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Re-warm-up strategies at halftime in team sports.

Conceptual model and implementation in soccer games

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Apesar das ruínas e da morte,
Onde sempre acabou cada ilusão,
A força dos meus sonhos é tão forte
Que de tudo renasce a exaltação
E nunca as minhas mãos ficam vazias.

Sophia de Mello Breyner Andresen

(Excerto de "Apesar das Ruínas e da Morte")

A vida é o perfeito encontro entre o Corpo e a Alma. Apesar da ciência "teimar" em tentar provar que é impossível dissociar estes dois elementos, já Sócrates, no *Fédon*, falava da alegria da morte e da Imortalidade da Alma…e eu verdadeiramente Hoje, acredito nesta separação em que a ***Alma não morre***… será sempre a transcendência entre a vida e a morte, a passagem para algo muito mais puro e especial…

Aos que permanecem vivos em mim e que hoje são o meu EU… só posso dizer que jamais deixarei de viver, de amar, de sonhar. Juntos, seguiremos este caminho da vida até que um dia as nossas almas se toquem!

Meu "**puto**",

Sei que deves estar imensamente orgulhoso de mim...

Durante muito tempo, talvez eu tenha sido um herói para ti. Hoje, és tu a força que existe em mim e me faz viver!

Vejo o teu rosto, respiro o teu sorriso, sinto a tua presença. O meu mundo está em silêncio, mas a minha alma vive em paz. Nada mais importa...nada...realmente nada importa, para além da certeza de que continuas vivo em mim.

A dor entranha-se, a saudade aperta, este amor é energia que me catapulta para um estado quase psicótico e obsessivo que não me deixa desistir....

Como disse no dia do adeus à tua vida terrena, sei que já danças com os anjos e falas com Deus. Sei que estás bem e feliz. E, por isso, miúdo, quando sei que estás bem, eu também fico bem.

Porque nada mais importa.
Nada pesa mais do que o amor.
Nada vence as memórias.
Nada apaga aquilo que és em mim.

Até ao dia em que nos voltarmos a abraçar, vou continuar a viver e a lutar.

Milhões de beijos para ti…meu filho Tiago

Da dor à saudade, da saudade ao amor, da alegria da morte à certeza da eternidade!

Amo-te...

(In Memoriam)

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"Eu não tenho filosofia: tenho sentidos…
Se falo na Natureza não é porque saiba o que ela é,
Mas porque a amo, e amo-a por isso,
Porque quem ama nunca sabe o que ama
Nem sabe por que ama, nem o que é amar…"

Alberto Caeiro
(heterónimo de Fernando Pessoa)

It is all about Gratitude…

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A faculty is much more than a place where professors and students come together; it is a community of people united by a shared purpose.

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ippo goto ni sekai

kimi ni deau"

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contribute to the evolution of a humanity that urgently needs to find a direction and inner peace so that everything we do may one day make sense!

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"Tudo vale a pena. Se a alma não é pequena."

(Fernando Pessoa)

Because it is all about Love…

To my daughter ***Naninha***… may you one day feel proud of your father… may you know that all the hugs, kisses… moments spent together are much more important than this doctorate… but may you also recognize the value of effort, commitment, will, and resilience in the face of life's adversities… may you know that your father was and will always be someone who does not bend before pain, before injustice, before inequality, oppression, violence, misogyny, or xenophobia. Someone who holds peace, equality, love, and the Olympic spirit of respect, friendship, and excellence as the great pillars of a life guided by an ethics that stands above any objective or victory. Life is much more than achievements… the path we take towards them is the true value and legacy we leave behind!

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This work is the fruit… of everything life should be between two human beings… ***Love***, ***respect***, ***friendship***, ***affection***…***sharing***…everything that sustains us on a foundation that makes the heart beat at the right rhythm… that makes life have more meaning… be easier and lighter…

To you… my love and for you, we will continue this journey of self-knowledge, acceptance, and peace together… we will continue together until forever… for nothing, not even the law of life, shall part us.

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List of Abbreviations

Abbreviation	Full term
ARMS	Acute Readiness Monitoring Scale
CMJ	Countermovement Jump
FIFA 11+	FIFA Injury Prevention Warm-Up Programme
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HSR	High-Speed Running
IMDP	Integrated Model of Dynamic Performance
IRW-Soccer	Integrated Re-Warm-Up Soccer
MDP	Most Demanding Period
MDPs	Most Demanding Periods
PAP	Post-Activation Potentiation
PAPE	Post-Activation Performance Enhancement
RPE	Rating of Perceived Exertion
RWU	Re-Warm-Up
SSG	Small-Sided Games
SSP	Soccer-Specific Protocol
SPBP	Strength-Power-Based Protocol
U19	Under-19

Abstract

We investigated the effects of short-duration halftime re-warm-up strategies on performance and readiness in team sports, using soccer as the primary competitive context. Given the high physiological demands of the sport, maintaining neuromuscular activation during the halftime interval is essential to preserve performance and readiness. However, traditional passive practices such as tactical briefings and medical interventions (although necessary) often lead to significant declines in muscle temperature and explosive capacity. To address this, we developed and examined 3-minute active re-warm-up protocols designed to fit within the practical and ecological constraints of elite competition. The investigation involved five teams (three female, two male), comprising four senior squads (professional and semi-professional) and one U19 female team.

However, only four of these teams were included in the main studies of this thesis, as the sample obtained from one team was too small to support a meaningful analysis. Data from this team were examined separately in an exploratory article, presented at a scientific conference and subsequently published, which is included as an appendix to this thesis. Three distinct 3-minute protocols were implemented and compared: a Strength-Power-Based Protocol (SPBP), a Soccer-Specific Protocol (SSP), and the Integrated Re-warm-up Soccer (IRW-Soccer) protocol, which combines neuromuscular control with sport-specific stimuli.

