor Variables, (2) Metabolic Measures and (3) Mechanical Variables.	Certain variables can represent as representatives of a collection of highly related variables, lowering the number of variables required in coaches' periodic physical analyses from 17 to 4.	66.7
(Carling et al., 2017) - Rugby	63 players of the French or Irish national u20 teams. (age: 19.8±0.5 y, body mass: 99.1±9.1 kg, stature: 185.4±7.0 cm)	GPS devices tracked running abilities: TDm.min-1, HSR m.min-1, HMLD m.min-1, Sprints n.min-1, ACC n.min-1.	Higher metabolic loads in back and forwards players. Players with the most match-play exposure exhibited moderate-to-	90.0

			large decreases in total and HMLD in backs.	
(Corbett et al., 2017) – Australian Football	39 elite athletes (age: 23 ± 4 years, height: 187 ± 8cm, mass: 86 ± 9 kg).	For all indoor matches, athlete physical output was collected via Local Positioning System (LPS). During outdoor matches, all participants wore a GPS device.	Two methods were developed to identify the relationship between physical, skilled, and temporal outputs, on and individual and team level.	93.7
(Rossi et al., 2017) - Football	22 elite players (age=21.96±4.53 years; height = 180.68±5.23 cm; weight = 72.36±4.19)	RPE and Training and Match Workload - 21 Kinematic, 37 Metabolic and 30 Mechanical metrics) were computed from the GPS raw data.	Results suggests that it is possible to predict RPE from GPS training and match data.	80.0
Cullen et al., (2017) –Gaelic Football	85 Gaelic football players (U-18) (17.57±0.53 years)	Anthropometry (%body fat), Vo2Max and Match running activity categories with GPS devices.	Players cover an average of 5,774±737 m in a 60-minute match and achieve %HRmax (81.6±4.3%) and %VO2max (70.1±7.75%). There are positional differences.	87.5
(Mangan et al., 2017) – Gaelic Football	432 Individual full match datasets collected across 52 matches of top teams.	Technical variables; Total distance (m) and high-speed distance (≥17 km h−1; m) with GPS units and minutes spent on the pitch.	Ball play duration, opposing team's short kick-outs, and possession time impact overall and high-speed distance run.	86.7
(Matthew C. Varley et al., 2017) - Football	6 Professional players (23.0 ± 1.8 years)	Velocity and subsequently GPS acceleration data that was used to quantify player movement.	Shorter durations showed inconsistencies in high-speed runs, sprints, and ACC. Longer minimum durations led to a decrease in efforts.	86.7
(Spice et al., 2017) – Field Hockey	10 male (age; 38.7±5.4 years, stature; 1.77±0.07 m) and 11 female (age, 33.5±6.5 years; stature; 1.66±0.04 m)	Effort frequency, distances and time were measured by GPS units	Differences between male and female in total distance covered, time spent engaged in High-Intensity running (HIR), frequency of HIR and distance covered during each HIR effort.	86.7
(Dempsey et al., 2018) - Rugby	118 elite male players (57 seniors aged 28.7±4.4 years; 61 juniors aged 17.2±0.5 years)	Positional game demands using a GPS unit and video analysis. The metrics Anthropometric, Locomotor, and Contacts were recorded.	Senior and junior players, including forwards and backs, have improved in tackles. Backs have higher kinematics and mechanical metrics than forwards	93.3
(Delaney et al., 2018) - Rugby	38 elite players (23 ± 3 years;1.87 ± 0.06 m; 99 ± 10 kg)	Heart rate training impulse (HR-TRIMP), sRPE-TL. GPS metrics were monitored: Mechanical Work; Impulse, Metabolic Work; HP Distance; ACC/DEC; HS Distance; Distance.	EL correlates strongly with IL indicators. Total Effective Load (TEL) is best determined by combining HR-TRIMP and EL, considering body weight and ACC/DEC.	100
(Izzo et al., 2018) - Football	5 matches and 60 players from Professional First Italian League.	Evaluate speed, acceleration, deceleration, and metabolic power in soccer players through video tracking (K-Sport Universal, Italy).	Most frequent events occur within 1-2 meters of ACC and DEC threshold. External Midfielders perform the highest intensity actions.	53.3
(Beard et al., 2019) - Rugby	188 professional players from teams from Ireland, Italy, Scotland, and Wales.	Positioning metrics using GPS-IMU: TD (m), meterage ($m.min^{-1}$), HSR; maximum velocity (m.s-1); number of efforts distance and repeated high-intensity locomotive efforts (RHILE) and HSR efforts	RHILE was higher in international games than in club games, out-side backs (OB) show greater distance and meterage in international games. Significant differences were observed across all six positional groupings ($P < 0.05$).	60.0
(Pino-Ortega et al., 2019) - Basketball	94 elite under 18-year-old basketball players (age, 17.6±0.8 years; height, 1.91±0.08 m; Body mass, 82.5±8.8 kg; BMI, 22.7±1.8 kg/m^2)	Time spent on activities during a soccer match for positional differences. EL using GPS technology: distance covered, player load (PL), ACC/DEC, peak speed, and peak acceleration.	Top teams had lower RD, with guards having higher RD than forwards and centers. First quarter showed higher RD, %HIR, and PL. Third match had higher demands in RD, HIR, and PL than first two matches.	100
(Bayliff et al., 2019) – American Football	43 collegiate players (age, 19.9±1.5 years)	DT (m); Maximum velocity (MV) Total Inertial movement analysis (Total IMA) = ACC, DEC. Positional differences [Wild receivers (WRs); Defensive backs (DBs); Offensive line (OL); Defensive line (DL).	DBs travelled farthest, but DLs exceeded them. MV found that DLs scored higher than OLs. WRs had the strongest acceleration. All positions differed in DEC intensity.	86.7
(Douglas & Kennedy, 2020) – Ice Hockey	20 elite male players. 7 defenders (age; 19.3±0.5) and 13 forward players (age 19.3±0.7)	Skating speed thresholds were monitored by period (1º;2º,3º) and by game situation (5v5; 4v5; 5v4):	During gameplay, forwards have more high intensity skating than defenders, while both positions experience a decrease in skating intensity during the third period.	86.7

(Wiig et al., 2020) - Football	18 male players (7 defenders, 5 midfielders, and 6 attackers) from the Norwegian Premier League (age, 26 years; height 183 cm, body mass 80 kg)	PL, layer Load; HIE, high-intensity events; HSRD, high-speed running distance; sRPE-TL, session rating of perceived exertion training load; VHSRD, the very high-speed running distance by GPS.	Total distance, PlayerLoad™, PlayerLoad2D™, and HIE > 1.5 had most likely substantial within-player effects on sRPE-TL. sRPE-TL showed large to very large between-session variability with EL.	90.0
(Principe & Vale, 2020) - Football	23 female elite players (age: 27.65 ± 4.66 years; height: 165.35 ± 5.82 cm; weight: 60.91 ± 5.34 kg).	EL [Walking distance (WD, m); Jogging distance (JD, m); Running distance (RD, m); Sprinting distance (SD, m); Different zones of ACC/DEC, were assessed by players positioning across different matches.	Decrease in external locomotor demands across played matches.	93.3
(Ribeiro et al., 2020) - Futsal	28 elite male players (age: 24.1±3.4 years) from eight futsal teams from the Final Eight of the Portuguese Cup 2018	The GPS measured various metrics, including distance covered, sprints, maximum speed, impacts, jumps, stress load, and metabolic power.	Player performance was assessed based on kinematics and metabolic metrics. Strongest correlation was found between cluster levels, DEC, and an increase in DT per minute in the second half.	96.7
(Illa et al., 2020) - Futsal	13 elite players (age: 28.8±2.4 years, weight: 73.7±6.2 kg, height: 175.9±5.9 cm)	With GPS units, Kinematics (Absolute high-speed running, relative speed running and total distance) and mechanical (PL), High-intensity ACC and DEC)) were assessed.	MD-2 is similar to the match. High- and very high-demanding scenarios (n) in the training session prior to the match dropped in comparison with the rest of the microcycle and the match.	93.3
(Serrano et al., 2020) - Futsal	14 elite players (age,30.21±3.98 years; height, 1.77±0.07 m; weight, 74.85±6.40 kg) from a professional club of Spanish Futsal first division League.	LPS monitored various metrics: distance, ACC, and velocity. These included Relative Distance, Explosive Distance (ED), HSR, ACC, DEC, ACC_{MAX}, DEC_{MAX}, ACC_{MEAN}, DEC_{MEAN}, Velocity $_{MEAN}$, and Sprints.	Physical requirements provided similar outcomes in the first and second halves. Wingers outperformed pivots in terms of HSR distance. All player positions have a high amount of ACC and DEC each minute.	93.3
(Barron et al., 2020) - Futsal	16 elite male futsal players (age, 25.74±4.71 years; body mass, 74.2±9.8 kg; body fat 11.1±5.8%)	Maximum Heart Rate (MHR) by Yo-Yo Intermittent Recovery Test. In Competition: Internal measures (Heart rate); EL: Low Medium and High ACC per/min; PL (a.u). Technical Variables	MHR via the Yo-Yo IR1 test (194.6±11.1 beats min^{-1}). Mean HR value during "court time" of 164.7±22.3 beats min^{-1}. 77.3% of ball receptions were completed with the sole of the foot. 80.1±16.7% of individual possessions used the dominant foot to receive and 84.1±10.7% to pass the ball.	73.3
(Milanez et al., 2020) - Futsal	87 male U17 athletes (3 to 5 sessions of weekly training) and 85 elite adult male athletes (8 to 12 sessions of weekly training).	Video tracking to record % very HIR, total distance covered (TDC)/min, successful passes, pass efficiency, and substitutions in each half.	The number of substitutions contributed to higher TDC, %VHIR. Decrease in %VHIR promotes lower pass efficiency. Substitution improves running performance.	93.3
(Ohmuro et al., 2020) - Futsal	79 top-league adult players (age: 28.4 ± 4.6 years) and 59 top-level youth players (age: 17.1 ± 0.7 years) i	Percentage of distance covered (%). Speed categories: walking (0–6 km/h), low intensity running (LIR; 6.1–12 km/h), medium intensity running (MIR; 12.1–15.4 km/h), HIR; 15.5–18.3 km/h, and sprint (>18.4 km/h). High intensity exercise (HIE) = sum of MIR, HIR, and sprint.	Youth players have longer playing time and lower HIE than adult players in sports. Pivot players cover less ground than wingers in adults, and defenders have lower levels of HIE without ball possession than wingers.	86.7
(N. Silva et al., 2020) - Futsal	43 elite male futsal players from six elite futsal teams	Warm-up routines: Closed skills; Open skills and Futsal-specific skills. EL was monitored by LPS: Total distance covered (m); Distance covered (m/min); running (m/min); Sprinting (m/min); ACC (n/min); DEC (n/min)	Including futsal-specific warm-up tasks prepare players for the game. ACC and DEC increase during warm-up, leading to higher intensity.	73.3
(Oliva-Lozano et al., 2021) - Football	19 football players (age, 26.78 ± 3.77 years old; body mass index, 23.1±0.19) from the La Liga.	GPS units to track the worst-case scenario (WCS): TD covered; HSR distance (HSRD) and sprint distance (SPD). The WCS were generated using fixed length and rolling average approaches based on playing position.	Fixed length methods of varying durations greatly underestimated the WCS of TD, HSRD, and SPD across playing positions. In professional football match-play, the rolling average approach is suggested for reliable WCS analysis.	86.7

(Cunniffe et al., 2021) – Field Hockey	24 international hockey players from an international hockey team (age=26±4, max aerobic speed=4.85±0.23 m.s⁻¹).	EL by GPS: Relative total distance (RTD); HSR; Sprints distance (SD); ACC; DEC; Low speed running (LSR), Dynamics stress load (DSL); ED, HML efforts; HML distance (HMLD); Total Load (TL)	Significant effects were found for possession status on several physical output metrics. Not possession, except for forwards, is the category with more demanding (RTD, ED, HSR).	93.3
(Novak et al., 2021) - Football	26 male professional players (age: 28 ± 4 years; height: 182 ± 6 cm; body mass: 78.8 ± 6.2 kg).	Optical tracking to determine de WCS for TD, high-speed running (>5.5 $m.s^{-1}$) and sprinting (>7.0 $m\text{-}s^{-1}$).	The WCS defined as the maximal physical load in a given time-window, produces unstable metrics lacking context, with high variability.	86.7
(Illa et al., 2021) - Futsal	14 professional players (age: 28.8±2.4 years, weight: 73.7 ± 6.2 kg, height: 175.9±5.9 cm)	LPS to measure EL by playing position: Relative distance ($m.min^{-1}$), HSR distance (m); HSR efforts > 18$km.h^{-1}$ (n); ACC (>2$m.s^{-2}$; $n.min^{-1}$), DEC (>2$m.s^{-2}$; $n.min^{-1}$); ACC distance (>2$m.s^{-2}$; $m.min^{-1}$); DEC distance (>2$m.s^{-2}$; $m.min^{-1}$).	EL load metrics vary among positions and players. Contextual factors can affect perceived difficulty of demanding scenarios.	100
(Altmann et al., 2021) - Football	25 male professional football players from the German Bundesliga.	GPS tracking to analyse the physical match performance; total distance, high intensity distance (17–23.99 km/h), sprinting distance (≥24 km/h), accelerations (≥1.5 s) for each player and each position.	The change in physical match performance can be explained by 44–58% through the normative positional data. Individual differences impact the way players perform when acting in different positions.	86.7
(Conte et al., 2021) - Rugby	11 Elite national team players (age: 24.3±3.3; stature 166.1±7.2 cm; body mass: 66.1±7.4 kg)	GPS Units to track EL measures: TD/min; Standing/walking (0-6.0 $km.h^{-1}$); jogging (6.1-12.0 $km.h^{-1}$) Cruising (12.1-14.0 $km.h^{-1}$); striding (14-1-18.0 $km.h^{-1}$); HIR (18.1-20.0 $km.h^{-1}$); sprinting (>20.1 $km.h^{-1}$); ACC(n) (>1.8 $m.s^{-2}$) and DEC(n)(< - 1.8 $m.s^{-2}$). IL was by s_RPE and well-being.	No significant differences between congested matches were observed in almost load measures. Congested match schedules negatively impact RPE, muscle soreness and overall wellness.	100
(de Jong et al., 2022) - Futsal	126 professional players, including goalkeepers 6.	Video tracking system (30Hz) to measure distance covered (DC) and percentage of DC in different speed ranges to identify differences per team and per sub-phase of the game (traditional vs. outfield goalkeeper situation.	With the outfield goalkeeper situation, the team spent higher percentage of the distance covered in the standing and walking speed range compared with the traditional goalkeeper positioning.	90.1
(Ribeiro et al., 2022) – FTS	17 male professional players (age: 28.8±2.4 years, weight: 73.7±6.2 kg)	WIMU LPS to assess high Intensity activities (HIA: sum of acceleration, decelerations, and high-speed running actions).	Players with more playing time and with a specific work-rest ratio (1.1 ±0.6 a.u.) show greater ability to repeat HIA per rotation.	100
(Nobari, et al., 2022) - Football	20 elite players (age, 29.4±4.4 y; height, 1.8±0.1 m; and body mass, 74.8±2.3 kg)	Chronic workload ratio (ACWR) via session-rated perceived exertion (s-RPE). GPS units tracked DC, HSR, SPD by starters and non-starters during the season.	ACWR was highest at the beginning and end of mid-season, with higher values at the start of early season, specifically through SPD. Correlations were found between EL and IL metrics across all three in-season periods.	96.7
(Caro et al., 2022) - Football	14 professional male players (age: 23.86±3.58 years; weight: 73.74±5.92 kg, height: 1.79±0.05 m)	Maximum Intensity Periods (MIPs) tracked BY GPS units: distance covered at HSR, and Sprinting, ACC density (AccDens), mean metabolic power (MetPow), metres per minute (Mmin) and HMLD >25.5 W/kg.	Differences in HSR, Sprint, AccDens, MetPow, and HMLD thresholds between players. Positional variations observed in MetPow, Mmin, and between halves in AccDens, MetPow, and Mmin.	93.3
(Nobari, et al., 2022) – Football	20 elite players (age: 29.40±4.35 years; body mass: 75.00±3.87 kg; height: 1.79±0.05 m; body mass index: 23.38±1.79).	ACWR and exponentially weighted moving average (EWMA) were calculated using session-rated perceived exertion (s-RPE), total distance (TD), HSR distance (HSRD), and SPD during three seasons. Kinematics metrics were evaluated using GPS devices.	Except for $EWMA_{sprint}$, workload measures observed in mid-season were higher compared with early season. Wingers and strikers tended to have greater workload compared to the defenders and midfielders.	96.7
(Oliva-Lozano et al., 2023) - Football	19 male elite players (26.8±3.8y., 1.79±0.08m, 73.6±6.4kg)	PL (Tri-axial) with GPS (WIMU tracking system) by player's position.	Total PL may be suitable for tracking locomotor demands or accelerometer-derived loads.	96.7
(Rabano-Muñoz et al., 2023) - Football	17 elite young players (15.2±0.3y., 171.4±6.5cm, 62.5±7.5kg)	During specific SSGs, EL such TDC moderate speed running (MSR), HSR, Sprinting running (m), ACC/DEC (n) and PL, by GPS. MHR, and RPE were also assessed	In SSGs, shorter defensive periods enhanced HSR, while longer defensive periods raised RPE.	100

5.3.6 Applicability of tracking system related to Performance Analysis of Training versus Matches Demands

Based on the analysis of the selected studies, at the same level, studies suggest that it is possible to predict IL such RPE from GPS training and matches data (Rossi et al., 2017) showing that the variation in workload efficiency throughout matches may be explained by the training load variables from the prior days and training cycles (Grünbichler et al., 2020). Additionally, the understanding of load dynamics across training and competition is also presented as an important propose related to the performance enhancement in team sports (Fernández et al., 2021; Grünbichler et al., 2020; Illa et al., 2020; Rago et al., 2021) showing, for example, how adjusting specific drills such large- medium- and small-sided games, may replicate game demands (Beato, de Keijzer, et al., 2023; Beato et al., 2023). Correlations between EL and IL in different season periods were applied in order to understand the fluctuation of some metrics such as players strength (Pereira & Freitas, 2022), players recovery (Schuth et al., 2022) or ACWR, between players positions, starters and non-starters (Ammann & Altmann, 2023; Martins, 2022; Nobari et al., 2022). Also, Pizarro et al. (2021) demonstrated how different occupational areas may promote different physical variables. The author states how the manipulation of "floaters" in SSGs according to specific purposes in FTS, promotes higher distances and speeds variables, accelerations, and decelerations. The same was described by De Jong et al. (de Jong et al., 2022) in which manipulation of the game momentum (with outfield goalkeeper) promotes changes in teams total distances covered (de Jong et al., 2022). Silva et al., (2014) demonstrated, that teams have the ability to co-adapt to performance constraints by manipulating SSGs. Additionally, add-ons to SSGs, such as number of player by drill, players positioning, or touch constraints, are being referenced as potential ways to increase or decrease EL (de Jong et al., 2022; Younesi et al., 2021). (Table 2)

Table 10. Articles predominantly related to Training versus Match Physical Performance Analysis

Study and Sport in which study has been carried	Sample	Main Outcomes Measured	Results	Quality Score (%)
(Neville et al., 2012) - Australian Football	2700 training or competition GPS recordings from 44 athletes.	Time spent at each speed was analysed using GPS, by; (1) Game Vs Training Comparison, (2) Player Comparison, (3) Intra-Season and (4) Position Comparison.	A strong correlation between the intensities of the training sessions and the physical demand of first grade games and small differences in the demand of different field positions was also observed.	53.3
(Polglaze et al., 2015) - Field Hockey	44 elite male players (age 27.0±2.7y, body mass 78.8±6.8 kg)	The Fisher Z test was used to analyse the relationships between distance and PL in absolute (m, AU) and relative (m/min, AU/min) terms between matches and training, as well as between positions within matches.	In competition, the absolute distance-PL relationship was very large overall, with no variances between positions. The relative distance-PL relationship was moderate overall, but weaker in forwards than in defensive midfielders' defenders. In training, the absolute/relative distance-PL relationship was very large.	100
Ritchie et al., (2016) –Australian Football	44 professional elite athletes (mean ± SD: age, 24.1±3.8 years; height, 187.7±7,2 cm; body mass, 87.3±8.2 kg)	IL data: RPE-based method and s-RPE. GPS units to get EL: total distance (m), HIR (>14.4 km/h (m) (HIR), PL and average movement speed (m/min).	During the pre-season, the RPE load was greater. The RPE load was significantly reduced in the final pre-season block. From pre-season to in-season, TD, HIR, and PL showed decreases.	93.3
(Jones et al., 2016) - Rugby	Performance analysts/strength and conditioning coaches from (n=3) Super Lead clubs in the North of England.	Michel Foucault's disciplinary analysis was used to explore how teams use wearable GPS technology and how it affects the physical, psychological, and emotional health of rugby football players.	GPS data can be used as a disciplinary tool to normalize and pressure athletes into complying with possibly harmful physical and physiological demands. When mismanaged amplifies the uncertainty, fear, and failure of the major obstacles of the professional demands.	71.4
(J. Fernández et al., 2016) - Football	A total of 2951 rows from training sessions (2478) and official match (473) of 42 elite players throughout the season 2015-2016.	GPS devices were used to collect (1) Locomotor Variables, (2) Metabolic Measures and (3) Mechanical Variables.	The use of summarized physical variation data has provided a relation between higher magnitudes of variation in 3-week time frames during training, and higher physical values in the following matches.	73.3
(Scott & Lovell, 2018) - Football	22 elite female players (age=28.3; Stature=168.6; Body Mass=64.3; % Body Fat= 18.8)	IL (heart rate metrics, ratings of perceived exertion [RPE], wellness ratings) and EL ((HSR, VHSR and maximal sprint speed were monitored (GPS)).	Correlations between HSR and VHSR vs. RPE were large; VHSR for the MSS technique was moderate; HSR was very-largely associated with heart rate indices and large for MSS.	86.7
(Pettersen et al., 2018) - Football	6 high-level female players (weight 59.6±6.8 kg, height 171.5±4.2 cm)	High-Intensity Run and Sprints were monitored between players positions using GPS tags on training and match sessions.	In a normal microcycle, full backs only covered 26% of the SPD they covered in the next match. Practitioners must carefully consider to proximity size and physical work pattern in microcycles to better resemble match performance.	73.3
(V. De Silva et al., 2018) - Football	150 players, aged between 18 and 23 years across four seasons (2014-2018)	GPS tracking to profile high-speed running (HSR) activity and distance covered (DIST) between training and match sessions and playing position.	Positional differences during games. Thus, the physical activity profile does not show positional differences during training sessions. Central Forwards face the highest demands for HSRs. Central Midfielders tend to cover more distances.	86.7
(Rossi et al., 2019) - Football	22 elite players (age=21.96±4.53 years; height =180.68±5.23 cm; weight = 72.36±4.19 kg)	EL by GPS; Kinematics and mechanical metrics. IL; RPE and s_RPE.	RPE and S-RPE are more affected by training volume than intensity. RPE is affected by the the previous training week workload. s-RPE reflects the workload performed in the current training session.	86.7
(Hudson et al., 2020) - Rugby	22 elite rugby players (age; 25.7 ± 4.1 years, body mass;104.6 ±12.6 kg).	Resting metabolic Rate (RMR); IL: RPE/s-RPE. EL: total distance covered, high-speed efforts/(n) and very highspeed efforts/(n) were recorded on match (GPS).	Elite rugby matchs can increase resting metabolic rate for up to three days after the game due to collisions during play.	87.5
(D. Fernández, Fernández, et al., 2020) - Rink Hockey	8 professional male players (age: 29.6±5 years; weight: 78.1±4.6 kg; height: 178.8±3.1cm)	Using LPS, the following EL metrics were monitored: DT; High-speed skating, HSS; ACC; DEC; and PL by players' positions: Exterior (EX); Interior (IN).	There were no significant differences between positions in all monitored metrics.	93.3
(Ispyrlidis et al., 2020) - Football	13 professional players (aged, 26±4.6 years; body mass, 77.4±6.96 kg; height, 181±50 cm; body fat, 8.7±1.51%)	Training and matches positioning differences: IL: Intensity zones of Heart rate (%HR_{max}); EL: DT with specific running speeds; number of sprints; ACC/DEC (n).	Higher HR in matches. Fullbacks, central midfielders, and defenders performed higher HR. Low running intensities are higher in training that in games. ACC and DEC are higher in training sessions than official matches.	93.3