Across the four studies, the effects of these protocols varied according to the population, protocol content, and outcome assessed. In Study 1, conducted with adult professional female players, SPBP and SSP did not produce significant between-protocol differences, with sprint performance declining in both groups, CMJ height showing only a small non-significant decline, and no significant protocol effect on Acute Readiness Monitoring Scale (ARMS) responses. In Study 2, conducted with adult professional female players in a two-team training-match context, IRW-Soccer was associated with a great improvement in sprint response than passive rest. CMJ height declined in both groups with a numerically smaller reduction in the IRW-Soccer group. In Study 3, conducted with U19 female players, both IRW-Soccer and the passive control condition

showed improvements in sprint performance, with no significant protocol effect on CMJ or ARMS responses. In Study 4, conducted with adult professional male players, SPBP and SSP produced trivial immediate effects on sprint and CMJ performance; however, SPBP was associated with more favorable ecological responses during the first 25 minutes of the second half, expressed by greater total distance, sprint distance, and high-speed running distance. Taken together, these findings suggest that the effects of halftime re-warm-up strategies are not uniform and may depend on factors such as population characteristics, competitive level, sex, accumulated fatigue, protocol content, competitive context, and the outcomes assessed.

Although the immediate effects on sprint performance, CMJ height, and subjective readiness varied across studies, active protocols, particularly IRW-Soccer and SPBP, showed potential to modulate performance responses and ecological indicators associated with second-half re-entry.

By examining the physiological and physical effects of these interventions, together with selected secondary indicators of subjective readiness, this work explores ecologically valid and time-efficient strategies aimed at regulating second-half readiness and attenuating halftime-related performance decrements. The findings suggest that the effects of re-warm-up strategies may be context-dependent and influenced by factors such as competitive level, sex, accumulated fatigue, and the specificity of the intervention.

Overall, this thesis contributes to the development of evidence-based re-warm-up approaches with high practical applicability across different competitive levels and populations, supporting the integration of power-oriented and soccer-specific exercises within real match environments.

Resumo

Investigámos os efeitos de estratégias de reaquecimento de curta duração realizadas durante o intervalo sobre o desempenho e o estado de prontidão em desportos coletivos, utilizando o futebol como principal contexto competitivo. Atendendo às elevadas exigências fisiológicas da modalidade, a manutenção da ativação neuromuscular durante o intervalo é essencial para preservar o desempenho e o estado de prontidão.

Contudo, as práticas passivas tradicionalmente adotadas, como as instruções táticas e as intervenções médicas, embora necessárias, conduzem frequentemente a reduções significativas da temperatura muscular e da capacidade explosiva. Para responder a este problema, desenvolvemos e analisámos protocolos ativos de reaquecimento com a duração de 3 minutos, concebidos para se enquadrarem nos constrangimentos práticos e ecológicos da competição de elite. A investigação envolveu cinco equipas, três femininas e duas masculinas, incluindo quatro equipas seniores, profissionais e semiprofissionais, e uma equipa feminina sub-19. Apenas quatro equipas foram incluídas nos estudos principais da presente tese, uma vez que a dimensão da amostra de uma das equipas era insuficiente para sustentar uma análise com significado. Os dados dessa equipa foram analisados separadamente num artigo exploratório, apresentado num congresso científico e posteriormente publicado, incluído como anexo à tese.

Foram implementados e comparados três protocolos distintos com a duração de 3 minutos: um protocolo baseado na força e potência "Strength-Power-Based Protocol" (SPBP), um protocolo específico de futebol "Soccer-Specific Protocol" (SSP) e o protocolo integrado de reaquecimento no futebol "Integrated Re-warm-up Soccer" (IRW-Soccer), que combina o controlo neuromuscular com estímulos específicos da modalidade.

Nos quatro estudos, os efeitos dos protocolos variaram em função da população, do seu conteúdo e da variável analisada. No Estudo 1, realizado com jogadoras adultas profissionais, o SPBP e o SSP não produziram diferenças significativas entre protocolos. O desempenho no sprint diminuiu em ambos os grupos, a altura no salto com

contramovimento “Countermovement Jump” (CMJ) apresentou uma pequena redução não significativa e não se verificou qualquer efeito significativo do protocolo nas respostas da Escala de Monitorização do Estado de Prontidão Agudo “Acute Readiness Monitoring Scale” (ARMS). No Estudo 2, realizado com jogadoras adultas profissionais num contexto de jogo de treino entre duas equipas, o IRW-Soccer esteve associado a uma resposta muito favorável no sprint comparativamente à recuperação passiva e a uma menor redução da altura no CMJ em ambos os grupos, mas com uma redução numérica inferior no grupo do IRW-soccer. No Estudo 3, realizado com jogadoras sub-19, tanto o IRW-Soccer como a condição de controlo passivo apresentaram melhorias no desempenho no sprint, não tendo sido observado qualquer efeito significativo do protocolo nas respostas do CMJ ou da ARMS. No Estudo 4, realizado com jogadores adultos profissionais, o SPBP e o SSP produziram efeitos imediatos triviais sobre o desempenho no sprint e no CMJ. Contudo, o SPBP esteve associado a respostas ecológicas mais favoráveis durante os primeiros 25 minutos da segunda parte, expressas por uma maior distância total percorrida e por maiores distâncias percorridas em sprint e a alta velocidade.

Considerados em conjunto, estes resultados sugerem que os efeitos das estratégias de reaquecimento realizadas durante o intervalo não são uniformes e podem depender das características da população, do nível competitivo, do sexo, da fadiga acumulada, do conteúdo do protocolo, do contexto competitivo e das variáveis analisadas. Embora os efeitos imediatos sobre o desempenho tenham variado entre os estudos, os protocolos ativos, particularmente o IRW-Soccer e o SPBP, demonstraram potencial para modular as respostas de desempenho e os indicadores ecológicos associados ao reinício da segunda parte.