(Grünbichler et al., 2020) - Football	14 professional soccer players age, 22.6±4.3 years; height, 181.5±5.7 cm; weight, 75.7±5.8 kg) from the Austrian Second League	GPS was used to track total distance (m); High, Very high and SPD (m); N of medium ACC/DEC (n); N of high ACC/DEC (n). The modified training impulse ($TRIMP_{MOD}$) was also obtained.	Previous day's training load affects workload efficiency in subsequent matches. Long sprints on D-3 and D-4, and total distance on D-1 impact workload efficiency. Sprint training on D-4 and D-3 positively influences workload efficiency in matches.	86.7
(S. Ryan et al., 2021) - Australian Football	45 professional players (age: 24.95±4.45y; height: 1.87±0.05m; body mass: 84.64 ± 9.01kg)	Training and match EL (TD; HSR and VHSR) measured with GPS units. IL assessed by s-RPE. Perceptual wellness (soreness, sleep, fatigue, stress and motivation) questionnaire.	Principal Component Analysis (PCA) identified eight uncorrelated components from 37 monitoring variables. Seven-day TD; Inertial Movement Analysis (IMA) event count and s-RPE load presented positive relationships with performance.	90.0
(D. Fernández et al., 2021) - Rink Hockey	9 elite professional players (age: 29.8±5.77 years, weight: 79.5±5.50 kg, height 180.4±4.03 cm)	GPS tracking for EL; DT (m); HSS (m); PL (a.u.) ACC (n); DEC (n) and IL (RPE and s-RPE).	MD-4 and MD-1 sessions with lower EL and IL. MD-3, MD-2 and MD presented higher external and IL with values near fatigue zone. Loa dynamics tend to show an inverted "U-shape".	93.3
(Rago et al., 2021) - Ice Hockey	17 elite male players (6 defenseman and 11 forwards); age = 26 ±5 years old, height = 181±6 cm, body mass = 81.6±6.9 kg, body fat=13.6%±2.2%.	GPS tracking for EL: ACC variables (*n*/per minute) included the number of total ACC (ACC_{tot}), ACC above 2 $m \cdot s^{-1}$ (ACC2), total DEC (DEC_{tot}) and DEC below −2 $m \cdot s^{-1}$ (Dec2). IL: HRmean, HRpeak, Edwards TL and $TRIMP_{MOD,}$ RPE and s-RPE.	ACC2 and DEC2, time spent >85% HRmean, Edwards TL and $TRIMP_{MOD,}$ RPE and s-RPE were greater during competition than during training however decrease toward game day. ACCtot and DECtot per minute were lower than competition.	93.3
(Oliva-Lozano et al., 2021) - Football	30 male professional players (age: 25.97±3.73 years old; height: 1.80 ± 0.07 m; weight: 74.60±6.61 kg)	GPS tracking to EL metrics (Mechanical, Kinematic and Metabolic) were collected in both training and match days (MD)	Metabolic power, total steps, and various distances covered were key factors in explaining the PCA. -1MD and +1MD had the lowest load variability compared to -5MD and -4MD.	100
(Pizarro et al., 2021) - Futsal	30 male futsal players from the U-19 (age, 17.7±0.71) from Spanish clubs.	LPS was used to analyse EL (kinematics and mechanical variables) and IL (heart rate) by manipulation of floaters in four different contexts of 3vs3 Small-sided Games (SSGs).	Differences in the physical variables were observed. "Goal line Floaters" is related to higher distance and speed variables, being the most demanding SSG. Lower HR values were obtained, and "Floaters off" is linked to the ACC and DEC variables.	93.3
(Younesi et al., 2021) - Football	20 professional soccer players (age: 28.1±4.6 years; height 176.7±4.9 cm; %BF 10.3±3.8%)	GPS units were used to measure TD, HIR, HSR, and mechanical work (MW) in small-sided games (3v3, 4v4, and 6v6 formats).	TD min-1 showed consistency in EL metrics across SSGs, with only minor variations between intervals observed in HIR-1, HSR min-1, and MW min. Limiting touches or adding goalkeepers did not cause significant changes in session-to-session differences.	90.1
(A. Z. Li et al., 2022) – Football	29 elite male players (age: 18.3±0.5 years, height: 175±6 cm, weight: 65.5±6.3 kg)	Small-sided games (8v8, 5v5, 3v3) with GPS units to measure maximum speed, distance covered, HSR, ACC, and DEC. HR bands and blood lactate to measure IL.	Players covered more distance and high-speed running in 8v8 and 5v5 compared to 3v3 format. HSR distance was higher in 8v8.	93.3
(Pereira & Freitas, 2022) - Football	18 Brazilian elite football players (24.3± 4.8 years; 180.0 ± 5.7 cm; 74.7 ± 8.3 kg).	Training loads with GPS units, measuring EL and IL variables, as well as assessing vertical jump performance during a 4-week preseason.	High internal and external training loads during preseason affected recovery and reduced jump performance, particularly in the group with higher VJ ability.	93.3
(Schuth et al., 2022) - Football	25 U16-U17 youth national team players	(GPS) units to track Kinematics and Mechanical efforts. Individual CK values were measured every morning.	Players could be classified based on their sensitivity to micromovements (MM), high-velocity (HV), or a combination of the two.	93.3
(Beato, de Keijzer, et al., 2023) - Football	24 male's professional players (27±9y, 79±15kg).	Large-Sided games (LSGs) were monitored. TD/(m)min, HSR/(m)min, Sprinting/(m)min, ACC/DEC(n)/min were assessed by GPS. RPE was also registered.	Desipite LSGs replicated and sometimes exceed some match-specifi intensity pararamerts, HSS and spriting were consistently lower than official matches.	100
(Ammann & Altmann, 2023) - Football	49 elite male professional players.	ACC/DEC (n), Dynamic load stress (a.u.) HMLD (m), HSR (m), SPD (m), DT (m) and PL (a.u.) were assessed by GPS.	Player presented different PL acrooss the microcycle, between trainning and matches and between positions on the field.	96.7
(Beato, Vicens-bordas, et al., 2023) . Football	25 male professional players (27±9y, 78±14kg)	Sided games were categorized (LSGs; Medium SGs, and SSGs). EL (HSR, sprinting distance, ACC, DEC) and IL (RPE) were compared by positions. GPS units.	Position differences for HSR, Sprinting and DEC. Sided games promote diferente RPE, DT, Sprinting (m), ACC and DEC. MSG promote higher ACC and DEC.	100

5.3.7 Applicability of Tracking system related to Injuries.

Regarding the analysis related to injuries prediction, some kinematics variables such distance covered, and mechanical such as accelerations / decelerations were considered. For example, in elite female FH players, the authors verified that the risk for in-game knee injury decreased with the increasing distance covered while running at low speed (Kim et al., 2016). In the same path, Caparrós et al., (2018) in a total of 2613 observations and 246 games from 33 different players of a professional male BK team described that athletes with less or equal than 3 decelerations per game and those running less or equal than 1.3 miles per game had higher risk of injury. Predictive injury models are also proposed by the use of tracking systems (Rossi et al., 2018). In this study with 26 Italian professional male players the author propose a multi-dimensional approach to injury forecasting in professional FTB based on GPS measurements (Rossi et al., 2018). Additionally, 3 studies from contact team sports (AUF and AMF) presented associations between specific levels of kinematics and mechanical variables with the occurrence of injurys (Li et al., 2020; Murray et al., 2018). Finally, some studies reported that lower workloads during pre-season, and higher workloads during competition training weeks, increase the risk of non-contact injuries (Fisher et al., 2022; Nobari et al., n.d.). (Table 3)

Table 11.Articles predominantly related to Injuries

Study and Sport in which study have been carried	**Sample**	**Main Outcomes Measured**	**Results**	**Quality Score (%)**
(Kim et al., 2016) - *Field Hockey*	32 Elite players from the Korean Female National Team: 11 defenders, 9 midfielders, and 12 forwards. Goalkeepers were excluded.	GPS monitoring was used to record distance travelled while running at various speeds, sprinting time, and top speed in 20 international competitions. Non-contact injuries with knee and ankle pain were documented.	Low-intensity running distance was considerably greater among athletes who didn't suffer an injury during the course of the trial. The risk of in-game knee injury decreased as the distance covered while running at low speed increased.	86.7
(Caparrós et al., 2018) - *Basketball*	2613 observations and 246 games from 33 different players of a professional male basketball team	Injuries that occurred during regular-season games were reported. Tracking data (speed and distance traveled, Mechanical Load variables, and locomotor factors) were recorded.	Athletes who experienced less than three DEC per game and ran less than 1.3 miles per game were at a higher risk of injury.	86.7
(Rossi et al., 2018) - *Football*	26 elite male players (age=26±4 years; height=179±5 cm; body mass=78±8kg).	Training workload by GPS: Two Features-Total Distance (d_{TOT}) and HSR Distance (d_{HSR}), and three features-Metabolic: Distance (d_{MET}), HML Distance (d_{HML}) and HMLD Distance per minute ($d_{HML/m}$).	Distance traveled (DT) can detect around 80% of the injuries with nearly 50% precision. The injury forecaster results in a cumulative f1-score=0.60 on the injury class; In an evolutive scenario, the features chosen modify as the season progresses.	73.3
(Murray et al., 2018) - *Australian Football*	45 Elite players from one club (age, 22±3 years, height, 190±7 cm; mass, 89±8 kg)	Running efforts using GPS units: absolute, pre-defined speed criteria or relative, individualized speed thresholds. Players were separated into three equal groups: (1) faster, (2) moderate, and (3) slower. Non-contact Injuries were documented.	Slower players with increased relative extremely high-speed running had a higher risk of injury, and greater absolute speed ACWR indicated an increase in injury, whereas greater relative high-speed ACWR promote a decrease in injury.	93.3

Gastin et al., (2019) – *Australian Football*	26 Elite male professional players (Mean±*SD*: age 22.8±3.3 years, range 18-30 years, height 187.1±7.2 cm; body mass 85.8±7.4 kg)	EL by GPS units [distance (m), SPD (>7 m-s-1(m), ACC (3-15 m-s-2(n)), DECC (-3 to -15 m-s-2) (n), PL (a.u), and impacts >3g (n)]. Creatine Kinase [CK] levels were tested before and after each match.	CK increased in competition. Impacts and game time were most strongly associated with post-match CK. DEC, ACC, impacts, and SPD are strong predictors of CK. CK is an indicator of muscle damage during competition, with impacts and HIR traits being the best predictors.	100
(R. T. Li et al., 2020) -*American Football*	115 players participated in the 2014-2015 season, and 117 participated in the 2015-2016 season.	GPS units were used to determine PL. All injuries sustained during practice or games were documented.	Injuries are associated with greater increases in workload. Individuals with an ACWR ratio greater than 1.6 are 1.5 times more likely than time- and position-matched controls to experience an injury.	86.7
(Fisher et al., 2022) – *Gaelic Football*	25 male elite-level players (n=25; age 25±3.7 years, height 182.2±6.2 cm; body mass (BF) 86.7±7.8kg; %BF 12.7±3.6%)	TD, PL, and meters covered at different running speeds were collected through GPS data. All injuries sustained during practice or games were documented.	Players who completed <50% of pre-season sessions had a greater probability of non-contact injuries. Increased pre-season running loads may lower the risk of injury while also improving or preserving aerobic fitness.	100
(Migallón et al., 2022) – Field Hockey	14 professional female players (age: 20.4±5.4 years; body mass: 60.7±7.2 kg; height: 167.0±1.0 cm)	Muscle strength, GPS data (TD; ACC/DEC intensity level, and player wellness during and after matches using various tools such as s-RPE, GPS units, 5-WQ, and TQR.	Players experienced decreased hip strength and acute fatigue after the second post-match, with prolonged reduced strength in the non-dominant limb. Fatigue levels returned to normal after 48 hours.	86.7
(Nobari et al., n.d.) – *Football*	21 professional players aged 28.3±3.9 years.	Acute workload (AW); Chronic Workload (CW); ACWR; and Increment in acute workload (Δ-AW) were estimated EL data by GPS units throughout training and matches.	Workload and the occurrence of non-contact injuries have a good association, according to high load weeks.	93.3
(F. Martins et al., 2023) - *Football*	33 male professional players 25.9± 3.8 years; 182.1±6.9 cm; 74.2±6.7 kg	GPS units to assess Kinematics (TD, HSR) and Mechanical (ACC/DEC) metrics. Injuries were also assessed.	Over a four-week period, a considerable increase in players' weekly external load performance may have an adverse effect on the occurrence of injuries.	93.3

5.3.8 Applicability of Tracking System related to Nutrition.

Two studies that analysed the variation in physical enhancement through nutritional intake were identified. Before and after subjects received 140 mL of beetroot juice (BJ) or placebo (PLA) on two separate days, a sample of ten competitive male BK players was monitored (López-Samanes et al., 2020). To measure physical improvements, a specific neuromuscular battery of tests followed by a 40-minute simulated BK match was used to measure players running profile, ACC, and DEC; however, acute moderate doses of BJ (12.8 mmol of NO3-) were not effective in improving neuromuscular performance (López-Samanes et al., 2020). In the other study, the same author verified that the ingestion of moderate doses of caffeine enhanced several physical variables such as jump height, running profile, number of body impacts, ACC, and DEC in FTS professional players (López-Samanes et al., 2021)(Table 4).

Table 12. Articles predominantly related to Nutrition

Study and Sport in which study has been carried	Sample	Main Outcomes Measured	Results	Quality Score (%)
(López-Samanes et al., 2020) ***Basketball***	10 male basketball players (15.6±0.5 years, body weight 76.3±9.0 kg, height 184.3±7.5 cm, body mass index 22.5±2.9).	Participants drank either beetroot juice or a placebo then played a simulated basketball game for 40 minutes. Physical metrics were tested afterward: jump, grip strength, agility, and sprinting. Kinematics/ mechanical metrics were monitored.	Acute moderate doses of BJ (12.8 mmol of NO_3^-) were useless in improving the player's performance.	93.3
(López-Samanes et al., 2021) - ***Futsal***	16 top-level male players (age: 28.0 ± 4.1 years; height:173.8 ± 6.1 cm; body mass: 71.2 ± 9.7 kg; futsal experience: 12.4 ± 2.9 years)	Futsal-specific tests (CMJ, 20-m sprint test, kicking velocity, and accuracy test). Simulated matches were conducted between the controlled (ingested 3mg/kg of caffeine) and placebo groups. Kinematics/ mechanical metrics were monitored.	Jump, sprint performance, high-speed running, ACC, and DEC, were improved by 3mg/kg of coffee. Caffeine supplementation improves futsal performance when used in moderation.	100

5.4 Discussion

The purposes of this scoping review were to understand the applicability of tracking systems in physical performance analysis in team sports over the last decade in order to gain an understanding of how manipulating different variables and research goals in this field may be beneficial to enriching the use of these technology and, as a result, to integrating the revised information in a comprehensive framework that could help to clarify the physical performance area for team sports and athlete's well-being. The main findings were that tracking technology has been applied in team sports as a valuable tool in the following research fields: *(1)* performance analysis of match demands; *(2)* performance analysis of training *versus* match information; *(3)* injuries, and *(4)* nutrition. Additionally, the groups of metrics mainly used are (1) kinematics and Mechanical; (2) Kinematics; (3) Kinematics, Mechanical and Metabolic. To seek an understanding of athlete's performance, several studies establish correlational analysis between specific EL metrics and IL information. However, the described EL metrics are manipulated individually rather than in an integrative model, which should include for example, the Principal Component Analysis (PCA) of each team sport. This indicates that it is still promising to go further into the understanding of how tracking technology can be used to improve training and performance by combining IL and EL data. Finally, studies appear to focus primarily on *(1)* characterization and comparison of drills, training, and match sessions, followed by *(2)* correlational analysis between metrics. In line with that, it was possible to consider such relationships for the development of a conceptual framework that both supports applied sport-sciences research and also practitioners monitoring and intervention (Figure 5). Indeed, the development of high-performance departments that combines *slow-thinking* (applied sport-science research) and *fast-moving* intervention (applied monitoring and intervention) (Coutts, 2016) supported by a coherent framework certainly promotes best preparation assessments and decision making based on reliable data (Coutts, 2016).

5.4.1 Tracking Technology and Physical Performance Analysis of Matches Demands and its Comparison with Training Demands

In team sports, coaches and performance personnel invest a lot of time and resources to follow up on their athletes. Physical training can describe in terms of EL (work) and the acute responses and long-term adaptations (IL) (Impellizzeri et al., 2004). Through the development of wearable technology for athletes over the past few years, team sports stakeholders have embraced the practice of monitoring their athletes' EL in both training and competition (Delaney et al., 2018). Consequently, technology is used by coaches and exercise physiologists with an intent of enhancing training data and achieving competitive advantage (Delaney et al., 2018). The focus in athlete's performance improvement has been sponsoring the need to understand training and matches demands. Several research have been characterizing and understanding EL metrics (mainly kinematics and mechanical) during specific training or competitive contexts (Mangan et al., 2017; Rossi et al., 2017). Additionally, and as an attempt to enhance knowledge for training improvement, links have been established between kinematics, mechanical and metabolic variables, and more recently with IL (Beato, de Keijzer, et al., 2023; Beato, Vicens-bordas, et al., 2023). However, and assuming the physiological adaptations of different team sports exigences, we believe that deeper steps must be given based on experimental approaches seeking to understand better the relationship between EL and IL and athletes recovery cycles (Rossi et al., 2019; Dempsey et al., 2018). In this regard, we believe that studying LSGs, MSGs, and SSGs may be helpful in determining which format is most suited to load specific kinematic or mechanical loads in line with a desired IL (Beato, de Keijzer, et al., 2023; Beato, Vicens-bordas, et al., 2023). Positioning, intra-games, level of competition and tactical comparisons have been also pointed out as references for the understanding of how performance may be improved by better understanding EL metrics, particularly in frequency, duration, and intensity. Besides the difficulties of collecting data at a top-elite level, in order to create a training program that accurately reflects the physiological demands of the game, we believe that more elite team sports game-specific data is required. In indoor high-intermittent team sports and based on the metrics selected by Ohmuro et al., (2020), in order to understand more accurately the games demands, we suggest the monitoring of EL by effective playing time (in-game). Despite the fact that an agreement between coaches and athletes about overall RPE and sRPE, as well as RPE and sRPE in moderate and hard categories, has already been recorded (Inoue et al., 2022), there is a lack of information about how demanding is the playing time, by player´s inter-change rotation, particularly in indoor intermittent team sports, and how can that knowledge benefits the training structure, and consequently teams performance.

Team sports performance is regarded as highly complex and multivariate. Researchers integrate players' technique with EL and IL, while there are studies in which EL and IL are categorized by players' position, exploring differences between training and competition (Ispyrlidis et al., 2020; Ohmuro et al., 2020; Principe & Vale, 2020). This correlational approach seems to translate differences which are assessed for a better individual and collective preparation, as reported by Florian et al., (2016). When selected EL fit with sports specification, we believe that this type of method is reliable for better interpretation of competitive microcycles. As proposed by Ispyrlidis et al., (2020) in FTB, and verified by Fernández et al.,(2021) in RH, this information may combine inter-changes of matches with competitive profiles trainings and improve all parameters of players physical output. At the same level, research indicates that understanding of load dynamics during training and competition, such as players' intra- and inter-week fluctuations, has a substantial influence on improving elite athletes' performance by properly regulating workload and recovery (Martins, 2022). In this review several studies developed a longitudinal understanding of load dynamic (combined kinematics, mechanical and metabolic metrics) across training and competition, proposing that performance enhancement may be a reflect of a proper adjustment of specific metrics (Fernandez et al., 2016; Tierney et al., 2016).

More recently, performance analysis research is stepping forward on the understanding of the HIA, and on predictive studies for fatigue and match performance. The literature suggests that during different phases of the training cycles, such as the baseline or competition phase, the training loads must be modulated to either enhance or reduce fatigue levels (Schuth et al., 2022). Due to this, it is important to understand the match HIA, to manage fatigue properly, matching this both variables to adaptation to training as well as for competitive performance (Halson, 2014; Ribeiro et al., 2022). On the other and, understanding HIA and it impacts in IL also improves the knowledge of individual player’s recovery strategies (Schuth et al., 2022). These importance to understand efforts of categories (moderate and hard) has been already suggested in a systematic review, in which agreements between coaches and athletes have been reported about the overall RPE and s_RPE (Inoue et al., 2022). Therefore, in order to effectively adjust the volume, frequency, and intensity of the metrics that are more closely associated to game pick periods, this information can assist in developing novel approaches on tapering training strategies. In this sense, kinematics and mechanical variables are statistically manipulated with indirect IL such as RPE, suggesting that it is possible to predict fatigue from GPS/LPS training and match data. Additionally, dissociation between EL and IL units may reveal the state of fatigue of an athlete, thus, detecting changes with statistical approaches may provide confidence and certainly for implementing changes (Halson, 2014). Nevertheless, in contact team sports like AUF, AMF, RG, and GF the use of mechanical metrics seems to be more significant to understand players fatigue and muscle damage (Bayliff et al., 2019; Mangan et al., 2017; Owen et al., 2015; S. Ryan et al., 2021).

Strength and conditioning coaches may daily obtain reports with more than 100 variables (Rojas-Valverde et al., 2020). Thus, it is crucial to choose and identify the key performance indicators according to sports specifications (Oliva-Lozano et al., 2021). In this review we identified research focused on proposing models for match performance manly based on kinematics, mechanical and metabolic variables (Grünbichler et al., 2020; Illa et al., 2020; Milanez et al., 2020; Murray et al., 2018; Pettersen et al., 2018). These studies demonstrate how crucial it is to adopt statistical techniques like PCA in team sports to accurately use significant performance variables by excluding the least significant.

5.4.2 Tracking Technology and Injuries

Athletes compete fiercely to become the greatest in their respective sports, particularly at the highest level. In team sports, the individual or collective success of this process is often compromised by the occurrence of injuries (Kim et al., 2016). Therefore, in this review we witnessed that the development of injury prevention programs is being supported by the association of tracking positioning systems like the use of GPS. Recently, studies tried to understand which (EL metrics) and how (volume, intensity and frequency) training and game demands have higher association to the occurrence of specific injuries such the risk for in-game knee injury (Kim et al., 2016). In specific intermittent team sports such as FH and BK, low kinematics (low intensity running) (Kim et al., 2016) and Mechanical (DEC) are associated to higher risk of injury (Caparrós et al., 2018). However this studies do not explain if this lower EL results from acute or chronic adaptations like the one of Li et al., (2020) which applied the use of technology to understand the relationship between soft tissue injury and training workload in AMF. For this author, the variation of training stimulus may induce higher risk of injuries. Once studies have shown that the ACWR is a more accurate predictor of injury than total workload (Gastin et al., 2019; Hulin et al., 2016) it is highly advised to use tracking technology to determine an athlete's chronic workload. According to the screened manuscript (Li et al., 2020; Rossi et al., 2018) we believe that the assessment of athlete's physical activity based on the intensity, duration and number of actions of kinematics, mechanical and metabolic metrics may also predict injuries with acceptable precision. Recently, higher pre-season workload, such running performance, was related to lower risk of injuries (Fisher et al., 2022). On the other hand, higher levels of weekly chronic workload (ACWR), indicates greater chances of occurring non-contact injuries (Nobari et al., 2022). We believe that these dichotomic reports, may support the need to better engage the longitudinal use of tracking systems in different team sports, to establish causal correlations between specific parameters and consequently, to improve injury prevention measures. The sparse research regarding the use of tracking technology related to injury forecast is manly developed in outdoor team sports, thus it is recommended that this research also head to high-intermittent indoor team sports like FTS, handball (HB), RH and BK. Finally, there is no injury forecast method that links the most demanding scenarios (MDS) or HIA in team sports according to specific EL variables and IL information. We believe that characterizing the dynamic of training workload related to teams' sports MDS may contribute to more reliable specific injury predictions.