Globalmente, esta tese contribui para o desenvolvimento de estratégias de reaquecimento baseadas na evidência, com elevada aplicabilidade prática em diferentes níveis competitivos e populações, sustentando a integração de exercícios orientados para a potência e de exercícios específicos do futebol em contextos reais de jogo.

Chapter 1- General Introduction, Dissertation Structure, and Theoretical Background

1. General Introduction

1.1. Warm-Up and Re-Warm-Up in Team Sports

Warm-up practices are widely employed in team sports, constituting a fundamental component of athlete preparation for competition (Ferraz et al., 2021; Taylor et al., 2013). The primary objective of a warm-up is to prepare athletes across different dimensions of performance, with particular emphasis on cardiovascular and neuromuscular activation, increases in intramuscular temperature, and the optimization of technical and tactical execution (Bishop, 2003; McGowan et al., 2015). This preparatory phase enhances players' technical-tactical readiness through specific drills and tactical schemes, while physically and mentally preparing the athlete to perform effectively (Bangsbo et al., 2007; Neiva et al., 2014).

Ferraz et al., (Ferraz et al., 2021), conceptualize warm-up as a process that extends beyond the pre-match period and encompasses four distinct moments: before training, before the match, during halftime, and during the match.

Beyond this traditional perspective, there has been growing interest in complementary concepts such as post-warm-up performed between the end of the initial warm-up and the start of competition and re-warm-up, specifically applied during halftime intervals (L. M. Silva et al., 2018). In soccer, these strategies are particularly relevant given the high physical and technical demands of the game, characterized by explosive actions such as sprints, jumps, and changes of direction performed under temporal pressure (Di Mascio & Bradley, 2013).

1.2. Post Warm-Up and Halftime Deactivation

Regarding the post-warm-up, the time between the end of the warm-up and the start of the match is approximately 12.4 minutes (Towlson et al., 2013). This period is often passive, leading to a loss of the physiological benefits achieved during the initial warm-up. Studies by (Abade et al., 2017) showed that this predominantly passive time window may negatively affect player performance, with reductions in muscle temperature and performance in jump and sprint tests. However, as the present thesis is focused on the halftime interval, the post-warm-up period is included only as contextual support,

illustrating how passive transitions between active states can compromise readiness, without being the object of investigation.

Similarly, the halftime interval represents a critical period of physiological "deactivation". The literature has consistently demonstrated that predominant passive rest may compromise physical performance, particularly in high-intensity actions like sprinting and jumping (Edholm et al., 2014; Lovell et al., 2013; Mohr et al., 2004). This deactivation involves the partial loss of the readiness state achieved during the initial warm-up, affecting heart rate, muscle temperature, and neuromuscular activation (Abade et al., 2017; Lovell et al., 2013). Scientific evidence suggests that passive halftime intervals may impair performance and potentially increase susceptibility to musculoskeletal injury (Lovell et al., 2013; Mohr et al., 2004). This negative effect reinforces the importance of re-warm-up strategies as targeted, time-specific interventions designed to attenuate these losses, rather than as generic addictions to the match-day routine.

Accordingly, re-warm-up strategies may help attenuate the physiological and neuromuscular declines associated with passive halftime intervals and support performance during the second half of team-sport matches (Russell et al., 2015; Towlson et al., 2013). Recent systematic reviews have confirmed the effectiveness of active re-warm-up strategies in improving speed and jump performance (Fernández et al., 2023; Gonzalez-Devesa et al., 2021; Neves et al., 2025). Various active re-warm-up protocols have been investigated, ranging from short cycling bouts to agility exercises and on-field re-warm-ups (Fashioni et al., 2020; Yanaoka, Hamada, et al., 2018). Exploratory work conducted with professional women's teams, including Abreu et al. (Abreu et al., 2025), suggests that structured halftime re-warm-up strategies may attenuate declines in neuromuscular readiness while remaining compatible with tactical and medical requirements.

1.3. Practical Constraints and Ecological Validity of Re-warm-up

Despite the favorable evidence supporting active re-warm-up strategies, their practical implementation faces significant limitations related to the organization of the halftime interval. In a competitive context, after time has been allocated to hydration, nutrition, and tactical instructions, only a short time window remains available for

physical activity (Russell et al., 2015; Towlson et al., 2013). Currently, only a portion of elite players report performing some form of halftime activation, which is often unstructured (Towlson et al., 2013). This highlights the practical relevance and ecological importance of the present investigation. Exercises inspired by the FIFA 11+ programme and small-sided games (SSGs) emerge as promising solutions (Bizzini et al., 2013; Dellal et al., 2011).

1.4. Female soccer and context-specific responses

Female soccer players may exhibit context-specific responses to re-warm-up strategies due to the interaction of sex-related physiological characteristics, training backgrounds, and maturation profiles, which may influence thermoregulation, neuromuscular readiness, fatigue responses, and repeated high-intensity performance. These factors suggest that protocols developed predominantly using male or mixed-sex samples should not automatically be assumed to be directly transferable to elite female cohorts without specific validation (Datson et al., 2014; Emmonds et al., 2020; Pardos-Mainer et al., 2021). This issue is particularly relevant given the persistent underrepresentation of female athletes in sports science medicine research, as much of the available evidence continues to be extrapolated from male populations. In the specific context of re-warm-up. González-Devesa et al. (Gonzalez-Devesa et al., 2021) highlighted that the existing evidence remains limited, heterogeneous, and mainly based on small or contextually diverse samples, reinforcing the need for further applied research in female soccer.