5.4.3 Tracking Technology and Nutrition

The use of nutritional supplements and ergogenic aids to improve performance is becoming more popular among intermittent sports (Williams, 2011), but few have demonstrated benefits (Maughan et al., 2018), such as creatine, caffeine, sodium bicarbonate, and beta-alanine. Indoor team sports (BK, FTS, HB, RH, or netball) are becoming more intense, with explosive demands (Fernández et al., 2021; Ribeiro et al., 2020) stronger athletes, and repeated combinations of short and long intermittent efforts (Ferraz et al., 2020). This review noticed almost no research on the use of tracking technology to measure nutritional impact in kinematics, mechanical, or metabolic metrics. In this manuscript, only two studies were screened. Regarding the experimental approach developed to understand if the nutritional supplement of beetroot juice had some impact on the monitored EL variables (López-Samanes et al., 2020) no significant results were found. Furthermore, the effects of supplementation on physical performance and match running load or true exposure during competition (total distance covered, speed achieved, number of accelerations and decelerations) in team sports are sparse or unknown (López-Samanes et al., 2020). Though, López-Samanes et al., (2021), in his recent study, demonstrated how the use of this technology might progress the experimental approach on athletes nutritional development. The author showed that 3mg/kg of caffeine enhanced physical variables associated with FTS such as jump and sprint performance, and improved kinematics (high-speed running) and mechanics (ACC/DEC) during simulated FTS match. This finding can be interpreted as a chance for researchers not just to provide experimental proofs of performance enhancement, but also to better understand nutritional supplementary in the athlete's recovery process. For our best knowledge there are no experimental studies aimed to understand athletes' recovery cycles with the influence of nutritional supplementary and monitored by tracking technology.

5.4.4 Limitations

The fact that this review only included papers published in English in the electronic databases PubMed, Web of Knowledge, and Scopus, may have led to the exclusion of relevant publications in other languages. Furthermore, the exclusion of all systematic reviews can be seen as a constraint because some categories related to the aims of this scoping review may have not been identified by this exclusion.

5.4.5 Actual Trends and Future directions

Currently, research with the use of tracking systems is mainly focused on the physical performance analysis on matches, training versus matches, followed by injuries, and nutrition. Kinematics and mechanical variables combined, then just kinematics, appear to be the primary observed metrics. In addition, we also verified that in some studies, IL information is combined solely with Kinematics or mechanical metrics. Few studies combined both metrics. These manipulated strategies used for integrating IL information with EL may have been established according to team sports specifications. Still, we believe that tracking and studying Kinematics, Mechanical, and IL parameters together in training and matches, would provide more accurate data for the purpose of enhancing our understanding of athlete's performance and, consequently, to better manipulate the structure of drills such for example the manipulations of LSGs, MLGs and SSGs, according to specific physiological responses.

Based on the main results screened in this review, further research and practice should consider how frequency, volume and intensity does may be adjusted according to optimal (1) training structure; (2) to promote injury prevention; (3) considering nutritional supplements; and (4) to promote physical performance analysis. The integration of these four dimensions has not yet been proposed. Consequently, how can performance analysis lead the process of enhancing athletes' performance? This integrative vision proposal illustrates the significance of the domains explored in this review and how they may be oriented in accordance with specified research methodologies for both outdoor and indoor team sports (Figure 5). Despite the existing studies, we consider that the combined information of training and match demands are still the main source of the physical performance analyses. However, the integrative and longitudinal contribution of the presented domains related to the proposed researched strategies may promote more reliable and accurate information promoting an enhancement of the training structure. The development of more correlational analysis between metrics or prediction studies will improve the understanding of athlete's performance enhancement. Also, the experimental and prediction studies, particularly on the domain of injury prevention and nutrition, as well as in the manipulation of the metrics measured and compared between training and match sessions, are highly recommended. Therefore, because of its impact on high levels of muscle damage, as well as neuromuscular and perceptual fatigue, longitudinal tracking of EL variables, including as kinematics, mechanical, and metabolic metrics, when combined with IL, can provide insights into injury prediction and prevention measures. Additionally, the application of tracking technology to nutrition in team sports is relatively unexplored, with limited research investigating the impact of nutritional supplements on such metrics. It emphasizes the current trends in research, the need for more integrative models combining EL and IL data, and the importance of experimental and prediction studies to advance the understanding of team sports' physical performance, injury prevention, and nutritional impact. Ultimately, the integration of these domains into a coherent framework can guide both applied sport science research and practical interventions, leading to improve athlete preparation and decision-making based on reliable data which may promote the implementation of new drills, training, or competitive designs.

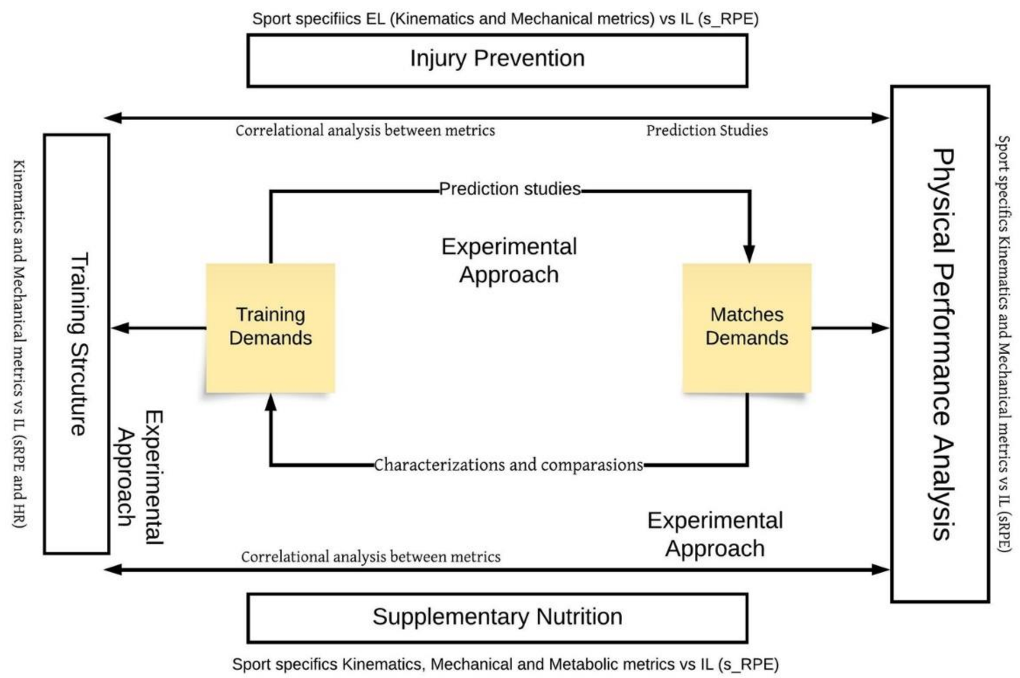

Figure 7. *Flow chart of the contextual research applicability of Tracking Systems based on the screened domains.*

6. Dynamics of training and competition demands in top-class male rink hockey: a case study of a rink hockey European Championship

Ferraz, A., Duarte-Mendes, P., Ribeiro, J. N., Yousefian, F., Valente-Dos-Santos, J., & Travassos, B. (2024). Dynamics of training and competition demands in top-class male rink hockey: a case study of a rink hockey European Championship. *International Journal of Performance Analysis in Sport*, 1–15.

6.1 Introduction

In team sports such as rink hockey, monitoring athletes' training load (TL) and competition load (CL) is important for understanding whether they are adapting to training programs as well as to determine their responses to competition (Halson, 2014; Rago et al., 2020). Therefore, it is important to monitor TL to appropriately adjust between stress and recovery during training microcycles (Rago et al., 2021) and minimize the risk of developing non-functional overreaching (Halson, 2014).

From TL, the external load (EL) is the work accomplished by the players to achieve a certain goal (i.e., distance, accelerations, decelerations, change of directions, or sprints, among others) during the training or competitive contexts (Fernández et al., 2021; Rago et al., 2021), the internal load (IL) represents the physiological stress imposed by the stimulus for training/competition-induced adaptation. Accordingly, EL may be classified into three main categories: *(1)* Kinematics, which quantifies overall movement during exercise; *(2)* Mechanical, which describes the player´s overall load during exercise; and *(3)* Metabolic, which quantifies overall movement energy expenditure during exercise (Impellizzeri et al., 2019). The internal load is usually measured through direct measures such as heart rate (HR) or indirectly through the rating of perceived exertion (RPE) (Rossi et al., 2018). In order to manage athlete fatigue and ensure peak performance during short concentrated competitions, it is crucial to assertively adjust the microcycles and modify the dynamics of training load to promote optimal responses to specific stimuli (Halson, 2014). In that sense, analyzing the relationship between EL and IL is key for monitoring player fatigue and readiness for competition (Halson, 2014). Thus, further research is expected to identify the variables that better characterize the dynamics of training weeks and competitive weeks and, the specific strategy of tapering before the competition.

Rink hockey is a team sport that is played by four field players and one goalkeeper, and official games have two periods of 25 minutes each (Hoppe et al., 2015). The game is performed on a court like futsal and handball, but with railings around the rink perimeter (Yagüe et al., 2013), promoting fewer interruptions compared to other indoor team sports (Fernández et al., 2021). Additionally, the use of quad roller skates facilitates the movement of the players on the court, making it easier to cover large distances. It is in fact a high-intensity intermittent sport in which non-continuous actions of different speed levels are followed by incomplete recovery periods, requiring a well-developed metabolism for short and long-duration efforts (Calò et. al., 2009). It is also characterized by high-intensity actions such as accelerations, decelerations, sprints, and changes of direction (Fernández et al., 2021). Additionally, intra- and inter-muscular and neuromuscular coordination are determinants for skating, ball mastery, and control using the stick (Ferraz et al., 2020). Despite rink-hockey popularity, research is still scarce, however, in the last years some studies have been conducted related to elite players, such as the analysis of the goalkeeper activity (Sousa et al., 2018), body composition and conditional profile (Ferraz et al., 2022), training, and competition demands (Fernández et al., 2021)

The availability of tracking technology provides an opportunity to increase the understanding of game and player demands in indoor sports such as rink hockey. To date, only four studies have been conducted regarding the characterization of physical demands in elite rink hockey (Fernández et al., 2021, 2023; Fernández, Varo, et al., 2020) Notwithstanding such studies, no research has been conducted to investigate the relationship between the impact of EL variables in the IL of players in a short and concentrated international competition such as the rink hockey European Championship. That is, what is the relationship between the structure of the training and the competition regarding the type of work developed (EL variables) and the stress imposed on the players (IL) in a short, concentrated competition such as the rink hockey European Championship? Is there any relationship between EL and IL between training and competition weeks, suggesting that the training process represents the competition's demands? Therefore, the aim of this research was to understand the dynamics of external and internal load across the training sessions of the two weeks of preparations and the competition week of the European Championship (three matches in a row). Consequently, we defined two specific goals: *(1)* to understand the dynamics and compare the EL and IL of training sessions and the competition weeks; *(2)* to understand the relationship between EL and IL in training sessions and competition matches EL.

6.2 Material and Methods

6.2.1 Ethics statement

Data collections were carried out according to the international ethical standards with humans based on the Declaration of Helsinki (Harriss et al., 2019) after approval by the Ethics committee of the University of Beira Interior **(**CE-UBI-Pj-2019-053:ID1519)**.** All participants were informed about the aims, the protocol, and the procedure, and provided signed written informed consent. Participation was voluntary and each participant could withdraw at any time. To ensure player confidentiality, all data were anonymized prior to the analysis.

6.2.2 Participants

A total of 9 top-level Portuguese male rink hockey players, (5 defenseman/midfielder and 4 forwards; age = 29.89 ± 3.41 years old, height = 175.7 ± 4.21 cm, body mass = 80.03 ± 8.33 kg, BMI= 25.94 ± 2.64 kg/m²) competing at the 2021 Rink Hockey European Championship participated voluntarily in the study. These world-class athletes compete in the main teams of the most prestigious rink hockey leagues (Arboix-Alió et al., 2021). Goalkeepers were not included. The inclusion criteria for participants in the study were: *(1)* the player had no injury or limitation during the period of analysis; *(2)* the player had completed the entire training session or game; and *(3)* the player participated in the competitive games at the 2021 Rink Hockey European Championship.

6.2.3 Study Design

An observational study was carried out during the preparation and competition phases at the 2021 Rink Hockey European Championship from the 1st until the 20th of November 2021 (Figure 1). A non-experimental descriptive method was used to characterize the training sessions and training matches during the two (2) concentrated pre-season weeks (TW-2 - two training weeks preceding the competition and TW-1 – one week before the competition) and the competitive games of the competition week (CW). Each preparation week included 2 cycles of 3 training sessions (TMD-3, TMD-2, TMD-1) followed by 1 training match (TMD). In total, players participated in 12 rink training sessions, 4 training matches and 3 international competitive games during the three weeks of the study. To monitor players' load in their training context, no information was given about the research design to the technical staff throughout the data collection period.

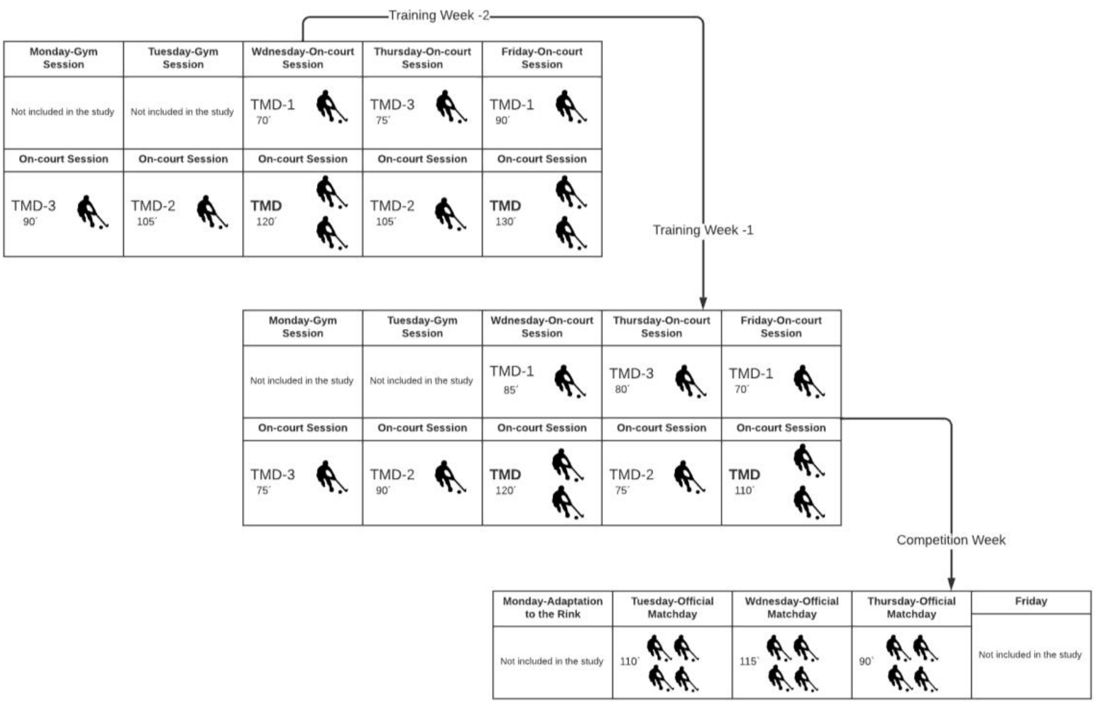

***Figure 8**. Flow chart of training sessions and official matchdays of the reported weeks.*

6.2.4 External Load Variables (EL)

Data collection related to player´s activity during in-court sessions with skates was carried out with Inertial Movement Units (IMUs) using an ultra-wideband (UWB) local positioning system (LPS) technology from WIMU PRO™ (Realtrack Systems SL, Almeria, Spain) and downloaded using its corresponding software (SPRO™, Realtrack Systems SL, version 986). The WIMU PRO™ is equipped with four 3D accelerometers (full-scale out output ranges are ± 16 g, ± 16 g, ± 32 g, and 400g; 100 Hz sample frequency), three gyroscopes (8000º /s full-scale out output range; 100 Hz sample frequency), a 3D magnetometer (100 Hz sample frequency), a global positioning system (GPS; 10 Hz sample frequency), and a UWB (18 Hz sample frequency) (Fernández et al., 2021; Impellizzeri et al., 2004). The devices were turned on 10-15 min before the warm-up began and placed in the upper part of the athlete's back, in a tight-fitting harness. Six antennas with UWB technology were fixed ±5 m to the court. The LPS system operates using triangulations between the antennas and the LPS unit devices and derives the unit's position (X and Y coordinates) using one of the antennas as a reference. Although training sessions and official games occurred in two different courts, to decrease possible technical differences, WIMU devices were calibrated according to the specific court design and antenna positions. The accuracy and reliability of the WIMU devices have been previously reported and validated (Bastida-Castillo et al., 2019).

From the collected positional data, the following variables were calculated in absolute terms to describe EL (Table 1): distance traveled (DT; m); medium speed skating, (MSS (12.1-18 km/h); /m); high-speed skating (HSS (18.1-30 km/h); /m); number of high-intensity impacts (HImpt (8-100 G); n); number of high-intensity accelerations (ACC [3 10] m/s^2); n); number of high-intensity decelerations (DEC [-3 -10]m/s^2); n); and Player Load (PL; au). High-intensity impacts were included in line with previous research in rink hockey (Yagüe et al., 2013). Training sessions and official game data were expressed in absolute values (load) – to translate and compare the demands of the official match sessions total load and the training routines.

Table 13. *EL variables recorded in this study.*

Type	Variable	Sub-variable	Unit	Description
Kinematics	Distance covered		DT (m)	Total distance skated in meters
		Moderate-Speed Skating	(12.1 – 12 km/h) MSS (m)	Total distance skated between 12.1 and 18 km/h
		High-Speed Skating	(18.1 – 30 km/h) HSS (m)	Total distance skated between 18.1 and 30 km/h
Mechanicals	High-intensity Impacts	Total	HImpt (n)	Total number of impacts recorded between 8 and 10 *g*
	Player Load	Total	PL (a.u.)	Accumulated accelerometer load in the three axes of movement
	Accelerations	Total	ACC/ [3 10]m/s² (n)	Total number of positive speed changes
	Decelerations	Total	DEC/ [-10 -3]m/s² (n)	Total number of negative speed changes

6.2.5 Internal Load Variables (IL)

Individual player´s rating of perceived exertion (RPE) was collected using a visual Borg category (0-10) scale, obtained approximately 30 mins after each in-court training and official game session, ensuring that the perceived effort reflected the whole session and not the most intense exercise (Impellizzeri et al., 2004). The overall TL was described by the session-RPE, which was calculated by multiplying the RPE score (0-10 AU) by the individual session´s duration (in minutes, excluding game warm-up) (Foster et al., 2001) in line with previous research in elite male Rink Hockey athletes (D. Fernández et al., 2021).

6.2.6 Statistical Analysis

All statistical analyses were conducted using IBM SPSS Statistics for Windows, (Version 20.0. Armonk, NY: IBM Corp.) Descriptive statistics (range, mean, standard error of the mean, and standard deviation) were calculated for the overall sample. Training and games were grouped by weeks (microcycles) according to previous descriptions (TW-2; TW-1 and CW). Also, training sessions were grouped according to the days distancing the training matches during the TW-2 and the TW-1 (e.g., TMD-3; TMD-2; TMD-1, and TMD). Data normality was tested by the Shapiro-Wilk test. To compare the differences between EL and IL across the weeks and the training days a two-way mixed design analysis of variance (ANOVA) was conducted. The Bonferroni method was used for multiple pairwise comparisons. The Kruskal-Wallis test was performed for variables with non-normally distributed data. Additionally, Cohen's *d* effect size analysis was used to determine the magnitude of effect, whenever the ANOVA test was used and was interpreted based on the following criteria: 0-0.20, trivial; 0.21-0.60, small; 0.61-1.20 moderate; 1.21-2.00, large; >2.00, very large (Hopkins et al., 2009b). In cases where the Kruskal-Wallis test was used, η^2 was obtained and the interpretation of the effect size was based on the following criteria: <0.01 no effect, <0.0-0.05 small effect, 0.06-0.13 moderate effect, and ≥0.14 large effect (Fritz et al., 2012b). In the presented results, the effect size was reported only where significant (p≤0.05) differences were found. Finally, to understand the relationship between players' EL and IL during training sessions and competitive matches a Spearman correlation test was performed.

6.3 Results

The analysis of training weeks revealed a general decrease in all the variables from TMD-3 to TMD-1. Significant differences (p≤0.05) were also observed between TMD-3 and TMD-2 in comparison with TMD-1 for PL. Further, significant differences (p≤0.05) were observed between TMD-3 and TMD-1 for DT and HSS (Table 2).

The comparison between training matches (TMD) and training sessions (TMD-3 to TMD-1) during the weeks TW-2 and TW-1 revealed that the total duration of the session (DS) and all EL and IL variables of TMD were significantly (p≤0.05) higher than in TMD-3, TMD-2, and TMD-1 (Table 2).

Table 14. *External load and IL metrics between training sessions and training matches (TMD) across TW-2 and TW-1*

Variable	**TMD-3 (*n*=35)**	**TMD-2 (*n*=32)**	**TMD-1 (*n*=39)**	**TMD (*n*=34)**	***Effect Size***	
	Value [95%CI]	Value [95%CI]	Value [95%CI]	Value [95%CI]	Value	Qual.
DS (min)	84±7.46 [81.44-86.56]	85.78±12.19 [81.39-90.18]	74.49±23.31 [66.93-82.04]	119.71±7.17 [117.20-122.21] # ** θ	# 0.86^{§2} ** 0.84^{§2} θ 1.07^{§2}	large large large
DT (ms)	7,586.59±1,113.74 [7,195.88-7,977.30] θ	7,122.66±1,894.09 [6,439.77-7,805.55]	6,221.13±1,590.34 [5,705.60-6,736.66]	9,055±874.72 [8,749.79-9,360.21] # ** θ	#0.65^{§2} **0.84^{§2} θ1.09^{§2}	large large large
MSS (m)	1,898.32±635.55 [1,680.01-2,116.64]	1,594.89±1,067.58 [1,209.98-1979.79]	1,571.39±596.85 [1,375.21-1,767.58]	2,145.63±408.26 [2,003.18-2,288.08] α β	α 0.69^{§1} β 1.11^{§1}	moderate moderate
HSS (m)	452.54±123.87 [409.98-495.09] θ	413.81±244.81 [325.54-502.07]	281.13±185.10 [221.12-341.13]	573.30±162.70 [516.52-630.06] α θ	θ 1.08^{§1} α 0.77^{§1} θ 1.67^{§1}	moderate moderate big
HImpt (n)	0.40±0.65 [0.93-1.93]	0.47±0.88 [0.70-1.49]	0.46±0.85 [0.85-2.07]	3.12±2.53 [3.30-6.06] * ** θ	* 0.45^{§2} ** 0.50^{§2} θ 0.48^{§2}	large large large
PL (a.u.)	35.68±6.37 [33.49-37.87] β	35.06±8.97 [31.82-38.29] β	29.79±7.59 [27.33-32.26]	45.49±5.81 [43.47-47.52] # ** θ	β 0.84^{§1} β 0.64^{§1} # 1.61^{§1} ** 1.39^{§1} θ 2.30^{§1}	moderate moderate big big very big
ACC (n)	116±31.19 [105.28-126.72]	102.59±40.27 [88.08-117.11]	89.08±40.90 [75.82-102.33]	157.59±54.84 [138.45-176.72] * ** θ	* 0.37^{§2} ** 0.48^{§2} θ 0.65^{§2}	large large large
DEC (n)	77.43±23.71 [69.28-85.57]	70.03±32.22 [58.42-81.65]	57.38±31.67 [47.12-67.65]	104.15±31.77 [93.06-115.23] * ** θ	* 0.96^{§1} ** 1.07^{§1} θ 1.48^{§1}	moderate moderate big
Declared RPE (0-10 scale)	5.71±1.82 [5.09-6.34]	5.19±2.48 [4.29-6.08]	4.87±1.96 [4.24-5.51]	7.24±1.37 [6.76-7.71] * α θ	* 0.36^{§2} α 0.45^{§2} θ 0.56^{§2}	large large large

s-RPE (a.u)	485.29±175.72 [424.92-545.65]	468.75±271.63 [370.82-566.68]	392.31±228.47 [318.25-466.37]	868.82±182.84 [805.03-932.62] # ** θ	# 0.64§2	large
					** 0.67§2	large
					θ 0.82§2	large

**Significantly higher than TMD-3 (p≤0.05); # significantly higher than TMD-3 (p≤0.001); α significantly higher than TMD-2 (p≤0.05); **significantly higher than TMD-2 (p≤0.001); β Significantly higher than TMD-1 (p≤0.05);* θ *Significantly higher than TMD-1 (p≤0.001);* §1 – Cohen's *d*; §2 - *η*2

DS, total duration of the session; DT, distance travelled; MSS, moderate-speed skating; HSS, high-speed skating; HImpt, number of high-impacts; PL, Player Load; ACC, high-intensity accelerations; DEC, high-intensity decelerations; RPE, rating of perceived exertion; s-RPE, sessional-RPE; TMD-3, 3 training sessions before the training game; TMD-2, 2 training sessions before the training game; TMD-1, 1 training sessions before the training match; TMD, training match day.

The analysis between training (TW-2 and TW-1) and competition (CW) weeks revealed significant differences (p≤0.05) in all metrics with higher values for CW when compared to both TW-2 and TW-1. TW-2 revealed higher significant values (p≤0.05) in IL metrics RPE and s-RPE and in EL metric (DT) in comparison with the TW-1 (table 3). In opposition, TW-1 revealed higher significant values (p≤0.05) in EL metric ACC in comparison with the TW-2 (Table 3). No other differences were observed in EL variables between TW-2 and TW-1.

***Table 15**. Comparison of the average metrics for the EL and IL during the preparation and competition weeks*

Variable	Total (*n*=165)	TW-2 (*n*=63)	TW-1 (*n*=77)	CW (*n*=25)	*Effect Size*	
	Value [95%CI]	Value [95%CI]	Value [95%CI]	Value [95%CI]	Value	Qual.
DS (min)	92.64±21.82 [89.28-95.99]	98.57±19.49 [93.66-103.48] #	83.77±22.61 [78.63-88.90]	105±12.24 [99.94-110-06] #	# 0.31§2	large
					# 0.44§2	large
DT (ms)	7,675.48±1,825.40 [7,394.89-7,956.08]	7,504.5±1,556.47 [7,112.51-7,896,50]	7,417.50±1,907.91 [6,984.70-7,850.78]	8,900.20±1,769.87 [8,169.72-9,630.67] ***β*** *	***β*** 0.40§2	large
					* 0.33§2	large
MSS (m)	1847.14±721.62 [1,735.87-1,958.40]	1,831.12±535.02 [1,695.25-1,966.99]	1,774.19±872.87 [1,576.07-1,972.31]	2,111.54±553.06 [1,883.25-2,339.84]	-	-
HSS (m)	463.65±229.93 [428.31-499]	431.97±209.07 [379.32-484.63]	419.77±212.29 [371.59-467.96]	678.65±220.63 [587.58-769.72] **θ** #	***θ*** 1.16§1	moderate
					# 1.21§1	big
HImpt (n)	3.70±5.29 [2.89-4.52]	2.44±2.97 [1.68-3.19]	1.94±2.55 [1.35-2.52]	11.24±7.08 [9.19-15.37] **θ** #	***θ*** 0.67§2	large
					#0.64§2	large
PL (a.u.)	37.81±9.85 [36.30-39.33]	37.28±8.91 [35.04-39.53]	35.46±9.41 [33.33-37.60]	46.40±9.08 [42.67-50.16] **θ** #	***θ*** 1.02§1	moderate
					# 1.18	moderate
ACC (n)	126.53±55.36	102.25±44.33	126.40±52.92	188.12±46.52	***β*** 0.22§2	large

	[118.02-135.04]	[91.84-112.66]	[114.39-138.41] **β**	[168.92-207.32] **θ** *	***θ*** 0.69§2 * 0.47§2	large large
DEC (n)	83.47±37.58 [77.69-89.24]	70.24±35.38 [61.33-79.15]	81.88±32.84 [74.43-89.34]	121.68±31.85 [108.53-134.83] ***β*** *	***β*** 1.49§1 * 1.22§1	big big
Declared RPE (0-10)	5.92±2.20 [5.58-6.26]	6.24±2.12 [5.70-6.77] *	5.31±2.04 [4.85-5.78]	7±2.34 [6.03-7.97] *	*0.21§2 *0.35§2	moderate large
s-RPE (a.u)	579.42±294.67 [534.13-624.72]	637.30±282.12 [566.25-708.35] *	476.30±265.91 [415.94-536.65]	579.42±294.67 [627.25-875.15] #	* 0.27§2 # 0.39§2	small small

**Significantly higher than TW-1 (p≤0.05); # significantly higher than TW-1 (p≤0.001) β Significantly higher than TW-2 (p≤0.05); θ Significantly higher than TW-2 (p≤0.001);* §1 – Cohen's d; §2 - η^2

DS, Total duration of the session; DT, Distance travelled; MSS, Moderate-speed skating; HSS, High-speed skating; HImpt, Number of high-impacts; PL, Player Load; ACC, High-intense accelerations; DEC, High-intense decelerations; RPE, rating of perceived exertions; s-RPE, Rate of perceived exertion x total duration of the session; TW-2, Two Training weeks until the competition week; TW-1, One Training week until the competition week; CW, Competition week.

The analysis of the correlations between EL and IL variables revealed different relations for TW-2 and TW-1 in comparison with CW. While TW-2 and TW-1 revealed significant correlations between all EL variables and the IL (s_RPE) the CW only revealed significant correlations between HImpt and DEC. Additionally, HImpt demonstrated lower correlations with s-RPE in TW-2 and TW-1 when compared to CW. Interestingly, CW also revealed a tendency to negative correlations (p≥0.05) between DT, MSS and HSS, and s-RPE.

Table 16*. Spearman Correlation Matrix between EL and IL metrics from TW-2 until CW*

	TW-2	TW-1	CW
	s_RPE	s_RPE	s_RPE
	r [95% C.I]	*r* [95% C.I]	*r* [95% C.I]
DT (m)	0.69** [0.53-0.80]	0.67** [0.52-0.78]	-0.10 [-0.47-0.30]
MSS (m)	0.57** [0.37-0.71]	0.46** [0.26-0.62]	-0.20 [-0.55-0.21]
HSS (m)	0.49** [0.28-0.66]	0.63** [0.47-0.75]	-0.23 [-0.57-0.18]
HImpt (n)	0.35** [0.11-0.55]	0.32** [0.10-0.51]	0.64** [0.33-0.83]
PL (a.u.)	0.69** [0.53-0.80]	0.65** [0.50-0.76]	0.08 [-0.33-0.46]
ACC (n)	0.72** [0.57-0.82]	0.52** [0.34-0.67]	0.39 [-0.01-0.68]
DEC (n)	0.71** [0.56-0.81]	0.60** [0.43-0.73]	0.43* [0.04-0.70]

*$p\leq0.05$; **$p<0.001$

DT, Distance travelled; MSS, Moderate-speed skating; HSS, High-speed skating; HImpt, Number of high-impacts; PL, Player Load; ACC, High-intense accelerations; DEC, High-intense decelerations; RPE, Declared rate of perceived exertions; s-RPE, Rate of perceived exertion x total duration of the session; TW, Training week; CW, Competition week.

6.4 Discussion

The present study aimed to understand the dynamics of external and internal load across the training sessions of the two weeks of preparations and the competition week of the male 2021 Rink Hockey European Championship. According to our expectations, during the training weeks, the management of the training load was developed with reference to the TMD, both in TW-2 and TW-1 with a wavy dynamic. Also, while TW-2 was characterized by high levels of RPE, s-RPE, and DT, TW-1 was characterized by high levels of ACC. In opposition, a different relationship was observed between EL and IL both in TW-2 and TW-1 when compared to CW, revealing that the training process seems to not sample the demands of the competitive matches. Thus, results generally support the idea that the competition week was not only more demanding but also promoted unexpectedly different kinematic and mechanical stress with impact in IL in relation to competition demands suggesting that training also did not fully replicate the demands of competitive matches by missing specific metrics such DEC and HImpt.

In line with previous research in an elite rink hockey club (Fernández et al., 2021), results revealed that DT, PL, and HSS were higher in TMD-3 in comparison with TMD-2 and TMD-1. As observed in other sports (soccer and futsal), this decrease of kinematics (DT and HSS) and mechanical (PL) metrics before the TMD, suggests a tapering strategy in which EL metrics tend to decrease as a match day approaches (Illa et al., 2020; Martín-García et al., 2018). Regarding the load dynamics of an elite rink hockey team that competes regularly, Fernández et al. (2021) have reported an inverted "*U-shape*" with higher EL and IL values on MD-3 and MD-2 during each microcycle. In this sense, and regardless of the tapering strategy, our results describe a different load dynamic than previously reported by Fernández et al., (2021). We believe that this may be related to the different structures of each championship and the strategy used to improve athletes' physiological adaptation as suggested by Tarragó et al., (2019). Accordingly, the number of matches per week, the days between matches, and the physical condition of the team, may impact the structure of the microcycle throughout a specific season (Tarragó et al., 2019).

In other indoor team sports, such as futsal (Illa et al., 2020) and soccer (Martín-García et al., 2018), MD-3 and MD-2 seem to establish a parallelism with the match day, by following the demands of training to those of the competition. Although in our study TMD-3 present higher values when compared to TMD-2 and TMD-1, they were nevertheless lower when compared to TMD values. The lack of information regarding match demands in rink hockey may contribute to such differences.

According to Halson (2014), training loads may be adjusted to each training cycle to either increase or decrease fatigue levels corresponding to a specific phase of training, such as baseline or competition. In our results, EL variables and DS presented higher values in TW-2 than in TW-1, associated with higher IL values of RPE and s-RPE, possibly revealing an attempt of tapering in the week before the competition (Fernández et al., 2021). To optimize training and competition adaptations, it is important to ensure the delay of the onset of acute and chronic fatigue development. Consequently, large dissociations between EL and IL may reveal an athlete´s state of fatigue (Halson, 2014). As such, since we did not observe significant differences in EL metrics between TW-2 and TW-1, we believe that the higher values of RPE and s-RPE observed in TW-2 when compared to TW-1 and CW, may have been influenced by the DS and not so much by EL variations. Moreover, we may infer that, at this stage of preparation, the volume of the training session has a higher impact on IL metrics than does intensity. With the exception of ACC, which was greater in TW-1 when compared to TW-2, statistical differences between TW-2 and TW-1 were not observed with other kinematic and mechanical metrics. Thus, it means that the possible attempt of tapering was promoted particularly based on the decrease in DS (Halson, 2014), and maintaining the intensity and structure of the training process.

As expected, CW EL and IL were significantly higher than in both TW-2 and TW-1. Once training is concerned with the planning, design, execution, and control of the tasks (Tarragó et al., 2019), these results may suggest the need for training optimization by adapting tasks to be performed in an environment that requires similar kinematics and mechanics demands as occurs in the game. There is a need to further understand the dynamics between exercises allowing to reach high kinematic and mechanic game demands, while promoting at the same time readiness for the competition at the right time.

An additional critical finding of this study is the characterization of demanding metrics related to an official international rink hockey match. It has been already reported that HSS, ACC, and DEC are the EL variables that better characterize the most demanding efforts in this sport (Fernández et al., 2021). Our results are aligned with that. However, it seems that PL is much higher in our study than in previous studies (Fernández et al., 2021), which may be explained by the playing time of each player, with fewer player interchange rotations than in a team that competes regularly. Thus, further research regarding this relationship may bring new insights concerning the impact of the number of player interchange rotations and playing time on athletes' fatigue development and, consequently, their performance.

One of the major findings in our study was the analysis of the relationship between EL and IL variables between training and competition weeks. Results revealed that, in opposition to the training weeks, in competitive matches, the number of HImpt presented a high value of correlation with s-RPE. To the best of our knowledge, there are no other studies that analysed HImpt in rink hockey games. This new information possibly supports the idea that the training drills used and the structure of the training sessions do not fully represent game demands (Fernández et al., 2021). This fact corroborates the need to understand the game demands seeking to create adjusted cycles of load modification, particularly increased frequency, duration, and intensity, as reported by Halson (2014). Additionally, it may also be important to understand how training drills are characterized in order to understand which drills may replicate the competition environment.

Finally, the impact of training sessions and competition matches on the EL and IL of players was analysed. Results highlighted that while in training sessions, all external load variables were related to the s-RPE, in the competition only the number of HImpt [8-10g] and the number of DEC were related to the s-RPE. Such differences between training and competition cycles distinguish the metrics that may be analysed to enhance players' performance. The impact of HImpt and DEC on s-RPE allows us to characterize rink hockey as a sport with high neuromuscular demand, as previously observed (Fernández et al., 2021). The influence of DEC and HImpt (>3g) have been previously reported in a collision team sport (Australian Football) as strong predictors of post-match creatine kinase (CK) levels and consequently as strong indicators of muscle damage (Gastin et al., 2019). Thus, such variables can be used as good metrics to monitor the tapering process followed, particularly on the day before the competition. However, in this work, the fact that HImpt and DEC were not highly represented during the training process may induce in athletes additional efforts related to the neuromuscular system for this fast and explosive action (Andersen & Aagaard, 2010). This mechanical variation has already been suggested as a factor of athletes' emotional exhaustion, constraining the conventional model of training load monitoring mainly because of the game´s unpredictability (Coyne et al., 2018). Consequently, it is legitim to suggest that these results may open a new perspective on the monitoring of training loads (TL). It has already been suggested that there is a need to understand the EL variables that impact athletes under training and competition constraints in order to develop a more accurate strategy to better comprehend how physiological adaptations can be promoted during training based on competition demands (Ferraz et al., 2023). According to some authors, biomechanical adaptations occur in musculoskeletal tissues due to mechanical stress (Coyne et al., 2018; Vanrenterghem et al., 2017). Therefore, as a result of the influence of HImpt on rink hockey players' IL (s_RPE) during the competition, we may consider HImpt to be a (Bio)mechanical EL variable (Coyne et al., 2018) that led to a perception of how difficult a training/competition session is. Finally, based on our findings and this monitoring approach, we can suggest that RPE likely reflects both types of IL (physiological and biomechanical stress) and should be monitored in an integrative way, defining the metrics (EL and IL) that best translate the physiological and biomechanical efforts. Notwithstanding the importance of understanding how EL and IL fluctuate and contrast across training microcycles and competitions, we acknowledge the potential limitations of the present investigation related to the sample size of players and the number of matches, which should be larger to increase the power of the results (Lupo & Tessitore, 2016). Therefore, further research should be developed considering different teams and their specific competitive context. Also, clustering EL demands per minute in training, while categorizing specific rink hockey drills and comparing them to competition, could further improve the knowledge of rink hockey training actions/density and how it impacts official matches.

6.5 Conclusions

In this study, different load dynamics were reported during the preparation of an elite male rink hockey for an international championship, which is in accordance with tapering strategies. However, training sessions do not translate the game demands, and HImpt followed by DEC has a greater influence on s-RPE during competition. Yet, these findings offer a novel perspective on the tracking of training loads (TL).

6.6 Practical Applications

The transfer of this evidence to the training process is significant; in so far 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 to optimize players' performance and reduce the risk of injury. Also, our findings can underpin considerations to identify the best variables that characterize rink hockey demands for the definition of dedicated monitoring tools, as well as for strategies of benchmarking between teams of different competitive levels. Finally, if the goal is to replicate the mechanical demands of competition, rink hockey training should be reviewed, and coaches should prescribe drills that contain a greater number of HImpt and DEC efforts. These changes may be necessary in order to better prepare athletes to deal with match-play challenges.

7. Bridging the Gap between Training and Competition in Elite Rink Hockey: A Pilot Study

Ferraz A, Pérez-Chao EA, Ribeiro J, Spyrou K, Freitas TT, Valente-Dos-Santos J, Duarte-Mendes P, Alcaraz PE, Travassos B. Bridging the Gap Between Training and Competition in Elite Rink Hockey: A Pilot Study. Sports Health. 2025 Jan-Feb;17(1):57-65. doi: 10.1177/19417381241273219. Epub 2024 Aug 27. PMID: 39189414; PMCID: PMC11569628.

7.1 Introduction

Team-sports, such as rink hockey, require players to perform several high-intensity efforts that include accelerations (ACC), decelerations (DEC), changes of direction, collisions, and short- and long-duration movements (e.g., medium- and high-speed distance), followed by short recovery intervals, which impose significant physiological, biomechanical, and psychological demands (Ferraz et al., 2020). In order for players to respond effectively to these demands, coaches and sports scientists must adjust the training to improve, among other things, their athletes' physical preparation accordingly (Fernández et al., 2021; Pizarro et al., 2021).

In this regard, proper quantification of competition and training load (TL) is a critical part of the process as it allows: i) understanding players' performance during match-play; ii) determining how well they are adjusting to training stimuli; and iii) assessing whether training regimens actually resemble, and replicate competition demands (Hausler et al., 2016). The use of time-motion tracking and heart rate (HR) monitoring has become a commonly employed approach to quantifying competition and TL through measures of external load (EL) and internal load (IL) (Lovell et al., 2013). The use of such measures allows to understand and monitor the relationship between the dose and response to properly manage fatigue and recovery and promote the readiness of players for the competition (Fernández et al., 2021; Hulka et al., 2020).

According to Rossi (Rossi et al., 2018), EL is considered as the dose, and is usually categorized into three main groups based on its nature: i) kinematics, which quantifies the total energy expended by movement during exercise (e.g., total distance [m]); ii) mechanical, which describes the player's overall load during exercise (e.g., ACC (n)); and iii) metabolic, which measures the total amount of energy expended during exercise (e.g., Metabolic Power). Complementarily, IL is defined as the response, and has been used to understand the physiological responses of players to EL (Rago et al., 2021), usually through rating of perceived exertion (Impellizzeri et al., 2019) or HR measures (Achten & Jeukendrup, 2003). Besides the common use of these metrics, a different approach that considers distinct physiological and biomechanical load-adaptation processes has been proposed by different authors (Coyne et al., 2018; Vanrenterghem et al., 2017) and that combines potential physiological efforts such as the combination of HR values (i.e., IL) with kinematic and mechanical (i.e., EL) metrics (e.g., ACC and DEC).

Particularly in rink hockey, recent research has been developed under this approach to assess the demands of training and competition (Fernández et al., 2021, 2023; D. Fernández, Fernández, et al., 2020), mainly through the global characterization of EL and IL. For example, Fernández et al. (Fernández et al., 2021) reported that high-speed skating (HSS >18km/h), ACC, and DEC were the EL variables that better characterized the most demanding efforts in this sport and that match-day (MD)-4 and MD-1 sessions tended to place athletes in a "low EL and IL" zone. Conversely, in MD-3 and MD-2 sessions, as well as in MD, where greater loads were recorded (i.e., ACC from 3 to 10 m/s^2, DEC from -10 to -3 m/s^2 and HSS >18Km/h), the majority of the players were found to be in a "high EL and IL" zone, with a tendency to disperse towards the fitness or tiredness zones (Fernández et al., 2021). Noteworthy, peak demands in rink hockey have been defined as position-dependent, with exterior players covering more distance and inside players performing more ACC, supporting the importance of using such metrics for the physical improvement of players with more exterior and interior tactical actions, respectively (Fernández et al., 2023). Still, despite these studies, further research is needed to better understand the different EL dimensions (i.e., kinematic, mechanic, and metabolic) and their relationship with IL during match-play.

Regarding training, previous rink hockey studies have described the fluctuations in intensity between and within microcycles (Fernández et al., 2023). However, only a general description of the training session as a whole, has been provided. Consequently, it does not allow a clear understanding of the demands of each specific exercise and its contribution to TL, or whether training drills replicate official match demands. For instance, as already verified in other team-sports (i.e., futsal) (Rico-González et al., 2022), it is conceivable that different training exercises may have a different impact on players' load and, consequently, in their preparation. As such, understanding the dose-response effects of exercises typically prescribed (Rico-González et al., 2022), and how they compare to match demands (Fernández et al., 2023; Lin et al., 2023), may enhance current knowledge in rink hockey and contribute to the optimization of the training process by highlighting specific adjustments that can be made to exercise or microcycle design.

Therefore, this study aimed to propose an applied approach to characterize and classify the training task specificity in relation to competition in a top-level rink hockey team.

Using a quadrant-based classification system, it was expected that this method would allow classifying training tasks and games according to physiological and biomechanical load, assisting sports scientists and coaches in improving load management and defining the best exercises according to their goals.

7.2 Materials and Methods

7.2.1 Study Design

An observational study was conducted during two consecutive microcycles (from March 21st to April 2nd of 2022) of a team competing in the 1st Division of the Portuguese rink hockey's League. Since the tracking system's antennas were not permitted at the opponents' pavilion, the two weeks were chosen based on the availability of the team and the competition schedule in order to monitor two sequential training microcycles and official home games. In total, players participated in 8 training sessions and 2 official games during the two weeks of the study. A non-experimental descriptive method was used to characterize the training drills of the different sessions (i.e., MD-4; MD-3; MD-2; MD-1) and official games (i.e., MD1; MD2). The exercises performed during the training sessions and games were split and categorized according to specific criteria (Rico-González et al., 2022): introductory technique-activation exercises (INT); analytical situations (ANLT); mid-court exercises (20×20m) (EX.MD); ¾ of the court exercises (15×18m) (EX.IN¾); full-court exercises (20×40m) (EX.FC); superiorities/inferiorities (EX.S/I); and official games considering effective (GM.EFF) or running time (GM.RUN) (Table 1). During the data collection, no instruction was given to the technical staff regarding exercise selection or in-match coaching decisions.