Despite the professionalization of women's soccer, female players, particularly in youth and U19 categories, may exhibit distinct physiological, maturational, and performance characteristics that warrant context-specific investigation considering both sex and age (Datson et al., 2014; Emmonds et al., 2020; Randell et al., 2021). This underrepresentation limits the ecological and practical generalizability of current re-warm-up guidelines and highlights the need evidence-based protocols that are sensitive to sex, age, and context-related factors and can be validated in real competitive settings, such as those included in the present doctoral thesis.

1.5. Readiness, re-warm-up approaches as a multidimensional process

Athletic performance is not solely determined by objective physical capacity, as subjective readiness, perceived recovery, and cognitive-affective states also contribute to athletes' preparedness to perform and should be considered within monitoring frameworks (Summers et al., 2021). In elite sport, readiness monitoring has become an important component of athlete management because it allows practitioners to interpret the interaction between training load, fatigue, recovery, and performance capacity (Halson, 2014; Kellmann et al., 2018). In team-sport contexts, monitoring fatigue and readiness may provide useful information regarding player availability, adaptation, and the ability to tolerate subsequent training or competition demands (Thorpe et al., 2017).

Readiness should therefore not be interpreted exclusively as the expression of maximal neuromuscular capacity, but rather as a dynamic and multidimensional state reflecting the athlete's ability to respond efficiently to the evolving demands of competition. In soccer, this perspective is particularly relevant because second-half performance depends on the interaction between neuromuscular, physiological, perceptual, and contextual factors that collectively influence athlete readiness. In female soccer, readiness monitoring may be relevant given the individual variability in recovery responses and the demands associated with repeated high-intensity actions and congested competitive schedules**.** Recent work in female soccer has emphasized the importance of monitoring readiness to train and perform, highlighting that readiness indicators can help practitioners interpret short-term fluctuations in performance capacity and support more individualized decision-making processes (Beato et al., 2024).

This perspective is also aligned with broader evidence showing that self-report measures are sensitive tools for monitoring athletes' responses to training and competition, particularly because they may capture changes in perceived well-being, fatigue, and recovery that are not always reflected by objective neuromuscular or physiological tests alone (Saw et al., 2016). Within the present thesis, the Acute Readiness Monitoring Scale (ARMS) was included as a secondary measure in selected studies, allowing subjective perceptions of readiness to be considered alongside objective performance indicators, (Summers et al., 2021).

During the halftime interval, players transition from an active competitive state to a temporary period of reduced physiological stimulation, followed by immediate re-exposure to high-intensity match demands. This transitional phase is characterized by fluctuations in muscle temperature, heart rate, neuromuscular activation and perceived readiness, and cognitive focus, all of which may influence the capacity to perform explosive actions during the early stages of the second half (Lovell et al., 2013; Mohr et al., 2004; Russell et al., 2015). Consequently, the effects of re-warm-up interventions may not be fully explained by isolated measures such as sprint or jump tests alone, but rather should be interpreted within the broader physical and contextual demands of competition.

From this perspective, re-warm-up strategies may function as dynamic mechanisms for regulating second-half readiness under ecological and time-constrained conditions. Therefore, their effectiveness may depend not only on the type of exercises performed, but also on factors such as competitive level, sex, accumulated fatigue, movement specificity, and the contextual demands imposed by the match itself**.** Accordingly, re-warm-up strategies should primarily be evaluated through objective performance outcomes, while selected subjective measures may provide complementary information regarding athletes' perceived preparedness**.**

This multidimensional perspective provides the conceptual basis for the present doctoral thesis, supporting the investigation of short-duration and ecologically valid re-warm-up interventions that integrate neuromuscular activation and movement specificity within real soccer environments, while considering subjective readiness as a complementary dimension.

1.6. Purpose of the Thesis

Considering the similarities between the halftime interval and the post-warm-up window in terms of their potential impact on physiological and neuromuscular readiness, this doctoral thesis focused on the development and evaluation of short-duration active re-warm-up strategies performed during halftime. The central research question was how different active re-warm-up strategies, implemented within a practical 3-minute window designed to minimize interference with other required halftime tasks, influence second-half readiness and performance regulation in soccer (Russell et al., 2015; Towlson

et al., 2013). The main objective of this doctoral thesis was to develop and examine the effects of short-duration active re-warm-up strategies on indicators of physical performance in male and female soccer players, while also considering selected indicators of subjective readiness in specific studies.

These studies were designed to address critical gaps identified in the literature, particularly the limited evidence regarding applied re-warm-up strategies in women's soccer and among U19 female players, for whom sex-related physiological characteristics, maturation profiles, and contextual demands may influence responses to re-warm-up stimuli (Datson et al., 2014; Emmonds et al., 2020; Gonzalez Fernandez et al., 2023).

Within this framework, the Integrated Re-Warm-Up Soccer protocol, hereafter referred to as IRW-Soccer, was developed as an ecologically valid and time-efficient approach to optimize the use of the limited halftime window available for performance reactivation. The protocol was designed to combine specific neuromuscular activation exercises with small-sided game stimuli, aiming to integrate neuromuscular reactivation with soccer-specific movement demands. This approach was based on the rationale that re-warm-up strategies should not only restore or maintain physiological activation, but also reproduce key perceptual, coordinative, and decision-making elements of match play, thereby supporting a more context-specific transition into the second half (Hammami et al., 2018; Lovell et al., 2013; Mohr et al., 2004).

By implementing this conceptual approach, the thesis aimed to better understand how short-duration re-warm-up strategies may regulate readiness and influence second-half performance responses. More specifically, it sought to examine whether neuromuscular activation, power-oriented exercises, and soccer-specific small-sided games could support physical performance indicators such as sprinting and jumping, while selected studies also explored athletes' perceived readiness before re-entry into match-play conditions. Therefore, this thesis contributes to the development of practical, time-efficient, and context-specific re-warm-up strategies with potential implications for match preparation, second-half performance, and applied practice in both male and female soccer players.