Table 17. *Task description for each analysed category.*

Exercise categories		Task description
INT	Introductory technique - activation exercises	✓ Skating activation with changes of direction ✓ Manipulate the stick with the ball, associating passes with/without opposition ✓ 1x1 ✓ Upper- and lower-body activation ✓ Goalkeeper warm-up ✓ Strength exercises ✓ Proprioception exercises
ANLT	Analytical situations	✓ Analytical, tactical movements with/without opponents with passes, specific changes of direction, and finalization (i.e., shooting) ✓ Changes of position while skating and passing, finishing with a shot on goal from different positions ✓ Shot on goal from the penalty spot/free kick
EX.MD	Mid-court exercises (20×20m)	✓ Game with/without goalkeeper in 2vs2; 3vs3; and 4vs4 formats
EX.IN¾	¾ of the court exercises (15×18m)	✓ Game (1vs1and 2vs2) with/without goalkeeper
EX.FC	Full-court exercises (20×40m)	✓ Game (3vs3 and 4vs4) ✓ Exercises involving both attacking and defensive actions (counterattack)
EX.S/I	Superiorities/inferiorities	✓ Situations with numerical superiorities/inferiorities
GM.EFF	Official Game	✓ Effective time registered
GM.RUN	Official Game	✓ Running time registered

Participants

Data from a convenience sample of ten elite-level male rink hockey players (4 defenders/midfielders and 6 forwards; age = 27.4 ± 5.5 years old, height = 174.8 ± 2.8 cm, body mass = 74.92 ± 2.83 kg, body mass index = 24.53 ± 0.95 kg/m^2) competing at the Portuguese elite national championship that participated voluntarily in the study were collected. These world-class athletes compete in one of the leading European teams in the most prestigious rink hockey league (Arboix-Alió et al., 2019). Goalkeepers were not included in the analysis because of the different training categories and match demands. Players were considered for inclusion if they: i) had no injury or court time limitation during the data collection period; ii) completed the entire training session or game. Throughout the data collection period, no athletes were dropped from the study.

7.2.2 Ethics statement

Data collection was carried out according to the international ethical standards with humans based on the Declaration of Helsinki (Harriss et al., 2019) after approval by the Ethics Committee of the Universidade da Beira Interior (CE-UBI-Pj-2019-053:ID1519). After being apprised of the protocol and procedures, all participants signed written informed consent forms. Participation was voluntary, and each participant could withdraw at any time. To ensure player confidentiality, all data were anonymized prior to the analysis.

7.2.3 Procedures

Data collection related to players´ activity during in-court sessions with skates was carried out with Inertial Movement Units (IMUs) using an ultra-wideband (UWB) local positioning system (LPS) technology from WIMU PRO™ (Realtrack Systems SL, Almeria, Spain). HR data was collected by using one GARMIN HRM-PRO chest strap (Garmin Ltd., Olathe, KS, USA) located below the chest. Also, training and matches were recorded on video. All data from WIMU and GARMIN were downloaded using their corresponding software (SPRO™, Realtrack Systems SL, version 986) and synchronized with the video.

The WIMU PRO™ is equipped with four 3D accelerometers (full-scale out output ranges are ± 16 g, ± 16 g, ± 32 g, and 400 g; 100 Hz sample frequency), three gyroscopes (8000° /s full-scale out output range; 100 Hz sample frequency), a 3D magnetometer (100 Hz sample frequency), a GPS (10 Hz sample frequency), and a UWB (18 Hz sample frequency) (Fernández et al., 2021; Impellizzeri et al., 2004). The devices were turned on 5-10 min before the warm-up began and placed in a tight-fitting harness in the upper part of the athlete's back. Six antennas with UWB technology were fixed ± 5 m to the court. The LPS system works by triangulating the LPS unit devices and the antennas and determining the unit's position (X and Y coordinates) by using one of the antennas as a reference. The accuracy and reliability of the WIMU devices have been previously reported and validated (Bastida-Castillo et al., 2019). To evaluate the GM.EFF and GM.RUN, an interactive program (Breakaway Time Rink Hockey, Sports Performance Analytic Inc., Toronto, Canada) was used to accurately calculate the time period during which players were actively engaged in the game versus the time when the game was paused.

From the collected data, EL and IL parameters were classified into physiological and biomechanical variables (Coyne et al., 2018) (Table 2). The physiological variables recorded were average HR, maximum HR, HSS, medium-speed skating, and TDS. The biomechanical variables consisted of the number of high-intensity impacts, high-intensity DEC, high-intensity ACC, and Player Load (see Table 2). In order to translate and contrast the demands of the overall load of official matches and training sessions, data were expressed as relative values per minute (min^{-1}).

Table 18. *Physiological and Biomechanical variables recorded in this study.*

Type	Variable	Unit	Description
Time of practice	Duration of the exercise/match	TMOP (m)	Total time of practice in minutes
Physiological	Heart Rate	HR_{AVG} (bpm)	Average heart rate (bpm)
		HR_{MAX} (bpm)	Maximum heart rate (bpm)
	Total distance skating	TDSmin^{-1} (m)	Total distance skated in meters
	Moderate-Speed Skating	MSSmin^{-1}(m)	Total distance skated between 12.1 and 18 km/h per minute
	High-Speed Skating	HSSmin^{-1}(m)	Total distance skated between 18.1 and 30 km/h per minute
Biomechanical	High-Intensity Impacts	HIMPCTSmin^{-1}(g)	Total number of impacts recorded between 8 and 10 *g* per minute
	Player Load	PLmin^{-1}(a.u.)	Accumulated accelerometer load in the three axes of movement per minute
	High-Intensity Accelerations	ACCmin^{-1} (m)/ [3 10]m/s^2 (n)	Total number of positive speed changes per minute
	High-Intensity Decelerations	DECmin^{-1}(m) [-10 - 3]m/s^2 (n)	Total number of negative speed changes per minute

Time of Practice (TMOP (min)); Heart rate average (HR_{AVG}; Maximum heart rate (HR_{MAX}); High-speed skating per minute (HSSmin^{-1}(m)); Medium-speed skating per minute (MSSmin^{-1}(m)); Total distance skated per minute (TDSmin^{-1} (m)); High Impacts per minute (HIMPCTSmin^{-1}(g)); Number of Decelerations per minute (DECmin^{-1}(m)).

7.2.4 Statistical analysis

Based on a prior power analysis through G*Power (3.1.9.2) (Cohen's d effect size [ES] of 0.8, probability of error of 0.05, and power of 0.8), a sample size of 8 rink hockey players was required (Hulka et al., 2020). Descriptive statistics (range, mean, standard error of the mean, and standard deviation) were calculated for the overall sample.

A linear mixed model with random intercepts was used to compare EL and IL differences between the analysed training and match categories, accounting for individual repeated measures. External (TDSmin^{-1}; MSSmin^{-1}; HSSmin^{-1}; HIMPCTSmin^{-1}; ACCmin^{-1};

DECmin^{-1}) and internal (HR_{AVG} and HR_{MAX}) loads were included as fixed effects, subjects were included as random effects, and the training and game categories were treated as a continuous variable. The distribution of the residuals was examined after fitting linear mixed model (Bates et al., 2015). Cohen's d ES and 95% confidence intervals (CI) were calculated and interpreted as follows: <0.2 trivial; 0.20–0.59 small; 0.60–1.19 moderate; 1.2–1.99 large; and ≥2.0 very large (Hopkins et al., 2009b). The significance level was set at $p<0.05$. Additionally, a two-step cluster analysis was performed to classify the training and game categories based on physiological and biomechanical load employing log-likelihood as the distance measure and Schwartz`s Bayesian criterion (McNabb, 2018). Finally, to determine the physiological load of each training task, an average was calculated for each training and game category based on the numerical load value of the cluster ranging from 1 to 2. The same was performed to determine the biomechanical load based on the biomechanical numerical load value of the cluster ranging from 1 to 3.

The statistical analysis was conducted using the statistical package Jamovi (version 1.8, 2021) for the linear mixed model analysis and IBM SPSS Statistics for Windows (Version 28.0. Armonk, NY: IBM Corp.) for the two-step cluster analysis.

7.3 Results

Table 3 presents the descriptive statistics and the results of the linear mixed model analysis for the physiological and biomechanical variables measured in each training and game category. For all physiological and biomechanical variables, the GM.EFF and GM.RUN showed significantly ($p\leq0.001$) higher values than all the training tasks. Despite significant differences observed among almost all categories of training, EX.MD and EX.FC consistently exhibit higher values ($p\leq0.001$) across all physiological and biomechanical variables.

Regarding the physiological impact, INT and EX.IN¾ training tasks displayed low physiological impact in HR_{AVG} and HR_{MAX} in comparison with other tasks. Also, EX.IN¾ and EX.S/I displayed the lowest values of TDS and MSSmin^{-1} , and INT and EX.S/I training tasks showed lower HSSmin^{-1}. Finally, GM.EFF and GM.RUN showed significantly higher values for all physiological metrics except for HR_{AVG} between EX.MD and GM.RUN (see Table 3).

When considering the biomechanical impact, several variations occurred. For the training tasks INT, ANLT, EX.IN¾, EX.S/I, lower values of DECmin^{-1}, ACCmin^{-1}, and PLmin^{-1} were observed in comparison with the EX.MD and EX.FC tasks (Table 3). GM.EFF and GM.RUN showed significantly ($p\leq0.001$) higher values of HIMPCTmin^{-1}, DECmin^{-1}, ACCmin^{-1}, and PLmin^{-1} than all the training tasks. EX.MD and EX.FC consistently displayed higher values of PLmin^{-1} (a.u.) ($p \leq 0.001$) in relation to other training tasks except for EX.S/I. Finally, GM.EFF tended to exhibit moderately higher ($p \leq 0.05$) biomechanical impact (i.e., DECmin^{-1}, ACCmin^{-1}, and PLmin^{-1}) than GM.RUN. No differences were observed between training tasks for HIMPCTSmin^{-1}.

Table 19. *Linear Mixed Model and Description of the Physiological and Biomechanical metrics by training and match categories.*

Variables	Exercises Categories												Game				
	INT ***n*=160** **(95% CI)**	**ES**	**ANLT** ***n*=290** **(95% CI)**	**ES**	**EX.MD** ***n*=40** **(95% CI)**	**ES**	**EX. IN¾** ***n*=120** **(95% CI)**	**ES**	**EX. FC** ***n*=160** **(95% CI)**	**ES**	**EX. S/I** ***n*=60** **(95% CI)**	**ES**	**GM.EFF** ***n*=18** **(95% CI)**	**ES**	**GM.RUN** ***n*=18** **(95% CI)**	**ES**	**Total** ***n*=866**
TMOP (min)	6.68±4.25 [6.01;7.33]		5.21±3.12 [4.85;5.57]		6.15±2.59 [5.32;6.98]		5.20±2.84 [4.69;5,71]		10±4.65 [9.32;10.77]		4.80±1.24 [4.48;5.12]		23.1±10.70 [17.77;28.46]		31.7±15.00 [25.23; 39.73]		7.23±6.39 [6.80;7.66]
Physiological																	
HR_{AVG} *(bpm)*	**** # Δ α β Φ ¥** 113.67±17.31 [110.96;116.37]	0.6 0.8 0.4 1.2 0.4 0.8 0.8	**# α Φ ¥** 126.59±16.95 [124.63;128.55]	0.5 0.8 0.6 0.6	**Δ βΦ** 147.65±16.79 [142.28;153,02]	0.5 0.4 0.2	**α Φ ¥** 124.72±16.36 [121.76;127.67]	0.7 0.6 0.6	**β Φ ¥** 144.92±25.07 [141.00;148.83]	0.4 0.3 0.3	**Φ ¥** 129.95±14.64 [126.17;133.73]	0.5 0.5	163.06±10.72 [157.72;168.39]		160.06±11.24 [154.47;165.64]		129.99±22.13 [128.52;131.46]
HR_{MAX} *(bpm)*	**** # Δ α β Φ ¥** 133.24±21.69 [129.85;136.63]	0.5 0.7 0.4 1.2 0.5 0.8 0.8	**# α Φ ¥** 144.64±16.70 [142.72;146.57]	0.5 0.9 0.6 0.6	**Δ β Φ ¥** 164.35±15.01 [159.55;169.15]	0.4 0.3 0.3 0.3	**α Φ ¥** 144.82±16.06 [141.91;147.72]	0.7 0.6 0.6	**β Φ ¥** 166.03±21.89 [162.61;169.45]	0.4 0.3 0.3	**Φ ¥** 151.53±12.32 [148.35;154.72]	0.5 0.5	181.17±8.51 [176.93;185.40]		181.17±8.51 [176.93;185.40]		149.42±22.12 [147.91;150.89]
$HSSmin^{-1}(m)$	**** # α Φ ¥** 1.29±2.54 [0.89;1.68]	0.3 0.4 1.3 2.6 2.6	**α Φ ¥** 5.90±6.76 [5.12;6.68]	1.1 2.5 2.5	**α Φ ¥** 7.35±4.75 [5.83;8.87]	0.5 2.0 2.0	**α Φ ¥** 5.23±5.02 [4.31;6.14]	1.0 2.4 2.4	**β Φ ¥** 9.98±6.40 [8.98;10.97]	0.8 2.0 2.0	**Φ ¥** 4.46±4.43 [3.31;5.61]	2.3 2.3	18.14±4.33 [15.99;20.30]		13.85±3.79 [11.97;15.74]		6.09±6.49 [5.67;6.52]
$MSSmin^{-1}(m)$	**# α Φ ¥** 19.87±31.22 [15.00;24.75]	0.3 0.4 0.7 0.4	**α Φ ¥** 23.53±14.80 [21.82;25.24]	0.3 0.6 0.4	**Δ β Φ¥** 32.09±12.27 [28.17;36.02]	0.3 0.3 0.4 0.2	**α Φ ¥** 17.81±8.08 [16.35;19.27]	0.4 0.7 0.5	**β Φ ¥** 31.56±18.46 [28.68;34.45]	0.3 0.5 0.3	**Φ ¥** 18.12±15.72 [14.06;22.19]	0.6 0.4	65.66±12.98 [59.21;72.12]		49.38±14.36 [42.24;56.52]		24.98±20.69 [23.60;26.36]
$TDSmin^{-1}$ *(m)*	**Δ Φ ¥** 99.89±56.92 [91.00;108.78]	0.2 0.9 0.5	**α Φ ¥** 89.07±32.84 [85.28;92.87]	0.4 1.0 0.5	**Δ β Φ ¥** 118.67±21.45 [111.81;125.53]	0.3 0.3 0.7 0.3	**α Φ ¥** 82.24±27.01 [77.36;87.13]	0.4 1.0 0.6	**β Φ ¥** 112.16±40.30 [105.87;118.45]	0.3 0.8 0.4	**Φ ¥** 82.78±25.63 [76.16;89.40]	0.9 0.5	**¥** 238.71±125.35 [176.38;301.06	0.3	172.69±87.07 [129.39; 215.99]		100.17±50.36 [96.82;103.52]
Biomechanical																	
$HIMPCTSmin^{-1}(g)$	Φ¥ 0.01±0.03 [0.001;0.010]	1.0 0.7	**Φ¥** 0.02±0.07 [0.01;0.03]	0.9 0.6	**Φ ¥** 0.03±0.06 [0.01;0.05]	0.8 0.5	**Φ¥** 0.02±0.09 [0.008;0.040]	0.9 0.6	**Φ¥** 0.04±0.07 [0.03;0.05]	0.9 0.6	**Φ¥** 0.02±0.06 [0.001;0.035]	0.9 0.6	0.26±0.17 [0.17;0.34]		0.18±0.13 [0.12;0.25]		0.03±0.08 [0.02; 0.04]
$DECmin^{-1}(m)$	**** # Δ α Φ ¥** 1.26±1.65 [0.99;1.52]	0.3 0.4 0.4 0.5 1.0	**α Φ ¥** 1.85±1.43 [1.68;2.02]	0.3 0.9 0.6	**β Φ ¥** 2.56±1.13 [2.19;2.92]	0.2 0.7 0.4	**Φ ¥** 2.18±1.60 [1.89;2.47]	0.8 0.5	**β Φ ¥** 2.48±0.87 [2.34;2.62]	0.3 0.8 0.5	**Φ ¥** 1.53±0.85 [1.31;1.75]	0.9 0.6	**¥** 6.44±2.67 [5.11;7.77]	0.2	5.51±2.81 [3.74;5.61]		2.06±1.65 [1.95;2.17]
$ACCmin^{-1}$ *(m)*	**** # Δ α Φ ¥** 1.07±1.32 [0.87;1.28]	1.1 0.6 0.5 0.5 0.6 1.2	**Φ ¥** 1.42±1.77 [2.19;2.60]	1.0 0.7	**β Φ ¥** 2.90±1.55 [2.41;3.40]	0.3 0.8 0.5	**β Φ ¥** 2.41±1.47 [2.14;2.67]	0.2 1.0 0.7	**β Φ ¥** 2.46±0.90 [2.33;2.60]	0.3 1.0 0.7	**Φ ¥** 1.59±0.92 [1.35;1.83]	1.1 0.8	**¥** 8.12±4.06 [6.10;10.13]	0.2	7.40±4.28 [4.71;8.07]		2.33±1.98 [2.20;2.46]
$PLmin^{-1}$*(a.u.)*	**# α Φ ¥** 0.46±0.19 [0.43;0.49]	0.9 0.4 0.4 1.2 0.8	**# α £ Φ ¥** 0.49±0.16 [0.47;0.51]	0.3 0.4 1.2 0.7	**Δ Φ ¥** 0.64±0.16 [0.59;0.69]	0.3 0.8 0.4	**# α Φ ¥** 0.49±0.14 [0.46;0.52]	0.3 1.1 0.7	**Φ ¥** 0.58±0.23 [0.55;0.62]	1.0 0.6	**Φ ¥** 0.53±0.15 [0.49;0.57]	1.0 0.6	¥ 1.24±0.37 [1.05;1.42]	0.3	0.96±0.30 [0.81;1.11]		0.54±0.23 [0.52;0.55]

Data presented as mean ± standard deviation and IC

Time of Practice (TMOP (min)); Heart rate average (HRAVG; Maximum heart rate (HRMAX); High-speed skating per minute (HSSmin-1(m)); Medium-speed skating per minute (MSSmin-1(m)); Total distance skated per minute (TDSmin-1 (m)); High Impacts per minute (HIMPCTSmin-1(g)); Number of Decelerations per minute (DECmin-1(m)).

** significantly different than ANLT ($p \leq 0.05$); # significantly different than EX.MD ($p \leq 0.05$); Δ significantly different than EX. IN¾ ($p \leq 0.05$); α significantly different than EX. FC ($p \leq 0.05$); β significantly different than EX.S/I ($p \leq 0.05$); Φ significantly different than GM.EFF ($p \leq 0.05$); ¥ significantly different than GM.RUN ($p \leq 0.05$); ES: Cohen's d effect size, reported only for significant differences and not reported for repeated significant differences. Repeated statistical differences between groups were not presented.

The cluster analysis classified the physiological parameters into two distinct groups: "Low Physiological Load" and "High Physiological Load." Both clusters were strongly related to the predictor variables, with HR_{AVG}, HR_{MAX}, HSSmin^{-1}, MSSmin^{-1}, and TDSmin^{-1} having predictor´s importance of 1.00, 0.76, 0.74, 0.57 and 0.47, respectively. The average silhouette measure of cohesion and separation (representative of the clustering quality) was 0.5, which indicated a moderate model quality (Table 4).

Regarding the biomechanical load, the cluster analysis classified the categories into three distinct groups: i) "Low Biomechanical Load," ii) "Medium Biomechanical Load," and iii) "High Biomechanical Load." The clusters displayed a strong association with the predictor variables, HIMPCTSmin^{-1}, DECmin^{-1}, ACCmin^{-1}, and PLmin^{-1}, having a predictor´s importance of 1.00, 0.96, 0.81, and 0.67, respectively. The average silhouette was 0.5, indicating a moderate model quality (Table 4).

Table 20. *Cluster analysis identifying exercises groups based on physiological and biomechanical load variables.*

Cluster	Variable	Importance of the cluster predictor	Low Physiological Load	High Physiological Load
PHYSIOLOGICAL CLUSTER	*HR_{AVG} (bpm)*	1.00	117.96 ± 17.09	149.25 ± 14.28
	HR_{MAX} (bpm)	0.76	138.68 ± 19.34	166.61 ± 13.90
	HSSmin^{-1}(m)	0.74	2.91 ± 3.80	11.19 ± 6.67
	MSSmin^{-1}(m)	0.57	15.94 ± 11.93	39.46 ± 23.37
	TDSmin^{-1} (m)	0.47	79.94 ± 36.23	132.56 ± 36.23
	Sample Size (N)		533	333
	Sample Percentage (%)		61.5%	38.5%
	Bayesian information criterion (BIC)		2287.52	
	Average silhouette		0.5	

Cluster	**Variable**	**Importance of the cluster predictor**	**Low Biomechanical Load**	**Medium Biomechanical Load**	**High Biomechanical Load**
BIOMECHANICAL CLUSTER	*HIMPCTSmin^{-1}(g)*	1.00	0.01±0.02	0.03±0.06	0.27±0.15
	DECmin^{-1}(m)	0.96	0.98±0.67	3.05±1.25	4.81±2.54
	ACCmin^{-1} (m)	0.81	1.18±0.74	3.28±1.48	5.98±3.81
	PLmin^{-1}(a.u.)	0.67	0.42±0.13	0.63±0.17	0.95±0.39
	Sample Size (N)		455	359	52
	Sample Percentage (%)		52.5%	41.5%	6.0%
	Bayesian information criterion (BIC)			1428.15	
	Average silhouette			0.5	

Heart rate average (HR_{AVG}; Maximum heart rate (HR_{MAX}); High-speed skating per minute (HSSmin^{-1}(m)); Medium-speed skating per minute (MSSmin^{-1}(m)); Total distance skated per minute (TDSmin^{-1} (m); High Impacts per minute (HIMPCTSmin-1(g)); Number of Decelerations per minute (DECmin-1(m)

Based on the previously performed cluster analysis by training and game categories, Table 5 provides the descriptive physiological and biomechanical average results. GM.EFF and GM.RUN showed higher physiological and biomechanical clusters average, followed by EX.FC and EX.MD. Finally, INT, ANLT, EX.IN¾ and EX.S/I were the exercises with lower physiological and biomechanical values.

***Table 21**. Descriptive analysis of physiological and biomechanical load for each training and match category*

Training and Match Categories	Physiological Load		Biomechanical Load	
	Mean ± SD	**Median**	**Mean ± SD**	**Median**
Introductory technique - activation exercises	1.13 ± 0.34	1	1.23 ± 0.42	1
Analytical situations	1.31 ± 0.46	1	1.45 ± 0.53	1
Exercises in mid-court (20×20m)	1.70 ± 0.46	2	1.72 ±0.50	2
Exercises in ¾ of the court (15×18)	1.14 ± 0.35	1	1.48 ± 0.59	1
Exercises in full court (20×40m)	1.78 ± 0.41	2	1.76 ± 0.51	2
Superiorities/inferiorities	1.21 ± 0.41	1	1.31 ± 0.53	1
Official Game (Effective Time)	2.00 ± 0.00	2	2.94 ± 0.23	3
Official Game (Running Time)	2.00 ± 0.00	2	2.72 ±0.46	3

Considering the results from Table 5, each training and game category was classified according to the calculation of the mean value of the classification of each player in each training task. The quadrant classification (Figure 1) showed that GM.EFF and GM.RUN were the unique categories that presented high biomechanical and physiological efforts. EX.FC and EX.MD were characterized as medium-high physiological efforts and low-medium biomechanical efforts. Finally, INT, ANLT, EX. IN¾, and EX. S/I were characterized as low physiological and biomechanical efforts. Interestingly, no exercise was described as a high biomechanical and low physiological effort.

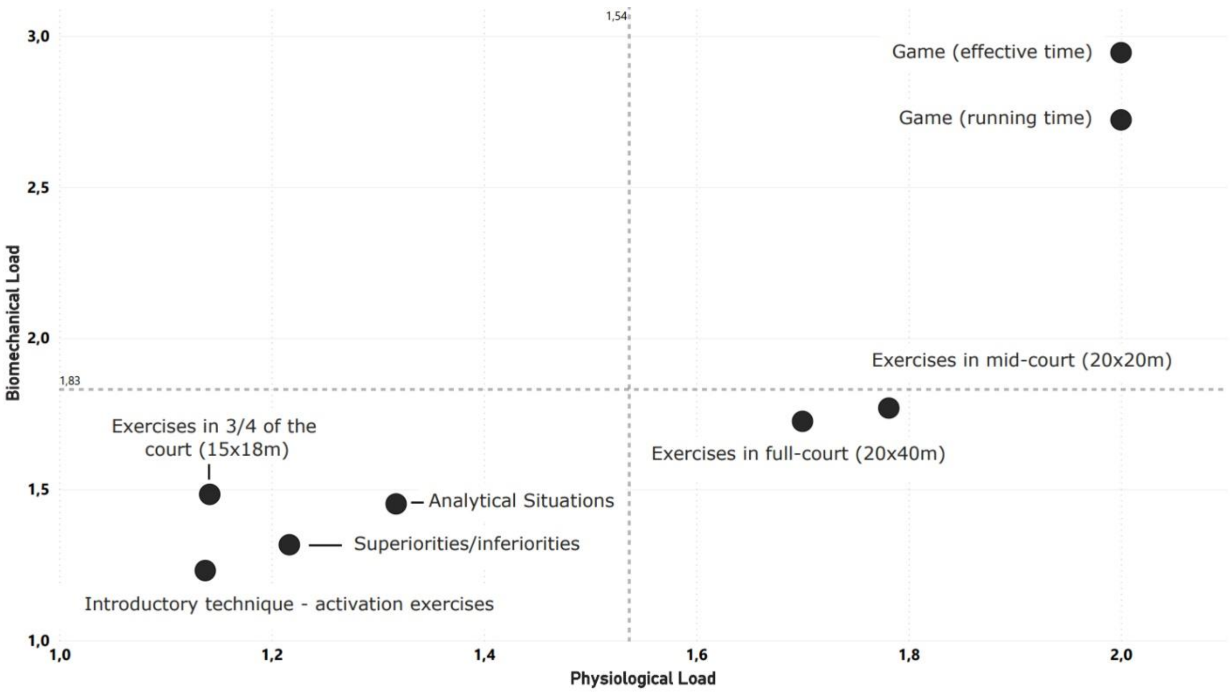

Figure 9. *Distribution quadrants of the physiological and biomechanical requirements of training exercises and the game demands*

7.4 Discussion

The aim of this study was to propose an applied approach to characterize and classify the training task specificity in relation to competition in a top-level rink hockey team. The results revealed that the training tasks didn't reach the specificity of load of the competition. The physiological and biomechanical metrics for GM.EFF and GM.RUN indicated higher demands compared to all training tasks. Furthermore, it was consistently observed, within the training tasks, that EX.MD and EX.FC exhibited significantly greater physiological and biomechanical metrics compared to the other exercises. Considering its structure and specificity, these findings provide valuable insights into the load management of rink hockey exercises and their integration in the microcycle.

Despite the concept that training tasks and sessions should be equivalent or even superior to game demands, previous research has shown that rink hockey training does not replicate the physical exigencies players experience during game-play (Fernández et al., 2021). Indeed, even though MD-3 and MD-2 have already been described as the most demanding training sessions (with the highest EL and IL of the microcycle), the training demands are still lower than the game's, compromising the specificity of the training and the preparedness of the players to face the competition demands (Fernández et al., 2021;

Fernández, et al., 2020; Gabbett, 2023). However, and despite the information regarding the differences between overall training and game demands, to the best of our knowledge, this is the first study to describe, in-depth, the specificity of training tasks in relation to competitive demands. This novel evidence-based analysis approach for the quantification of the load in elite rink hockey is detailed through relative values (per minute), outlining the compilation of EL and IL responses across various task types in comparison to the demands observed during the games. Therefore, the results herein may provide important information and contribute to a more comprehensive understanding of the impact of each training task to the preparedness of rink hockey players to face the competition (Gabbett, 2023).

It is well-established that team-sport training and competition promote physiological adaptations that improve athletic performance by contributing to the development of endurance, speed, and power (Vanrenterghem et al., 2017). Thus, identifying which metrics may lead to greater adaptations is relevant for the training process. The method presented in this study allowed us to classify each drill according to the level of physiological (i.e., low- and high-physiological load) and biomechanical (i.e., low-, medium- and high-biomechanical load) exigency and, at the same time, to clarify which variables had a greater impact in such clustering. Unsurprisingly, the results show that HR_{AVG}, HR_{MAX}, and HSS have a strong influence on rink hockey training and game physiological loads, whereas HIMPCTS, DEC, and ACC seem to be the main determinants of the biomechanical demands of this sport. This is the first time these metrics are presented in terms of a cluster predictor's relevance which may be helpful for coaches. Based on the present data, practitioners may adjust their programming (i.e., exercise selection) depending on the need to increase or decrease the physiological and biomechanical stress to be imposed on their players in each training session, as it has been already proposed in different team-sports, such as futsal (Rico-González et al., 2022) and basketball (Pino-Ortega et al., 2019). For example, in practical settings, if rink hockey coaches want to impose a high physiological stress on their athletes, EX.MD (e.g., 2vs2, 3vs3, or 4vs4 formats in a 20×20m area) may be the most suitable option.

Notably, one of the most relevant findings of the present study was that no training task was placed on the "high-biomechanical Load/ high physiological load" quadrant as occurs with the GM.EFF and GM.RUN. Moreover, no training task was characterized by simultaneously having low physiological and high biomechanical loads (Table 5 and Figure 1). In line with the low predictor's importance on the cluster analysis, the low incidence of HIMPCTS and DEC during training may have promoted a reduction in the biomechanical load experienced by the players. Based on previous research, it has been demonstrated that mechanical training stress has the ability to promote adaptations related to "fitness" or "fatigue" (Coyne et al., 2018). Therefore, it appears that modifying training task characteristics to increase the frequency of efforts that imposed high mechanical stress during training (e.g., HIMPCTS and DEC) might be a good strategy to better prepare rink hockey players to endure game-play demands (Rago et al., 2021). Additionally, the lack of specific tasks with high HIMPCTS and DEC counts may lead to lower levels of unpredictability and fatigue-inducing activities in open sports (Coyne et al., 2018) like rink hockey. In this regard, differences in the specificity between the training environment and game-play are important to account for since they may be associated with a higher level of discomfort, mental exhaustion, and greater risk of injuries during competition (Coyne et al., 2018; T. Gabbett, 2023). As argued by some authors, the main reason why injuries in team-sports are higher in competitive settings is due to the unmatched physiological demands (Castillo et al., 2021; De Pablo et al., 2022) in training sessions. Interestingly, our results may bring a new perspective to this matter by showing that, in elite rink hockey, training drills do not replicate competition demands in terms of their biomechanical load. This is a crucial aspect to consider because, as in other contact sports, mechanical metrics such as HIMPCTS and DEC play an important role in the characterization of game-play (Harper et al., 2019; Hyldahl et al., 2017). Therefore, according to the present data, it could be argued that proper monitoring and manipulation of the biomechanical load in rink hockey training drills is fundamental in order to protect players from possible post-competition muscle damage as a consequence of HIMPCTS and DEC (i.e., eccentrically biased efforts by nature). This approach may also conceivably enhance athletes' performance by enabling coaches to track relevant data during training cycles, thus, effectively managing the dynamics of the load to ensure better preparedness for the physical requirements of a game.

Despite the importance of understanding the physiological and biomechanical demands of game-play and of different exercises in a high-level rink hockey team, there are limitations to the current study that must be addressed. The fact that only one team and coaching staff was involved in this study limits the generalization of the findings with respect to the demands of the specific drills presented. Also, the results and methodology herein may be used as a benchmark for training monitoring in rink hockey in order to promote an innovative vision of microcycle manipulation and load management. Furthermore, the classification of each training task according to a quadrant's representation is a novel approach that may help practitioners better comprehend, visualize, and evaluate the appropriateness of typical rink hockey drills by having game-play demands as a reference for the physiological and biomechanical players may be submitted to.

7.5 Practical applications

The present findings may assist trainers and strength and conditioning coaches to bridge the gap between training and competition, improving the specificity of training tasks and routines to improve players' preparedness for competition. Moreover, the proposed categorization of exercises into quadrants (Figure 1) can be a valuable tool for optimizing training plans and load management in elite rink hockey. From a practical perspective, the current results indicate that if the aim is to impose physiological loads similar to those observed in competition, coaches should use training tasks such as EX.MD (e.g., game with/without goalkeeper in 2vs2; 3vs3; and 4vs4 formats) or EX.FC (e.g., exercises involving both attacking and defensive actions and counterattacks) that elicit great HR_{AVG} and HR_{MAX} responses and that include high HSS distances. Conversely, if the goal is to replicate the demands of competition in terms of biomechanical loading, coaches should use training tasks such as conditioned games (number of players, time of play, and tactical constraints) in mid-court that elicit a higher number of HIMPCTS, DEC, and ACC efforts.

7.6 Limitations

Major limitations must be addressed in this study. The fact that only one team of 10 players and one coaching staff were involved in this study during two microcycles severely limits the generalization of the findings with respect to the demands of the specific drills presented. Also, the moment of the season or the type of competition (e.g., European competition vs domestic competition) were not considered variables.

7.7 Conclusion

Game-play physiological and biomechanical loads are significantly greater than all training drills. The quadrant assessment for each exercise category revealed that only GM.EFF and GM.RUN were characterized by having high biomechanical and physiological loads. The physiological efforts of EX.FC and EX.MD were medium-high, whereas the biomechanical efforts were low-medium. Finally, exercises such as INT, ANLT, EX. IN¾, and EX. S/I were found to place minimal physiological and biomechanical demands in players, when compared to game-play. The current methodology constitutes an innovative way to monitor rink hockey loads by classifying and adjusting specific exercises having gameplay demands as reference.

8. Optimizing training load monitoring for Elite Rink Hockey according to playing positions

Ferraz, António; Duarte-Mendes, Pedro; Ribeiro, João Nuno; Valente-Dos-Santos, João; Travassos, Bruno. " Optimizing training load monitoring for Elite Rink Hockey according to playing positions". Under Revision – *Sports Science for Health* (2025)

8.1 Introduction

Rink hockey is a highly specialised, physically demanding indoor team sport in which players move in the field on specified four-wheeled quad skates, combining such demands with manipulating a wooden stick and a hard ball (Ferraz et al., 2020). Despite the high specificity and the high levels of muscular injuries reported in this sport (de Pablo et al., 2022), there is a scarcity of studies focused on understanding the dynamics of training sessions and competition, particularly the issues related to training loads (TL) (Fernández, Varo, et al., 2020; Fernández et al., 2023).

The training process is the most effective method to improve athletes' performance throughout the season (Lago-Fuentes et al., 2020). It can assist in increasing strength, power, speed, and endurance in accordance with game demands (Cross et al., 2016). However, while excessive training without enough recovery can negatively affect performance and increase the probability of injury, a lack of training can also limit the athlete's development, recovery, and maintenance of performance (Vanrenterghem et al., 2017). Consequently, the implementation of monitoring and management systems focusing on workload analysis during the training sessions may significantly increase sports performance and consequently decrease the risk of injuries during the season (Cross et al., 2016; Ferraz et al., 2023).

In this line of reasoning, it has been showed that the measure of training load combining external (EL) and internal load (IL) has become a standard method for characterizing training and competitive demands (Helwig et al., 2023; Lovell et al., 2013). In recent years, an intensified focus on training load monitoring has been observed, to assist coaches in crafting more effective and efficient plans for team sports training (Impellizzeri et al., 2019; Pereira & Freitas, 2022). Sports scientists have sought to unravel the intricacies of competition efforts to replicate them in training settings. However, a notable disparity remains, with fewer studies comparing training to competition (Ferraz et al., 2023). Therefore, it is essential to accurately measure the competitive training load (TL) in order to gain insights into players' performance during games, assess their ability to adapt to training, and evaluate if training routines accurately reflect the demands of actual competition (Hausler et al., 2016). As a result, monitoring training and weekly sessions are recommended as a key to identifying demand variations (Clemente et al., 2019; Grünbichler et al., 2020) but at the same time to correlate that information with actual competition demands to promote an integrative approach, particularly on manipulating metrics analysed between training and match session (Ferraz et al., 2023.; Oliva-Lozano et al., 2020).

For that, individualizing players monitoring according to specific game positions is crucial (Jacopo A. Vitale et al., 2016). Despite the importance of analysing game and training demands according to players' positions, only two studies have been conducted in rink hockey to understand players' positional differences (Fernández, Varo, et al., 2020; Fernández et al., 2023). In the first study, no differences have been found between players' positions (interior and exterior players) in the average physical demands [total distance skated (TDS), high speed skated (HSS), number of accelerations (ACC) and decelerations (DEC)] imposed on athletes by games (Fernández, Varo, et al., 2020). However, in the second study, it was observed that peak demands in rink hockey official games are position-dependent, with exterior players covering more TDS and inside players doing more ACC (Fernández et al., 2023). Besides the relevance of such understanding, which may help coaches adjust the training scenarios according to game information, the metrics are measured separately, with no information regarding the training load exposure. Also, as verified in other team sports (i.e., basketball) (Román et al., 2019), the process of monitoring and management system should consider the impact of different training sessions according to players' positioning during a microcycle (Rico-González et al., 2022) and compare them to game demands (Fernández et al., 2023; Lin et al., 2023). To the best of our knowledge, no research has been conducted on rink hockey with this approach.

Therefore, this study proposes a new approach for characterizing and classifying the load demands, considering training and games' physiological and biomechanical demands according to playing positions (defender-midfielders and forwards) in a top-level rink hockey team. It is expected that training and competition loads are position dependent. To examine that, a quadrant-based classification system was developed that relates and classifies players' physiological and biomechanical demands.

8.2 Materials and Methods

8.2.1 Study Design

An observational study was conducted over two consecutive microcycles, from March 21st to April 2nd, 2022, on a team competing in the 1st Division of the Portuguese rink hockey league. Due to the restriction on using tracking system's antennas at the opponents' pavilion, the two weeks were chosen based on the team's availability and the competition schedule. The study aimed to monitor two sequential training microcycles and official home games. During the two weeks of the study, the players participated in 8 training sessions and 2 official games.

A non-experimental descriptive method was used to characterize different training sessions (i.e., MD-4; MD-3; MD-2; MD-1) and official games (i.e., MD1; MD2) according to players position [Dedender/Miedfilders (DEF-MID); Forwards (FWD)]. The demands

performed during training and games were categorized based on specific criteria (Coyne et al., 2018)(table 1).
During the data collection, the technical staff was not instructed regarding training sessions or in-match coaching decisions.

8.2.2 Participants

Data was collected from a convenience sample of ten elite-level male rink hockey players, comprising 4 defenders/midfielders (DEF-MID) and 6 forwards (FWD). The participants were aged 27.4 ± 5.5 years old, had an average height of 174.8 ± 2.8 cm, an average body mass of 74.92 ± 2.83 kg, and an average body mass index (BMI) of 24.53 ± 0.95 kg/m2. The players who voluntarily participated in the study were part of one of the leading European teams from the Portuguese elite championship. Goalkeepers were not included in the analysis due to their distinct characteristics and substantial technical differences from court players (Fernández et al., 2023). Players included in the study didn't have injuries and completed the entire training session and game.

8.2.3 Ethics statement

Data collection was carried out with humans according to international ethical standards based on the Declaration of Helsinki (Harriss et al., 2019) after approval by the local Ethics Committee University (CE-UBI-Pj-2019-053:ID1519). All participants provided written informed consent and could withdraw at any time. Data were anonymized for confidentiality.

8.2.4 Procedures

Training and competition data was collected using local positioning system (LPS) technology from WIMU PRO™ (Realtrack Systems SL, Almeria, Spain). Six antennas equipped with UWB technology were calibrated and fixed ± 10 meters from the court to collect indoor tracking data of players. The accuracy and reliability of the WIMU devices have been previously reported and validated (Bastida-Castillo et al., 2019). HR data was collected using one GARMIN HRM-PRO chest strap (Garmin Ltd., Olathe, KS, USA) below the chest. Data from WIMU and GARMIN were downloaded and synchronized using the dedicated software SPRO™ (Realtrack Systems SL, version 986).
The WIMU PRO™ system was turned on 5-10 minutes before warm-up and was placed in a tight harness on the athlete's upper back.
From the collected data, the physiological and biomechanical metrics were grouped according to the proposal of Coyne et al. (2018). The physiological variables recorded were High-Speed Skating (HSS), Total Distance Skating (TDS), average Heart Rate

(HRAVG), and maximum Heart Rate (HRMAX). The biomechanical variables recorded consisted of the number of high-intensity decelerations (DEC), high-intensity accelerations (ACC), high-intensity impacts (HIMPCT), and Player Load (PL) (see Table 1).

Table 22. *Physiological and Biomechanical variables recorded in this study.*

Type	Variable	Unit	Description
Physiological	High-Speed Skating	HSS(m)	Total distance skated between 18.1 and 30 km/h
	Total distance skating	TDS(m)	Total distance skated in meters
	Heart Rate	HR_{AVG} (bpm)	Average heart rate (bpm)
		HR_{MAX} (bpm)	Maximum heart rate (bpm)
Biomechanical	High-Intensity Decelerations	DEC (m) [-10 -3]m/s^2 (n)	Total number of negative speed changes
	High-Intensity Accelerations	ACC (m)/ [3 10]m/s^2 (n)	Total number of positive speed changes
	High-Intensity Impacts	HIMPCT(g)	Total number of impacts recorded between 8 and 10 g
	Player Load	PL(a.u.)	Accumulated accelerometer load in the three axes of movement

8.2.5 Statistical analysis

Based on a prior power analysis through G*Power (3.1.9.2) (Cohen's d effect size [ES] of 0.8, probability of error of 0.05, and power of 0.7), a sample size of 8 rink hockey players was required (Faul et al., 2007b). Descriptive statistics (range, mean, standard error of the mean, and standard deviation) were calculated for the overall sample. Training and games were grouped by playing positions and according to the days distancing the official games (e.g., MD-4, MD-3, MD-1, and MD). A linear mixed model with random intercepts was used to compare physiological and biomechanical differences between the analysed training/game day and players' position, accounting for individual repeated measures. Physiological (HSS; TDS; HR_{AVG} and HR_{MAX}) and biomechanical (DEC; ACC; HIMPCT and PL) loads were included as fixed effects, and subjects were included as random effects. The training and game (MD-4; MD-3; MD-2; MD-1; MD) and the player's position [Dedender/Miedfilders (DEF-MID); Forwards (FWD)] were treated as a continuous variable. Data regarding normality was tested using the Shapiro-Wilk test, which showed a deviation from normality. To solve the deviation of normality the distribution of the residuals was examined after fitting a linear mixed model. Cohen's d ES and 95% confidence intervals (CI) were calculated and interpreted as follows: <0.2 trivial; 0.20–0.59 small; 0.60–1.19 moderate; 1.2–1.99 large; and ≥2.0 very large

(Hopkins et al., 2009b). The significance level was set at $p<0.05$. Additionally, in line with the purpose of the study, a two-step cluster analysis was performed to classify the training and game demands based on physiological and biomechanical load employing log-likelihood as the distance measure and Schwartz`s Bayesian criterion (McNabb, 2018). Finally, to determine the physiological load of each exercise, an average value was calculated for each session, and the player position was determined based on the numerical load value of the cluster ranging from 1 to 2 (e.g., 1-low physiological load; 2-high physiological load). The same was performed to determine the biomechanical load based on the biomechanical numerical load value of the cluster (e.g., 1-low biomechanical load; 2-high biomechanical load). Statistical analyses were performed using IBM SPSS statistics for Windows (Version 28.0. Armonk, NY: IBM Corp.). A graphical representation of the classification of the players' positions and days was presented using a quadrant plot.

8.3 Results

When considering physiological metrics, some differences are verified by players' positions across the different sessions; specifically, FWD players present higher TDS (m) on MD-4 and MD-2 when compared to MD and lower HR_{MAX} (bpm) on MD-4 and MD-3 when compared to MD-2 and MD ($p<0.001$) (Table 2). Besides some observed average variations, statistical differences in DEF-MID across the microcycle were not verified.

Regarding the biomechanical impact of players' positions, several variations occurred along the microcycle. For example, FWD has lower biomechanical metrics across the training sessions when compared with MD, such as DEC on MD-3, ACC on MD-3, MD-2, and MD-1, lower HIMPCTS on MD-4, MD-3, MD-2, and MD-1 ($p<0.001$). Finally, DEF-MID players also experience significantly lower HIMPCTS on MD-4, MD-3, and MD-1 compared to MD ($p<0.001$) (Table 2).

Table 23. *Physiological and Biomechanical descriptives, effect size, and statistically significant differences between training sessions by playing positions.*

Variables	Players Position *DEF-MID/FWD*	Training Versus Game Day MD-4 *n*=39 / *n*=59 (95% CI)	ES	MD-3 *n*=39 / *n*=59 (95% CI)	ES	MD-2 *n*=39 / *n*=59 (95% CI)	ES	MD-1 *n*=39 / *n*=59 (95% CI)	ES	MD *n*=39 / *n*=59 (95% CI)	ES
Physiological											
HSS(m)	***DEF-MID***	313.75±131.04 [204.19-423.20]		448.43±262.24 [229.19-667.66]		485.64±127.15 [379.34-591.94]		274.65±111.98 [181.04-368.26]		442.32±181.21 [181.04-368.26]	
	FWD	354.39±158.13 [253.91-454.86]		494.11±254.54 [332.38-655.83]		481.90±125.01 [402.47-561.33]		302.64±145.95 [209.91-395.37]		415.17±168.31 [209.91-395.37]	
TDS (m)	***DEF-MID***	6202.07±998.06 [5367.67-7036.47]		5619.41±693.19 [5039.89-6198.93]		6720.93±796.17 [6055.31-73.86.54]		5660.66±1022,01 [4806.24-6515.09]		5337.03±1625.15 [4806.24-6515.09]	
	FWD	6377.63±911.10 # [5798.74-6956.51]	**# 0.80**	5689.00±885.18 [5126.58-6251.42]		6972.39±897.21 # [6402.33-7542.45]	**# 1.01**	5921.86±1079.54 [5235.95-6607.76]		4632.12±1691.18 [5235.95-6607.76]	
HR_{AVG} (bpm)	***DEF-MID***	123.63±12.31 [113.33-133.92]		127.75±12.43 [117.36-138.14]		133.75±12.49 [123.31-144.19]		122.50±10.00 [114.14-130.86]		134.43±7.74 [114.14-130.86]	
	FWD	124.50±9.98 [118.15-130.85]		128.00±10.59 [121.27-134.73]		137.17±11.44 [129.90-144.44]		131.75±7.01 [127.30-136.20]		126.45±17.54 [127.30-136.20]	
HR_{MAX} (bpm)	***DEF-MID***	167.50±8.19 [160.65-174.35]		168.50±10.17 [160.00-177.00]	**α 0.77**	177.88±9.76 [169.71-186.04]		171.13±5.94 [166.16-176.09]		176.86±2.97 [166.16-176.09]	
	FWD	168.58±10.36 **α** # [162.00-175.17]	**α 1.00 # 1.09**	171.75±9.32 **α** # [165.83-177.67]	**# 0.87**	181.92±6.53 [177.77-186.07]		180.75±7.14 ** [176.22-185.28]	****0.92**	183.82±9.83 [176.22-185.28]	
Biomechanical											
DEC^1(m)	***DEF-MID***	124.63±39.50 [91.60-157.65]		106.38±10.72 [97.42-115.33]		111.13±21.76 [92.94-129.31]		106.88±26.74 [84.52-129.23]		146.71±56.88 [84.52-129.23]	
	FWD	121.25±30.91 [253.91-454.86]		95.00±16.83 # [84.31-105.69]	**# 0.80**	122.50±27.97 [104.73-140.27]		114.67±43.75 [86.87-142.46]		144.36±53.46 [86.87-142.46]	
ACC (m)	***DEF-MID***	140.75±44.28 [101.61-177.78]		119.75±9.60 [111.72-127.78]		132.13±17.64 [117.38-146.87]		126.37±34.20 [97.78-154.97]		159.14±62.07 [97.78-154.97]	
	FWD	130.50±37.26 # [106.83-140.89]		108.25±15.90 # [98.15-118.35]	**# 0.97**	124.75±24.40 [109.25-140.25]	**# 0.76**	134.83±44.69 # [106.44-163.23]	**# 0.80**	180.45±77.37 [106.44-163.23]	
HIMPCTS(g)	***DEF-MID***	2.25±1.83# [0.72-3.78]	**# 0.75**	2.38±3.38 # [-0.45-5.20]	**# 0.73**	2.63±2.50 [0.53-4.72]		1.50±0.93 # [0.73-2.27]	**# 0.87**	7.00±6.90 [0.73-2.27]	
	FWD	1.17±1.03 # [0.51-1.82]	**# 0.79**	1.08±1.31 # [0.25-1.92]	**# 0.82**	1.33±0.99 # [0.71-1.96]	**# 0.76**	0.92±0.67 # [0.49-1.34]	**# 0.84**	5.09±4.91 [0.49-1.34]	
$PLmin^{-1}$(a.u.)	***DEF-MID***	31.24±3.92 [27.96-34.51]		31.36±4.46 [27.62-35.09]		33.78±3.50 [30.85-36.71]		28.87±3.25 [26.15-31.59]		29.78±8.98 [26.15-31.59]	
	FWD	36.91±4.86 [33.83-40.00]		34.47±5.38 [31.05-37.89]		38.48±6.73 [34.20-42.75]		33.01±6.56 [28.84-37.18]		32.98±8.01 [28.84-37.18]	

DEF-MID: Defenders-Midfielder; FWD: Forwards

*Data presented as mean ± standard deviation and IC. *Significantly different than FWD; # Significantly different than MD; ** significantly different than MD-4; Δ significantly different than MD-3; α significantly different than MD-2; ES: Cohen's d effect size, reported only for significant differences and not for repeated significant differences. Repeated statistical differences between groups were not presented.*

The cluster analysis classified the physiological parameters into two distinct groups: "Low Physiological Load" (1) and "High Physiological Load" (2). Both clusters were strongly related to the predictor variables HSS (1.00), TDS (0.69), HR_{AVG} (0.38), and HR_{MAX} (0.12). The average silhouette measure of cohesion and separation (representative of the clustering quality) was 0.5, which indicated a moderate model quality (Table 3).