2 Dissertation Structure

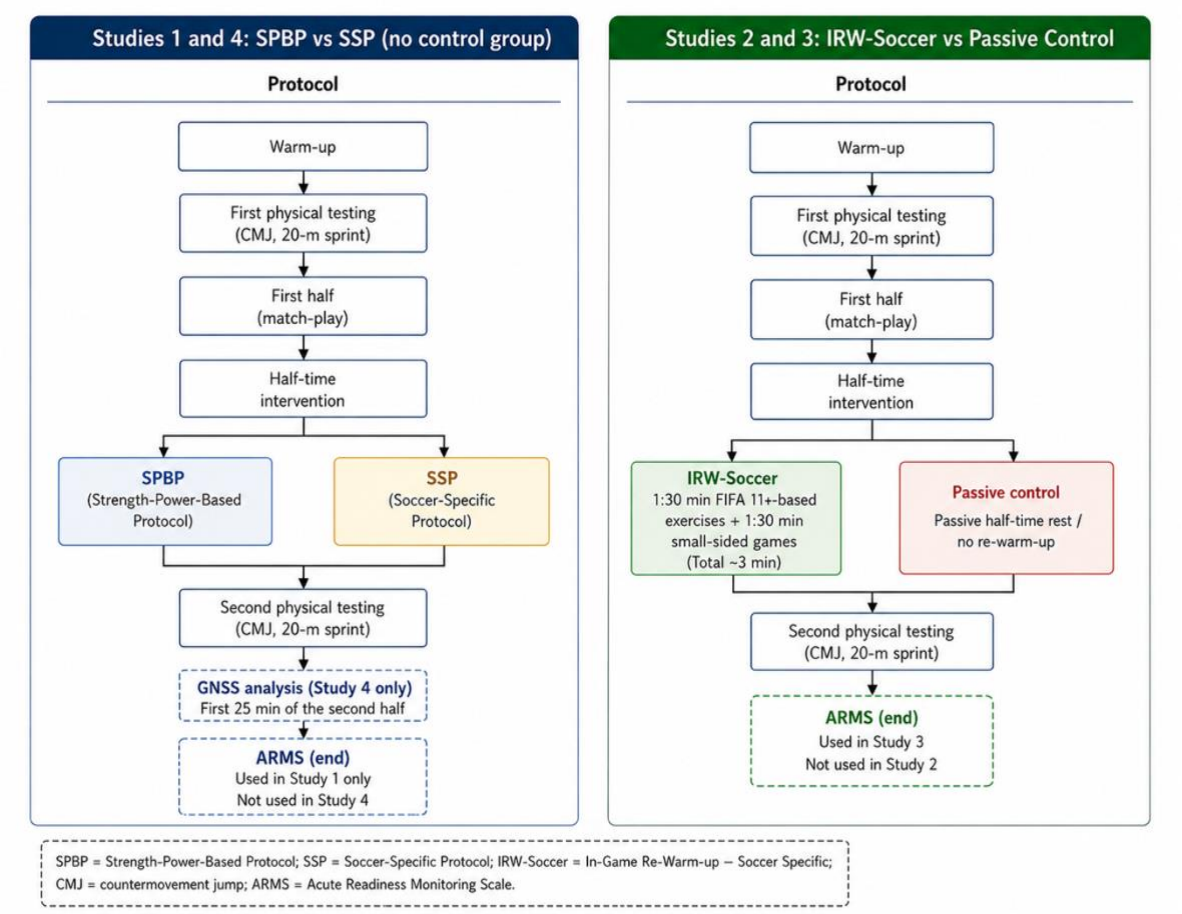
This dissertation was developed following the "Scandinavian Model," in accordance with the guidelines for the writing and presentation of dissertations and reports of FADEUP, June 2009 (3rd Edition). The thesis is divided into four chapters, whose structure is presented in Table 1. Chapter 1 includes the Introduction and Literature Review. Chapter 2 presents the papers that were written and submitted to scientific journals. Chapter 3 provides a general discussion of the results described in all papers, integrating the main findings within a multidimensional and ecological perspective of halftime readiness in soccer. Chapter 4 compiles all bibliographic references cited throughout the thesis, while the references for each study included in Chapter 2 are also presented at the end of the corresponding study

Table 1. Dissertation chapters and specific objectives addressed

Chapter	Content	Specific objective addressed
Chapter 1	1. Introduction 2. Dissertation Structure 3. Theoretical Background	To establish the conceptual, physiological, and contextual rationale for investigating short-duration active re-warm-up strategies during the half-time interval in football.
Chapter 2	Paper I - Warm-Up Strategies at Halftime: A Pilot Randomized Controlled Trial in a Professional Women's Soccer Team	To examine the acute effects of different half-time warm-up strategies on physical performance responses in professional women's soccer players.
Chapter 2	Paper II - Should Soccer Players Re-Warm-up at Half-Time? An Exploratory Randomized Controlled Trial in a Professional Women's Team	To investigate whether active re-warm-up strategies performed during half-time influence second-half readiness and performance-related outcomes in professional women's soccer players.
Chapter 2	Paper III - Effects of an Integrated Half-Time Re-Warm-Up Protocol (IRW-Soccer) on Neuromuscular Performance in U19 Women's Soccer Players: An Exploratory Study	To evaluate the effects of an integrated half-time re-warm-up protocol combining neuromuscular activation and soccer-specific stimulation on neuromuscular performance in U19 women's soccer players.
Chapter 2	Paper IV - Neuromuscular and High-Intensity Match Performance Responses to Re-Warm-Up Protocols at Halftime: A Pilot Randomized Trial in Professional Male Soccer Players	To analyze neuromuscular and high-intensity match-play responses to half-time re-warm-up protocols in professional male soccer players.
Chapter 3	Overall Discussion	To synthesize and interpret the findings of the four experimental studies, highlighting their theoretical, methodological, and practical implications.
Chapter 4	Final Considerations References	To present the main conclusions, practical applications, limitations, future research directions, and the complete list of bibliographic references cited throughout the dissertation.