In terms of biomechanical load, the cluster analysis divided the categories into two groups: "Low Biomechanical Load" (1) and "High Biomechanical Load" (2). The clusters had a high relationship with the predictor variables DEC (1.00), ACC (0.88), HIMPCTS (0.31), and PL (0.01). The average silhouette was 0.5, indicating a moderate model quality (Table 3).

Table 24. *Cluster analysis identifying positioning differences by training and competition based on physiological and biomechanical load variables.*

Cluster	Variable	Importance of the cluster predictor	Low Physiological Load	High Physiological Load
PHYSIOLOGICAL CLUSTER	*HSS (m)*	1.00	252.99 ± 102.27	534.65 ± 130.79
	TDS (m)	0.69	5048.36 ± 1172.69	6716.21 ± 630.22
	HR_{AVG} (bpm)	0.38	122.52 ± 11.45	134.88 ± 9.11
	HR_{MAX} (bpm)	0.12	172.20 ± 10.69	177.98 ± 8.58
	Sample Size (N)		46	52
	Sample Percentage (%)		46.9%	53.1%
	Bayesian information criterion (BIC)		264.89	
	Average silhouette		0.5	

Cluster	Variable	Importance of the cluster predictor	Low Biomechanical Load	High Biomechanical Load
BIOMECHANICALCLUSTE R	*DEC (m)*	1.00	102.38 ± 21.13	164.50 ± 33.99
	ACC (m)	0.88	116.04 ± 21.91	187.54 ± 49.89
	HIMPCTS(g)	0.31	1.46 ± 1.35	4.77 ± 5.29
	PL (a.u.)	0.01	33.35 ± 6.46	34.11 ± 6.04
	Sample Size (N)		72	26
	Sample Percentage (%)		73.5%	26.5%
	Bayesian information criterion (BIC)		264.50	
	Average silhouette		0.5	

Heart rate average (HR_{AVG}; Maximum heart rate (HR_{MAX}); High-speed skating (HSS(m)); Medium-speed skating per minute (MSS(m)); Total distance skated (TDS(m)); High Impacts (HIMPCTS(g)); Number of Decelerations (DECmin-1(m) Total Distance skated (TD(m)).

Based on the results from cluster analysis, table 4 provides the descriptive physiological and biomechanical average results for training days (MD-4, MD-3, MD-2, and MD-1) and game (MD) per players' position. For physiological clusters, MD-2 for both DEF-MID and FWD, MD/DEF-MID, MD-1/FWD, and MD-3/FWD were classified as "High physiological load" (2). In contrast, for biomechanical clusters, only MD for both DEF-MID and FWD were classified as "High biomechanical load" (2) (see Table 4).

Table 25. *Descriptive positioning analysis of physiological and biomechanical load for each position by training and game day*

Training and Game Categories	**Physiological Load**		**Biomechanical Load**	
	Mean ± SD	**Median**	**Mean ± SD**	**Median**
MD-4/DEF-MID	1.13 ± 0.35	1	1.25 ± 0.46	1
MD-4/FWD	1.50 ± 0.52	1.5	1.33 ± 0.49	1
MD-3/DEF-MID	1.38 ± 0.52	1	1.13 ± 0.35	1
MD-3/FWD	1.58 ± 0.51	2	1.03 ± 0.22	1
MD-2/DEF-MID	1.88 ± 0.35	2	1.13 ± 0.35	1
MD-2/FWD	1.83 ± 0.39	2	1.08 ± 0.29	1
MD-1/DEF-MID	1.13 ± 0.35	1	1.13 ± 0.35	1
MD-1/FWD	1.58 ± 0.51	2	1.25 ± 0.45	1
MD/DEF-MID	1.71 ± 0.49	2	1.86 ± 0.38	2
MD/FWD	1.45 ± 0.52	1	1.64 ± 0.51	2

Considering the results from Table 4, each session and player positioning was classified according to the mean value of the respective physiological and biomechanical load value of the player and microcycle session. The quadrant classification (Figure 1) shows the physiological and biomechanical efforts of DEF-MID and FWD players across training days. The DEF-MID players revealed a tendency to present low physiological and biomechanical load during the training days, except for MD-2, which showed high physiological and low biomechanical load and high physiological and biomechanical load during the game day. In opposition, the FWD players revealed a tendency to present high physiological and low biomechanical load for all training days and low biomechanical load and high physiological and low biomechanical load during the game day.
Interestingly, any training session replicated the demands of the MD for any playing position.

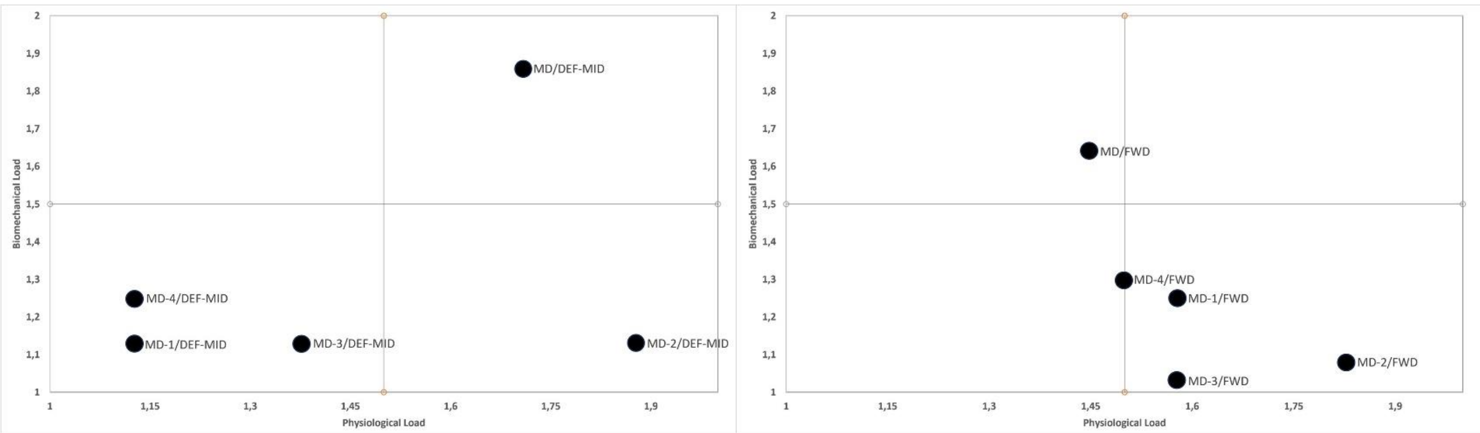

Figure 10. *Representation of the Physiological and Biomechanical efforts of Def-Mid (left panel) and FWD (right panel) according to training and game days separate.*

In general, none of the training sessions reproduced the biomechanical demands of the game (upper quadrants). Except for MD-2, which revealed high physiological and low biomechanical load for both DEF-MID and FWD, the physiological demands of DEF-MID in MD-1, MD-3, and MD-4 were consistently lower than the physiological demands of FWD. In opposition, the physiological demands of DEF-MID during the games were higher than the physiological demands of FWD (Figure 2).

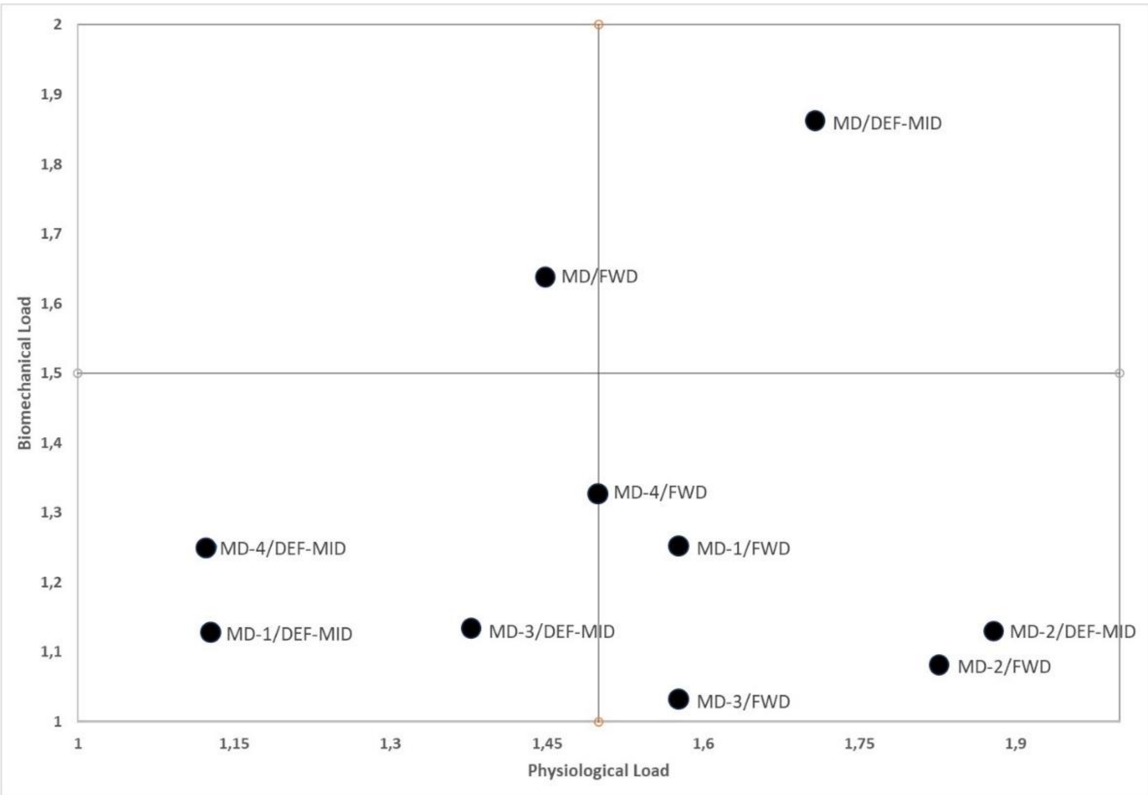

Figure 11. *Integrative Distribution of Physiological and Biomechanical Efforts Across Player Positions and Microcycle Sessions*

8.4 Discussion

Understanding sports competition demands and the influence of different training sessions on performance is crucial for developing and improving effective training regimens and potentiating players' adaptations (Hulin et al., 2016). Consequently, implementing a reliable and functional process of monitoring and managing the load of the training and competition is highly recommended (Gabbett, 2023; Gabbett et al., 2014).

This study proposes a new approach for characterizing and classifying the load demands, considering training and games' physiological and biomechanical demands according to playing positions (defender-midfielders and forwards) in rink hockey. A quadrant-based classification system that relates and classifies players' physiological and biomechanical demands was developed for that. Once no research has been conducted on rink hockey with this approach, this study allows us to compare the training session impacts and dynamics over the week in relation to the physiological and biomechanical stress met during official games. In general, the approach allowed to distinguish the variations in physiological and biomechanical demands of training sessions and competition according to player's positions in rink hockey. It can be used as a reliable strategy for monitoring and benchmarking of microcycle and playing position demands.

Considering the current approach, it is important to consider that, in comparison with previous approaches, the analysis of the relationship between physiological and biomechanical impact should be considered to understand the different contributions for load monitoring and improve players' readiness to perform.

Given the intermittent nature of the rink hockey game model (Ferraz et al., 2020), players must perform both long and short-duration actions such as ACC, DEC, HIMPTS, and HSS, which increases the game's physical stress (Fernández et al., 2020; Ferraz et al., 2024). These demands rapidly evolve at the elite level and should be readily identifiable by team staff members (Coyne et al., 2018). Therefore, this approach supplies a visual representation of both (physiological and biomechanical) efforts in training and competition. Its visualisation can promptly offer information that will assist team staff in adjusting training physiological and biomechanical load based on training objectives and players' distinct requirements, allowing them to meet the physical demands of the game while reducing the risk of injury by misaligning both loads (de Pablo et al., 2023; De Pablo et al., 2022).

In particular, results showed that the training sessions didn't sample the biomechanical demands of the competition. The training sessions revealed different physiological demands according to the days of the competition. However, MD-2 was the unique training session that revealed higher physiological demands than the competition. In opposition to the MD, in which MID-DEF tend to show higher physiological and biomechanical demands than FWD, in training sessions, except MD-2, the physiological demands of FWD were higher than the physiological demands of MID-DEF. Thus, although it is assumed that training sessions should be designed to be specific and representative of game demands according to players positions demands, results show that training sessions didn't replicate the demands that players experience during game-play (Fernández et al., 2021), particularly the ones related with the biomechanical demands.

Regarding physiological variations across the microcycle, only FWD players present significant variations, specifically on HR_{MAX}, which tends to be lower on MD-4 and MD-3 when compared with the rest of the training sessions and game, proposing that MD-2 and MD-1 are characterized by similar moments of HR_{MAX} as verified on MD. Therefore, high values of HR_{MAX} are constant from MD-2 until the MD, which may support the idea that high-intensity drills are explored accumulatively until the MD, not promoting lower values of HR_{MAX} on MD-1, which could boost effective cycles of fatigue and recovery for this physiological metric before MD (Gabbett et al., 2014). Also, for FWD players, some variations are observed on TDS with higher values for MD-4 and MD-2 compared to other training sessions and games. When examining the quadrants of effort, FWD players exhibit slightly higher physiological profiles in training sessions than DEF-MID players. This is mainly influenced by tendentially higher TDS, HR_{AVG}, and HR_{MAX} values, which intriguingly contrasts with observations during MD. Previous research has described exterior players (DEF-MID) as experiencing higher values of HSS and TDS during competition(Fernández et al., 2023), which is in accordance with our results. Also, these findings align with those in other indoor sports, where the inherent demands of playing positions play a crucial role in explaining these outcomes(Abdelkrim et al., 2007). For instance, we believe that DEF-MID players tend to have higher values of TDS and HSS during MD because of their trajectories on the court, involving technical-tactical obligations, which are characterized by performing more exterior corridors (Fernández et al., 2023). However, these positional demands are not replicated in any training session.

Regarding biomechanical efforts, greater differences are observed during training for both FWD and DEF-MID players when compared to competitions. Besides some training sessions do not replicate ACC and DEC for FWD players, interestingly HIMPCTS is barely experienced by both positions in all training sessions. This is consistent with a recent study, which found that HIMPCTS has a strong influence on players' session ratings of perceived exertion (s_RPE) during competition but is never replicated during training sessions (Ferraz et al., 2024). Therefore, when observing the quadrant of effort, MD is characterized by having high biomechanical demand for both positions, mainly because of the number of HIMPCTS. Despite the absence of statistical differences, the quadrant of efforts reveals that DEF-MID players generally experience higher biomechanical demands than FWD, which may be associated with their technical-tactical obligations involving court trajectory near the rink hockey fence associated with the HSS during offensive and defensive transitions (Fernández et al., 2023). Consequently, there is a necessity to adapt training sessions by promoting similar or higher loads for specific biomechanical metrics, aiming to enhance players' readiness for competition (Impellizzeri et al., 2019; Vanrenterghem et al., 2017), which may decrease the risk of injuries on rink hockey official games (de Pablo et al., 2023).

Observing the integrative distribution of physiological and biomechanical efforts across player positions during the microcycle sessions, once MD-2 is expressed by being a high physiological session, we suggest that MD-3 should be characterized by higher biomechanical load, specifically to players' position, with increased ACC, DEC, HIMPTS, and consequently, PL. Furthermore, because MD-4 and MD-1 are sessions mainly characterized by lower physiological and biomechanical demands, these adjustments could improve biomechanical readiness by modifying fatigue and recovery cycles according to the players' position and the training session (Coyne et al., 2018; Vanrenterghem et al., 2017). Also, no training is characterized by being low physiological and high biomechanical session. This strategy could improve players´ biomechanical adaptations by exploring this high particular load as it happens on MD-2 with the physiological load while also boosting specific loads and their recovery (Lovell et al., 2013). Finally, aside from the significant variations verified in some physiological and biomechanical metrics across the microcycle, it is possible to understand an apparent misalignment between the specificity of the positional physiological and biomechanical loads during competition, compared with the training session. This information can help coaches improve their training tasks to increase biomechanical efforts such ACC, DEC, and HIMPTS on specific training sessions such as, for example, MD-3. With options ranging from adding conditioning areas focused on the particular demands of specific positions (i.e., FWS or DEF-MID) to changing the rules, number of players, or spaces in conditioning small-sided games (i.e., reducing court space as literature on small-sided games demonstrates that is a variable that highlights the ACC and DEC demands)(Aguiar et al., 2012). It is currently unclear how HIMPTS can be replicated during rink hockey training sessions. However, we consider that including continuous transitional movements in small-sided games in specific areas of the court, combined with explicit defending and attacking rules, can benefit DEF-MID players by using exterior corridors and FWD players in interior corridors.

Despite the relevance of identifying the physiological and biomechanical demands of gameplay and different player positions in a high-level rink hockey team, the current study has limitations that must be addressed. Because only one team and coaching staff were part of this study, the conclusions cannot be generalized. Further research with higher observations and in different team sports is recommended. Nonetheless, the findings and approach presented here can be used as a benchmark for training monitoring in rink hockey to encourage an innovative perspective of microcycle adjustment and load control according to training session and player position.

8.5 Practical applications

The current findings may help trainers and strength and conditioning coaches bridge the gap between training and competition by boosting the specificity of players' positioning, training objectives, and routines to increase players' competition readiness and assist players in dealing with the physical demands of the game. The application of this evidence to the training process is significant; knowing the physiological and biomechanical load of each position and which variables best characterize it allows coaches to concretely manipulate and adjust the physical demands of practice tasks during the microcycle to game demands to optimize players' performance and reduce the risk of injury. Consequently, increasing biomechanical load by promoting tasks with a higher number of ACC, DEC, and HIMPTS on specific training sessions (i.e., MD-3 or MD-2) may positively influence the load variability and, consequently, the readiness of players for competition. Also, consider incorporating continuous transitional movements in small-sided games in specific sections of the court, which, when combined with specified defensive and attacking regulations, can assist DEF-MID players in exterior corridors and FWD players in interior corridors to experience a higher number of HIMPTS based on their position.

8.6 Conclusion

The study indicates that FWD players have a slightly lower physiological and biomechanical profile than DEF-MID during competition. There is a misalignment between the specific stresses experienced by both positions during competition and training sessions, emphasizing the importance of taking a nuanced approach when planning training regimens. Independent of the player’s position, the game is characterized by a high biomechanical load, which is not replicated in any training session. Also, for both positions, MD-2 is the training with a higher physiological load, and MD-3 with the lower biomechanical load.

Finally, the proposed quadrant approach offers trainers and coaches a visual tool for analyzing variations in physiological and biomechanical demands between player positions, comparing training sessions and competition.

9.General Discussion

In elite rink hockey, like in other team sports, the pursuit of optimal player performance and team effectiveness requires a multifaceted comprehension of player traits, game dynamics and demands, and training methodologies. For that, adequate monitoring methodologies are paramount to capture the key factors constraining players' development and team performance. This thesis was prompted by the need to contribute to a further understanding of rink hockey game demands and the key factors required for performance enhancement. Out of the three major topics, six studies were developed to accomplish that purpose. The sequence of studies was defined from the athlete to the game demands characterization, ending with understanding the manipulation of training and competition according to player positioning. Each major topic integrates multiple objectives, demonstrating how they interconnect and collectively contribute to a deeper understanding of the subject matter. This reorganization not only streamlines the theoretical structure but also enhances the clarity and coherence of the research outcomes. Therefore, the first major topic develops amplified knowledge related to previous research in this sport and in the characterization of specific players´ anthropometric traits and conditional profiles, such as grip strength. The second major topic studied and proposed the major issues that should be integrated for the development of an appropriate monitoring load strategy for rink hockey. This strategy was designed to identify the variations between training and competitions while also classifying which metrics best represented game needs. Finally, the third proposed a new methodology that classifies the physiological and biomechanical responses of training and competition while providing a visual tool to team staff members that may assist in tailoring their training sessions to the objectives.

9.1 What characterizes elite rink hockey players´ anthropometric traits and conditional profiles?

Rink hockey is characterized by high physical demands and quick transitions between short and long efforts with small recovery periods, requiring an extensive understanding of its players' physiological and functional demands (Yagüe et al., 2013). While efforts have been made to reproduce match demands and assess physiological profiles, there are still substantial gaps in the research. In this section, we attempt to characterize rink hockey players by combining findings from physiological responses, cardiorespiratory adaptations, anthropometry, body composition, strength, and injuries in the game (study 1 and study 2)

In the first study, we verified that previous research had analysed physiological parameters during rink hockey competitions, noticing that the heart rate flows between 85% and 95% of the HRmax and blood lactate performance is between 4.0 and 4.6 mmol/l^{-1} (Yagüe et al., 2013). However, based on the literature, there is a tremendous gap in experimental research in order to replicate these physiological game demands on training like it has been done in other multi-sprint sports (Pelliccia et al., 1999; Thomas et al., 2020; Bonafonte et al., 1994). Only one study was developed with the goal of replicating the physiological demands of the game on a laboratory assessment, and no significant differences were found in mean heart rate between the simulation tests and the competition (189 ± 6.2 vs. 188 ± 5.6) (Yagüe et al., 2013). On the other hand, the same author showed that blood lactate during the simulated test (4.5-5.5 mmol/l^{-1} in the middle and 5.5-6.5 mmol/l^{-1}at the end) was slightly lower than Rink-Hockey matches (5.2 ± 01.0 mmol/l^{-1} and 7.2 ± 1.0 mmol/l^{-1}). There is, therefore, a research gap in understanding how training may replicate this physiological parameter in order to create drills based on game demands and lactate performance.