To facilitate the understanding of the experimental organization of the doctoral thesis, Figure 1 provides a schematic overview of the halftime re-warm-up protocols and assessment procedures applied across the four studies. Studies 1 and 4 compared two active re-warm-up strategies, the Strength-Power-Based Protocol (SPBP) and the Soccer-Specific Protocol (SSP), without a passive control group. In contrast, Studies 2 and 3 compared the Integrated Re-Warm-Up Soccer protocol (IRW-Soccer) with a passive control condition. Across the studies, physical performance was assessed through countermovement jump (CMJ) and 20-m sprint tests before and after the half-time intervention, while the Acute Readiness Monitoring Scale (ARMS) was additionally used in Studies 1 and 3. In Study 4, match-related external-load variables were also monitored during the first 25 minutes of the second-half using GNSS/GPS technology.

Figure 1. Experimental overview of the half-time re-warm-up protocols applied across Stud



Legend. ARMS = Acute Readiness Monitoring Scale; CMJ = countermovement jump; GNSS = global navigation satellite system; GPS = global positioning system; IRW-Soccer = Integrated Re-Warm-Up Soccer; SPBP = Strength-Power-Based Protocol; SSP = Soccer-Specific Protocol

Note: *The image was developed using generative artificial intelligence, based on instructions, iterative feedback, and conceptual assumptions provided by the author. The creative idea, conceptual organization, and definition of the scientific elements represented are the responsibility of the author, while the visual design was produced with AI support.*

3. Theoretical Background

3.1. Warm-Up and Re-Warm-Up in Team Sports

The physiological and neuromuscular preparation of athletes in team sports is commonly supported by structured warm-up and re-warm-up strategies. Across different sports, these strategies may be understood as deliberate, time-limited preparation periods that can contribute to short-term performance readiness by influencing thermal, cardiovascular, neuromuscular, perceptual, and attentional processes (Bishop, 2003; McGowan et al., 2015; L. M. Silva et al., 2018; Towlson et al., 2013). Rather than being interpreted as a single standardized routine, the warm-up should be considered a flexible and context-dependent preparation process, in which the selected exercises, intensity, duration, and structure should be aligned with the subsequent task demands, athlete characteristics, and practical constraints of the competitive environment (Afonso et al., 2024). Although warm-up practices are sometimes discussed in relation to injury-related outcomes, this relationship should be interpreted cautiously; therefore, the present thesis frames warm-up and re-warm-up primarily in relation to performance readiness and second-half reactivation (Afonso et al., 2025).

Warm-up may contribute to functional readiness through several complementary mechanisms, including cardiovascular stimulation, increased intramuscular temperature, enhanced neuromuscular activation, and improved attentional focus (Bangsbo et al., 2007; Bishop, 2003; McGowan et al., 2015). In applied soccer contexts, warm-up content may range from general activation activities to more specific exercises designed to replicate aspects of the physical, technical, tactical, and perceptual demands of the game (Afonso et al., 2024; Fradkin et al., 2010; McGowan et al., 2015; L. M. Silva et al., 2018). This broader interpretation is relevant because soccer performance does not depend solely on isolated physiological activation, but also on the player's ability to respond to intermittent high-intensity actions, rapid transitions, decision-making demands, and sport-specific movement patterns.

Within this perspective, re-warm-up should be distinguished from the initial warm-up. While the pre-match warm-up prepares players before competition, re-warm-up is performed after players have already completed a period of match activity and subsequently experience a passive or low-activity interval. Therefore, re-warm-up is not

a process of preparing the athlete from an initial resting state, but rather a strategy aimed at maintaining or restoring relevant aspects of readiness before returning to competition. This distinction is particularly important in soccer, where the halftime interval imposes specific temporal, spatial, organizational, and tactical constraints that limit the type and duration of activities that can be realistically implemented (Russell et al., 2015; Towlson et al., 2013).

Structured neuromuscular exercises and soccer-specific activities may provide useful options within this context because they can be adapted to short-duration formats and aligned with the demands of match re-entry. Exercises inspired by the FIFA 11+ programme may offer a practical source of neuromuscular activation through dynamic stability, balance, strength, plyometric, and movement-control tasks, while small-sided games may provide a more ecological stimulus by combining physical activation with ball interaction, perceptual engagement, decision-making, and technical and tactical involvement (Bizzini et al., 2013; Dellal et al., 2011; Hill-Haas et al., 2011; Impellizzeri et al., 2013; Thorborg et al., 2017). Accordingly, FIFA 11+-based exercises and small-sided games provide a practical rationale for the development of integrated re-warm-up strategies that combine neuromuscular activation with soccer-specific re-engagement. Such approaches are particularly relevant for the present thesis because several of these components can be adapted into short-duration halftime strategies. In this context, re-warm-up is considered not as a generic extension of the initial warm-up, but as a constrained, time-efficient, and context-specific intervention designed to support second-half readiness within the practical realities of soccer competition.

3.2. Post Warm-Up and Halftime Deactivation

Beyond the initial preparation phase, the concepts of post-warm-up and re-warm-up have gained increasing attention in the sports performance literature (L. M. Silva et al., 2018). Both periods illustrate how transitions from an active state to a passive or low-activity state may reduce some of the physiological and neuromuscular benefits previously achieved during warm-up. However, in the present thesis, the post-warm-up period is considered only as contextual support, whereas re-warm-up during the halftime interval constitutes the primary focus of investigation. Post-warm-up refers to the period between the end of the initial warm-up and the start of competition, while re-warm-up

refers to strategies implemented during the halftime interval before returning to play (Ribeiro, 2017). In elite soccer settings, the post-warm-up window has been reported to last approximately 12.4 ± 3.8 minutes (Towlson et al., 2013), and passive periods of this nature may be associated with reductions in muscle temperature and decrements in jump and sprint performance (Abade et al., 2017).

A similar issue may occur during the halftime interval, although this period differs from the post-warm-up window because players have already completed a demanding first half before entering a temporary phase of reduced activity. Soccer imposes intermittent high-intensity demands, and the early stages of the second half may require players to rapidly re-engage in actions such as sprinting, jumping, accelerating, decelerating, and changing direction (Oliva-Lozano et al., 2020; Oliva-Lozano et al., 2023). This requirement contrasts with the largely passive nature of the interval, creating a potential mismatch between reduced physiological stimulation and the immediate demands imposed by match re-entry (Mohr et al., 2004; West et al., 2013). In team sports, the halftime interval commonly represents a transition from high-intensity competition to passive rest, often lasting up to approximately 15–20 minutes depending on the competitive context and organizational routines (Russell et al., 2015).

During this period, players often remain seated in the dressing room, consume fluids or nutritional supplements, receive tactical instructions, and may undergo brief medical or massage interventions. Although these tasks are relevant to match management, they are largely non-physical and may therefore contribute to a temporary reduction in physiological stimulation (Russell et al., 2015; Towlson et al., 2013). Passive rest during halftime has been associated with a 1.5–2.0 °C decline in muscle temperature, which may impair explosive performance, including sprint capacity and vertical jump performance (Mohr et al., 2004; West et al., 2013). This physiological deactivation may also influence heart rate, neuromuscular activation and metabolic responses, thereby creating a critical window in which performance capacity may be reduced at the start of the second half (Lovell et al., 2013; Russell et al., 2015; Towlson et al., 2013).

Importantly, halftime deactivation should not be interpreted as an exclusively physiological phenomenon. The transition from active match play to a passive dressing-room environment may also involve perceptual, psychological, and cognitive changes. Tactical instructions, nutritional routines, and passive recovery may be necessary, but

they may also coincide temporary changes in alertness, attentional focus, and perceived readiness before returning to play (Carling et al., 2016; Towlson et al., 2013). Although these subjective responses remain less extensively investigated than physiological changes, they may provide complementary information regarding players' preparedness to resume competition. In selected studies within the present thesis, the Acute Readiness Monitoring Scale (ARMS) was used as a secondary measure in selected studies to examine perceived readiness alongside objective performance indicators (Saw et al., 2016; Summers et al., 2021).

Despite the potential relevance of this transitional period, many elite teams continue to prioritize passive halftime routines focused mainly on tactical instructions, hydration, nutritional strategies, and organizational requirements (Carling et al., 2016; Russell et al., 2015). This reflects the practical reality of the halftime interval, in which performance reactivation must coexist with several essential match-management tasks. From this perspective, the halftime interval can be understood as a complex transitional period in which physiological, neuromuscular, perceptual, and cognitive readiness may fluctuate simultaneously. This interpretation is particularly relevant to the present thesis, as it supports the need to examine re-warm-up not only as a physical intervention, but also as a practical and time-constrained strategy to regulate readiness before re-entry into second-half match demands.

3.3. Practical Constraints and Ecological Validity of Re-Warm-Up

Systematic reviews and narrative syntheses indicate that active re-warm-up strategies may positively influence physiological and physical responses and support readiness responses during the transition from halftime to the second half (Gonzalez-Devesa et al., 2021; Hammami et al., 2018; L. M. Silva et al., 2018). Brief and structured re-warm-up protocols may attenuate the physiological "de-priming" induced by the halftime interval and support a smoother transition back into high-intensity match demands (Gonzalez-Devesa et al., 2021; Russell et al., 2015). From a physiological perspective, this rationale is partly supported by the relationship between muscle temperature and power output, with evidence suggesting that increases in muscle temperature may enhance power performance, whereas reductions in temperature may negatively affect explosive actions (Racinais & Oksa, 2010). This is particularly relevant

because match-simulation studies have shown that the half-time interval may be associated with a 1.5–2.0 °C decline in muscle temperature (Edholm et al., 2014; Mohr et al., 2004).

From a performance perspective, active re-warm-up strategies have been associated with small improvements or attenuated decrements in high-intensity actions such as sprinting and jumping (Fashioni et al., 2020; Gonzalez-Devesa et al., 2021; Yanaoka, Kashiwabara, et al., 2018). Although these effects may appear modest at the individual level, they can be practically meaningful in competitive soccer contexts, where small differences in speed, power, and high-intensity actions may influence transitions, defensive recovery, attacking opportunities, and match-related outcomes (Gonzalez Fernandez et al., 2023). However, the magnitude and direction of these effects appear to depend on several contextual factors, including the type, duration, timing, intensity, and specificity of the re-warm-up protocol.

Recent evidence syntheses have supported the potential efficacy of different re-warm-up approaches. Gonzalez-Devesa et al. (Gonzalez-Devesa et al., 2021) reported average improvements in speed and jump performance, suggesting that short protocols may be effective when performed close to the start of the second half and when composed of structured, rather than improvised, physical activity. Similarly, other recent work has highlighted the potential relevance of short re-warm-up strategies in applied and competitive contexts (Gonzalez Fernandez et al., 2023; Neves et al., 2025). Nevertheless, the available evidence remains heterogeneous, with protocols varying substantially in duration, intensity, modality, and ecological applicability. Therefore, rather than assuming that all re-warm-up strategies produce similar effects, protocol design should consider the specific match context, available space, time constraints, player readiness, and competitive demands.