It was also mentioned that rink hockey training can cause concentric and eccentric cardiac hypertrophy (Madeira et al., 2008). While rink hockey is not a traditional endurance sport, cardiorespiratory fitness seems essential for maintaining high levels of physical activity while promoting rapid recovery (Yagüe et al., 2013). Therefore, long-term engagement in rink hockey and its sport-specificity demands leads young players to have greater left auricle diameters and ventricular wall thicknesses than athletes in other team sports and individual sports such as football or judo (Valente-dos-Santos et al., 2013). The same study reveals that male rink-hockey players aged 15.4 ± 0.6 years achieved a peak oxygen uptake of 3.89 L-min-1 (Valente-dos-Santos et al., 2013). However, these findings are mainly related to young players. The association between peak oxygen consumption and maximal exertion in adult elite athletes has been sparsely explored. As far as we know, simulation and laboratory tests report values between 50 and 60 mL/Kg/min (Blanco et al., 1995; M. W. Hoppe et al., 2015). This relationship between peak oxygen consumption and maximal exertion may be critical to establishing an optimal physiological profile for rink hockey, allowing to develop more adjusted training zones to the specific demands of the rink-hockey (Forsythe et al., 2018).

Elite rink hockey players require comprehensive training programs that target a diverse range of physical attributes such as strength, speed, power, and agility (Hoppe et al., 2015). Besides, some information has been published regarding U-17 players for elite selections, defending that specific anthropometric and strength traits are related to greater performance (Coelho-E-Silva et al., 2012). Still, in study 1, it was observed a lack of research regarding the body composition of adult elite rink-hockey athletes and no research regarding hand grip strength (De Pablo et al., 2022; Hoppe et al., 2014).

The literature on team sports shows a clear relationship between body composition, strength, performance, and injury prevention in elite athletes (Alejandro et al., 2015; de Pablo et al., 2023; Jacopo A. Vitale et al., 2016). Once understanding the particular requirements of elite-level sports performance can provide useful information on what is truly needed for competitive success in sports (Slimani & Nikolaidis, 2019). The anthropometric assessment may provide important insights into elite rink hockey players' physical features, which may then be used to guide long-term training and performance enhancement strategies. Particularly, elite players are typically tested for anthropometric parameters of body composition and muscular strength (le Gall et al., 2010). The sports-specificity profile may be addressed as a benchmark strategy to understand players' capacities and predict players' physiological and biomechanical development (Toong et al., 2018).

Accordingly, the second study evaluated a large sample size (n=100) of elite male rink hockey athletes regarding body composition, grip strength, and respective predicted variables. As reported in previous research (Ackland et al., 2012), results revealed specificities in the anthropometric and grip strength profile of elite rink hockey players. Aside from providing valuable insights about an individual's bone density and functional state (Coelho-E-Silva et al., 2012; Wind et al., 2010), grip strength is required in most hockey-specific motions, with players constantly performing complex abilities while grabbing a stick (Toong et al., 2018). Given these neuromuscular adaptations from training, rink hockey players are likely to have increased grip strength. However, results from study 2 show that elite rink hockey athletes have lower body fat percentage and grip strength than regular healthy men (Vaara et al., 2012). Additionally, in comparison to other team and individual sports, such as ice hockey, handball, water polo, tennis, and gymnastics, elite rink hockey players also have lower grip strength levels (Cronin et al., 2017). These references are valuable for (1) strength and conditioning coaches that may develop specific programs to increase grip strength, and (2) should promote further research into how upper strength impacts athletes' performance and injury rates (De Pablo et al., 2022; Walker et al., 2023).

It has been found that differences in training have a significant impact on both muscle and body fat percentage (Walker et al., 2023). Therefore, increasing awareness about strength training and its effects on elite rink hockey athletes is essential. This will help develop strategies to enhance the players' performance according to the game's requirements.

The second study described the metrics that better explain body fat percentage and hand grip strength. The multiple regression analysis yielded an overall significant model for body fat percentage and grip strength for each ethnicity. ABC, RTC, RCC, and ethnicity showed a significant interaction effect on the body fat percentage. Besides ethnicity, which is commonly known to be a variable that impacts functional and morphological traits in athletes and non-athletes (Augustine & Howard, 2018), results showed that certain anthropometric variables constrain the body fat percentage of elite rink hockey players. This promotes new evidence that may help strength and conditioning coaches to adjust the strategies to analyse and develop athletes' body composition analysis. For example, abdominal circumference has been reported as a performance variable related to intense training by presenting lower subcutaneous and visceral abdominal fat (Romero Martín et al., 2020). Also, it has been proposed that the proportions of segment fat mass and fat-free mass within the entire body for athletes are event-specific (Hoshikawa et al., 2010). As a result, it was assumed that particular actions of the game pattern, such as energetic and mechanical demands of skating, accelerating and decelerating at different intensities, linked with training adaptations, might explain why RTC and RCC are high predictors of body fat in elite rink hockey players.

In relation to upper strength, three variables produced an overall significant model for the variance in grip strength. Ethnicity, age, and the circumference of the right distal thigh. It has been referenced in other hockey disciplines, such as ice hockey, that grip strength increases with age (Toong et al., 2018). This increase may also be due to neuromuscular adaptation from practice time in elite athletes. Interestingly, the last predictor of grip strength has also been reported in other studies as a reference to upper strength (Hashimoto et al., 2020). Therefore, due to the anthropometric adaptation to the game's demands (i.e., ACC and DEC) and long-term training adaptation, this metric may be used as a normative value for performance and injury prevention, helping strength and conditioning coaches improve their practices.

When looking into injury prevention, the first study refers to a gap in the literature. Aside from the results from the second study, little information is known regarding athletes' traits that can be used to develop injury-specific prevention programs. It seems that the competition level influences the injury level (De Pablo et al., 2022). In professional competitions, injuries are mainly moderate, while in amateur play, these are much more serious (de Pablo et al., 2022). Additionally, at an elite level, athletes present higher levels of proprioception than non-athletes, which contributes to injury prevention and enhanced performance (Venâncio et al., 2016), particularly in preventing the chronic groin pain due to the constant mechanical effort of athletes to brake and change direction (Vitale et al., 2019). In this sense, the results from study 1 and study 2 provide new insights regarding the athletes' traits and types of injuries, which may help coaches and strength and conditioning coaches to develop specific training programs in order to decrease the high number of injuries during competition (de Pablo et al., 2023), and at the same time, to stimulate research regarding how strength work may prevent injuries and potentiate players' performance. Such profiling and characterization results about rink hockey players can serve as benchmark purposes across teams.

9.2 How can rink hockey monitoring load strategies be improved?

According to the first study, one of the major research gaps in the literature about this team sport was the lack of knowledge regarding rink hockey demands and players' performance monitoring. It is commonly known that monitoring workload is an essential strategy for understanding the sport demands and, at the same time, to evaluate athletes' physical readiness for performance (Rossi et al., 2019). Also, the studies developed for monitoring purposes solely considered external load variables neglecting the collection and analysis of internal load (such as heart rate responses and subjective exertion). Despite the intentions to improve the knowledge about the game, it lacks the impact of the physical performance of players during training and competition, not allowing for a wide perspective of analysis. To understand players' overall workload during elite team sports competitions, a combination of variables from at least external and internal load variables is required (Grünbichler et al., 2020). Consequently, to further understand the main hot topics and possible future trends in the research of monitoring team sports using tracking systems, study 3 was developed. Our main goal was to systematize the knowledge regarding the use of tracking systems for monitoring performance in team sports in order to create a model that sustains the study of rink hockey and the next steps of this thesis.

Results of study 3, showed that in the last decade, tracking systems research primarily focused on *(1)* analyzing physical performance during competition, *(2)* comparing training and matches, *(3)* injuries analysis, and (4) nutrition strategies.

While it is crucial to understand the demands of the game, it is equally important to have a sense of what happens during training sessions in order to bring about significant changes and, at the same time, to have a scoping perspective in the development of specific strategies to performance enhancement and of injury prevention based on both chronic loads (de Pablo et al., 2023). Therefore, despite previous research in this area, which is solely focused on training (Beato, Vicens-bordas, et al., 2023) or competition (Serrano et al., 2020), a comprehensive understanding of athletes' physical performance can only be achieved by considering both training and match demands (Beato, de Keijzer, et al., 2023) in order to promote an integrative approach of kinematics and mechanical variables for EL and specific IL metrics such as s-RPE or heart rate variables. Additionally, metrics should be selected based on sports-specificities (Beato, Vicens-bordas, et al., 2023; Coyne et al., 2018; Younesi et al., 2021).

Regarding injury analysis, there is a particular interest in understanding which metrics have a greater impact on the prevalence of injuries (Gastin et al., 2019). However, results sometimes seem controversial. If exploring lower-intensity metrics during training seems to be a trigger for injuries during competition (Caparrós et al., 2018), the accumulative workload also seems to increase the risk of injuries (Murray et al., 2018). Not less important, recent studies regarding contact sports have focused on mechanical metrics such as ACC, DEC, and impacts, which have shown evidences of how this type of effort may also promote a greater risk of injuries (Gastin et al., 2019). Thus, future research should integrate by order of importance, metrics according to sports specificities, allowing to promote different levels of physiological and biomechanical responses during training and competition (Beato, Vicens-bordas, et al., 2023; Coyne et al., 2018; Younesi et al., 2021). Additionally, a gap of experimental studies related to EL and IL response according to nutritional status has also been verified (López-Samanes et al., 2021). This type of study could provide new insights into nutritional supplementation and its impact on players' responses.

Finally, incorporating the aforementioned categories as essential pillars of a team sports science department could supply teams with pertinent data concerning the implementation of performance enhancement approaches and enable a greater understanding of the injury process. Study 3 also showed that the characterization and comparison of drills, training, and match sessions, followed by correlational analysis between metrics, are the main research methodologies in tracking systems in the past few years. In this sense, we believe that it is important to provide rink hockey practitioners with practical and realistic strategies based on the sport's research state of maturity. Based on the actual research level in this sport, a more simplified approach in rink hockey is required. In study 3, we proposed that it is crucial to create integrative models for analyzing and integrating EL and IL metrics within each team sport, which may be an interesting direction for future research in rink hockey, specifically as we proposed in studies 5 and 6.

In line with results of study 3, study 4 was designed to further characterize and compare training and competition sessions and simultaneously correlate EL (Kinematics and Mechanical) with IL (perceived exertion). It is commonly known that training sessions need to accommodate physical, technical and tactical game demands to prepare the players for to the competition (Taylor et al., 2017). For that, training sessions over the week need to accommodate variations in physical, technical, and tactical demands to promote immediate and long-term adaptations of players to perform (i.e., accelerations, decelerations, changes in direction, short-term movements) (Grünbichler et al., 2020). The literature accurately defines the importance of fatigue and recovery cycles in achieving this physiological and/or biomechanical adaptation, ensuring that training must provide an equal or greater stimulus compared to competition (Gabbett, 2023; Ryan et al., 2019). However, the challenge is greater when the understanding of sports-specific demands is scarce, like in rink hockey.

Based on that, study 4 focused on understanding the demands of training and competition during an international championship. Previous research referenced that training does not replicate the demands of the competition (Fernández, Varo, et al., 2020). The comparison between training days showed that MD-4 and MD-1 sessions have lower EL (ACC, DEC, DT, and PL) and IL (RPE and s-RPE) than MD-3 and MD-2, promoting an inverted "*U-shape*" of load dynamics during the week as recommended (Fernández, Varo, et al., 2020). Results of study 4 were similar to the results of Fernández et al., (2020). MD-3 and MD-2 revealed the great EL values (PL, TDS, and HSS) during the week. Also, the training weeks did not represent the competition. Curiously, the analysis of the correlation between EL variables and the s-RPE in training sessions and competition also revealed different relationships. Only HIMPT and DEC variables impacted s-RPE during the competition, which are less explored during training - especially HIMPTCS. This was the first time that such results were exposed in research in rink hockey, which may provide a new perspective on how training load may be interpreted in such sport and how research may shift to study more specific metrics. For example, there is a special interest in understanding why there are so many injuries during competition in elite rink hockey championships (De Pablo et al., 2022). The literature supports that the epidemiology of injuries in rink hockey is mainly due to the inadequacy of physiological adaptations during training (de Pablo et al., 2023). In contact sports like Australian football, it has been reported that HIMPT and DEC influence players´ muscular damage by lowering the level of muscular creatine kinase during competition (Gastin et al., 2019). Study 4 suggests that potentializing mechanical gaps during training sessions may provide new insights into players' mechanical readiness for competition performance and can also be an important strategy for reducing the risk of injuries during competition. However, further research regarding the influence of such metrics in specific training and competition contexts is required, particularly to understand how long-term HIMPT during game play may influence specifically players fatigue and injuries, and which proper load management during training session can provide greater players mechanical readiness.

9.3 How could monitoring strategies be used to clarify training and competition responses?

In team sports, coaches and performance specialists dedicate significant resources and time to monitoring their players' performance (Russell et al., 2021). As presented in this thesis, over the last few years, the emergence of electronic devices for performance analysis has led to measuring athletes' load in both training and competition while simultaneously evaluating the implementation of recommended loads or reducing the risk of overtraining and soft tissue injuries (Delaney et al., 2018).

By considering the results of studies 3 and 4, there was an inconsistency between training and competition. The game is mechanically more demanding than training (HIMPT, DEC). However, besides the novelty of the information, the results were presented without a contextualization of the type of exercises developed. Therefore, new methods are necessary in order to provide novel information to help technical staff adjust their objectives and monitoring tools in this sport. The analysis of the relationship between physiological and biomechanical demands (Coyne et al., 2018) according to the types of exercises considered is required. Based on Coyne et al., (2022), studies 5 and 6, developed a new approach that aims to analyse training exercises and competition demands. In this sense, properly quantifying such demands allows for (1) understanding players' performance during match play (physiological and biomechanical demands), (2) determining how well they are adjusting to training stimuli, and (3) assessing whether training regimens resemble, and replicate competition demands (Hausler et al., 2016).

Study 5 combines IL and EL metrics on physiological [HR_{AVG}; HR_{MAX}; HSSmin -1 (m); MSSmin -1 (m) and TDSmin -1 (m)] and biomechanical [HIMPTCSmin -1 (n); DECmin -1 (n); ACCmin -1 (n) and PLmin -1 (m)] parameters with different demanding levels. The major result was that no training task presented a “high-biomechanical Load/ high physiological load,” as occurs with the game demands. Also, none of the training tasks were identified as having low physiological loads and high biomechanical loads. These results based on this approach underline the importance of gathering and comparing game and training information in order to adjust the training stimulus properly, promoting an adequate physiological and biomechanical adaptation (Coyne et al., 2022; Gabbett, 2023). This is the first time it has been tested and presented in elite rink hockey. This approach allows us to see, in this case, that there is an urgent need to adjust training stimulus by increasing biomechanical demands as no training task has reached the game biomechanical efforts. Rink hockey seems to be considered a contact sport, which has previously been described (Yagüe et al., 2013). Yet, until now, metrics such as HIMPCTS and DEC have not been recognized as significant predictors of biomechanical efforts in rink hockey. Increasing these metrics may be critical to adjusting training tasks. Additionally, this categorization of efforts allows coaches to manipulate microcycles according to physiological and biomechanical demands to promote proper adaptation to rink hockey specificities (Rago et al., 2021; S. Ryan et al., 2019). This manipulation may also induce players to perform at higher levels and simultaneously reduce the risk of injuries, mainly caused by biomechanical flaws (de Pablo et al., 2022).

Study 3 reinforced that the study of team sports athletes' performance should consider the specificity of demands between players' positions. The literature is concise on this matter. Physical match performance has been demonstrated to vary among playing positions (Altmann et al., 2021).

In rink hockey, this analysis of players' positioning is limited. It has been assumed that due to the game characteristics and tactical behavior, no physiological differences were reported between players' positioning (Hoppe et al., 2015; Yagüe et al., 2013) as well as in EL metrics (DT, HSS, PL, ACC, and DEC) (Fernández, Varo, et al., 2020). However, recently, one study reported differences between players' positioning (interior and exterior players) regarding peak periods of 30 seconds [(total distance (m), distance covered at >18 km/h^{-1} (m), ACC (≤-2 $m.s^{-2}$ (n) and DEC (≤-2 $m.s^{-2}$ (n)] (Fernández et al., 2023). Study 6 also reinforced differences between training and game profiles using the same approach as Study 5. Particularly, these findings probably shed light on the relationship between training regimens and the physiological and biomechanical demands placed on athletes during competitions. They might offer details about how various training sessions (MD-4, MD-3, MD-2, and MD-1) relate to the biomechanical and physiological requirements of player positioning in gameplay (Coyne et al., 2018; Illa et al., 2021; Vanrenterghem et al., 2017). There is an attempt to promote physiological adaptations through adjustments in training loads across different sessions. For example, there is an effort to increase physiological loads on MD-2 while decreasing them on MD-4 and MD-1. This implies a strategic approach to training aimed at enhancing players' physiological capabilities in alignment with the demands of their positions during games. However, there is a huge gap in the management of biomechanical load across training sessions. For both positions, no high biomechanical efforts are verified. This implies that there may be a flaw in how training sessions replicate the biomechanical demands of gameplay. The development of methods that more closely resemble the biomechanical demands of games could enhance training sessions and provide players with more thorough preparation, such as, for example, enhancing the biomechanical load on MD-3 and MD-2, allowing players to recover on MD-1

This clearly states how both players' positions lack adjusted loads according to their specificity. Consequently, this bridge between training and competition may create decreased biomechanical readiness, which may influence players' ability to resist fatigue while increasing the risk of injuries (De Pablo et al., 2022; Gabbett et al., 2014).

Considering the intermittent nature of rink hockey games and taking into account the proposal to cluster physiological and biomechanical loads in a visual quadrant of efforts, it is evident that training sessions should focus on promoting both long and short-duration actions such as HIMPCTS, ACC, DEC, and HSS for all playing positions. This may help to maintain a high physiological load with greater HR_{AVG} and HR_{MAX} and promote higher biomechanical loads. Thereby enhancing the players' overall performance.

Besides the results referenced in this thesis, some considerations for future research should be addressed. Due the influence of goalkeepers in this sport, there is a sense of urgency to understand their specific game demands in order to promote new or adjusted training methodologies. More teams should be involved in full-season studies to increase the range of research, such as the moment of the season or the type of competition (e.g., European competition vs domestic competition). It would also allow a greater generalization of the findings. Additionally, we suggest that conducting more correlational analysis between metrics monitored during training sessions and competition could stimulate a better understanding of how performance may be manipulated by adjusted cycles of fatigue and recovery. Also, there is a gap in understanding how chronic misalignment load management contributes to the injury process. Finally, no experimental studies are related to the impact of small- medium, and large-sided games on the physiological and biomechanical high-performance demands. These experimental approaches may bring new insights into understanding the performance enhancement process in elite rink hockey players.

Despite the importance of the novelty of the findings and the proposal for understanding the physiological and biomechanical demands in elite rink hockey, some limitations must be addressed in this thesis. Only one team was engaged in each study, which may limit the generalization of the findings. Also, due to the small sample size and its unique technical requirements, goalkeepers were not included in the studies related to load monitoring. Furthermore, characteristics such as season timing or competition type (e.g., European competition vs home competition) were not considered as variables.

10. Conclusions

According to the studies developed and in line with the proposed goals, this thesis could be synthesized in the following conclusions:

- Elite rink hockey can lead to a specific body fat percentage and handgrip strength. Abdominal circumference, right tight circumference, right calf circumference, and ethnicity appear to have a substantial interaction effect on body fat percentage. Additionally, ethnicity, chronological age, and right distal thigh circumference limit the variation in handgrip strength among elite male rink hockey players. Such information can advise strength and conditioning coaches to redirect specific training programs to adjust body fat mass and strength.
- Tracking technology has been used in various research fields, including performance analysis, load management, injuries, and nutrition. However, it has rarely been applied to rink hockey research.
- The use of tracking technology should be encouraged by combining the relationship between EL and IL variables.
- In preparing an elite male rink hockey team for an international competition, training sessions fail to represent game demands accurately, and in opposition to training sessions, HIMPCT followed by DEC has a greater impact on s-RPE during competition.
- Physiological and biomechanical demands are greater in the game than in training sessions, such as exercises like INT, ANLT, and EX. IN¾ and EX. S/I have lower physiological and biomechanical demands on players compared to game play.
- The proposed quadrant approach offers teams' technical staff a visual tool for verifying variations in physiological and biomechanical demands between training and competition based on training tasks and player positioning.
- The examination of training tasks and players' positional profiles unanimously suggests that no training session replicates the game's biomechanical requirements.
- The main integrated physiological metrics in rink hockey are HR_{AVG} (bpm), HR_{MAX} (bpm), and HSS (m), while the integrated biomechanical metrics are HIMPCTS(g), DEC(n), and ACC(n).
- Further research is required to promote more holistic approaches to the analysis of rink hockey.

These findings are designed to provide knowledge to all rink hockey stakeholders, field professionals, and sports scientists. It allows a greater awareness of the physiological and biomechanical demands that rink hockey athletes face during training and competitions and, at the same time, to classify those demands according to specific training goals and players' specifications. Additionally, these conclusions may improve the analysis of elite rink hockey traits, contributing to adjusting training load according to sport-specificities while enhancing athletes' performance and injury prevention. Finally, this knowledge may be considered evidence-based practice to improve coach decisions.

11. Practical Applications

This chapter intends to propose practical applications based on our main conclusions.

1. Coaches, strength and conditioning trainers, and physicians working with elite rink hockey players may find body composition and grip strength testing useful for comparing performance and player traits and establishing a reference standard.
2. The following variables can be used best to describe elite rink hockey players' body fat mass %: (1) abdominal circumference, (2) right thigh circumference, (3) right calf circumference, and (4) ethnicity. Additionally, (1) chronological age, (2) right distal thigh circumference, and (3) ethnicity may help to explain gripper strength in these athletes.
3. Sports sciences departments may use monitoring data of training and competition sessions for correlational and experimental analysis as it seems to be one of the major gaps in rink hockey research.
4. By increasing the number of specific metrics, such as HIMPCTS and DEC, coaches can concretely modify and adjust the physical needs of training tasks within the microcycle to game demands, promoting higher levels of players 'readiness.
5. Training tasks such as EX.MD (e.g., a game with/without a goalkeeper in 2vs2, 3vs3, and 4vs4) or EX.FC (e.g., exercises involving both attacking and defensive actions and counterattacks), which cause greater HR_{AVG} and HR_{MAX} outcomes and include high HSS distances, may place physiological loads similar to those observed in competition.
6. To simulate the demands of competition in terms of biomechanical loading, coaches could use training tasks in mid-court, such as conditioned games (number of players, time of play, and tactical constraints), which trigger a higher number of HIMPCTS, DEC, and ACC efforts.
7. Introducing tasks with increased ACC, DEC, and HIMPTS occurrences during specific training sessions (MD-3 or MD-2) can enhance biomechanical load variability and potentially improve players' readiness for competition.
8. Incorporating continuous transitional movements within small-sided games and specific defensive and attacking regulations tailored to different player positions can strategically enhance performance in certain court sections. Emphasizing transitional movements in exterior corridors may benefit defensive-midfield (DEF-MID) players, while focusing on interior corridors may be advantageous for forward (FWD) players, potentially leading to increased occurrences of HIMPTS relevant to their positional demands.

12. References

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