Several re-warm-up modalities have been investigated, including short-duration cycling protocols, agility-based exercises, whole-body vibration, on-field re-warm-up routines, and passive heat-maintenance strategies (Fashioni et al., 2020; Lovell et al., 2013; Russell et al., 2018; Russell et al., 2015; Yanaoka, Hamada, et al., 2018). Passive heat-maintenance strategies, such as heated garments or survival jackets, may help preserve thermal readiness during periods of reduced activity, particularly in cooler environments or when players remain inactive for extended periods (Kilduff et al., 2013;

Russell et al., 2018). However, the practical feasibility of these approaches may depend on environmental conditions, competition regulations, access to equipment, player acceptance, and the organizational constraints of the halftime interval.

The practical implementation of active re-warm-up is particularly challenging in soccer because the halftime interval is already occupied by several essential tasks, including hydration, nutritional intake, tactical feedback, medical care, and preparation for re-entry onto the pitch (Russell et al., 2015; Towlson et al., 2013). Research suggests that the final minutes of halftime may represent a realistic "window of opportunity" for brief physical activation without substantially interfering with these tasks. In this context, the use of approximately 3 minutes for re-warm-up appears practically relevant, as it may coincide with the period in which players return to the field, reorganize collectively, and prepare for the start of the second half (Russell et al., 2015; Towlson et al., 2013). This is important because only a proportion of elite players report performing halftime activation, and such routines are often unstructured (Towlson et al., 2013), suggesting a gap between scientific recommendations and applied practice.

Within this constrained window, protocols integrating power-oriented exercises or soccer-specific activities may be especially relevant. Strength-power-based approaches may provide a short neuromuscular stimulus through explosive actions potentially associated with post-activation performance enhancement (PAPE) mechanisms, depending on the balance between potentiation and fatigue (Blazevich & Babault, 2019; Hodgson et al., 2005; Seitz & Haff, 2016). In practical terms, a Strength-Power-Based Protocol may stimulate neuromuscular excitability, force-production capacity, and thermal or metabolic readiness for subsequent high-intensity actions (Blazevich & Babault, 2019; Hammami et al., 2018). However, this type of protocol should be interpreted cautiously, as its effectiveness may depend on exercise selection, intensity, recovery time, player training status, and accumulated fatigue.

In contrast, soccer-specific re-warm-up strategies may provide a more ecological stimulus by reproducing relevant perceptual, technical, tactical, and movement demands of match play. Small-sided games, particularly formats such as 5v5, can combine physical activation with ball interaction, decision-making, interpersonal coordination, and high-intensity transitions, depending on pitch size, rules, number of players, and work-rest structure (Asian Clemente et al., 2019; Asian-Clemente et al., 2021; Dellal et al., 2011;

Hill-Haas et al., 2011). Therefore, whereas strength-power-based approaches may primarily target neuromuscular priming, soccer-specific protocols may support a broader re-engagement with the perceptual and tactical demands of the game.

Within the present thesis, these considerations provide the rationale for examining different short-duration re-warm-up strategies under ecologically valid conditions. The Integrated Re-Warm-Up Soccer protocol, hereafter referred to as IRW-Soccer, was designed to optimize the use of the limited halftime window by combining neuromuscular activation exercises with SSG stimuli. In this sense, IRW-Soccer attempts to integrate two complementary components: neuromuscular activation through FIFA 11+-based exercises and soccer-specific re-engagement through small-sided games. Rather than being presented as a definitive or universally superior protocol, IRW-Soccer is interpreted as an exploratory and ecologically valid attempt to regulate readiness within the practical constraints of soccer halftime.

3.4. Female Soccer and Context-Specific Responses

There is a critical need for research specifically addressing female populations in soccer performance and re-warm-up strategies. Current evidence in sport science has historically been derived predominantly from male cohorts or mixed-sex samples, with comparatively fewer studies involving female athletes, particularly in elite and youth soccer contexts (Datson et al., 2014; Emmonds et al., 2019). This imbalance limits the generalizability of current recommendations and reinforces the need to examine how sex, age, maturation, competitive level, fatigue, and training background may influence responses to short-duration re-warm-up protocols.

Female soccer players may exhibit physiological neuromuscular, and contextual characteristics that influence their responses to the re-warm-up stimuli. Factors such as differences in body composition, strength and power profiles, thermoregulatory responses, fatigue development, recovery kinetics, and maturation status may contribute to variability in acute responses to halftime interventions (Datson et al., 2014; Emmonds et al., 2020; Pardos-Mainer et al., 2021). These considerations are particularly relevant in youth and U19 female cohorts, where biological maturation, training age, and competitive experience may vary substantially between players and may affect readiness, neuromuscular performance, and tolerance to high-intensity actions.

In the specific context of re-warm-up, available evidence remains limited and heterogeneous. Gonzalez-Fernandez et al. (Gonzalez Fernandez et al., 2023) reported differences in physiological responses, between male and female players, while recent reviews have highlighted that the literature on re-warm-up is still characterized by variation in protocols, samples, outcomes, and ecological validity (Gonzalez-Devesa et al., 2021; Neves et al., 2025). This emerging evidence suggests that male and female athletes may not respond identically to the same re-warm-up stimulus, and that the optimal intensity, duration, content, and timing of re-warm-up should not be assumed to be identical across sexes without specific validation.

From an applied perspective, this issue is particularly important because re-warm-up strategies must be feasible within the real constraints of soccer competition. Protocols designed primarily within male professional contexts may not fully account for the physiological, maturational, organizational, and contextual realities of female soccer, especially in youth or U19 populations. Therefore, research involving female soccer players should not only replicate protocols previously tested in male populations, but should also examine whether the structure and dose of re-warm-up are appropriate for the characteristics and needs of female cohorts.

In this regard, the present doctoral thesis seeks to contribute preliminary and ecologically grounded evidence on short-duration re-warm-up strategies across female and male soccer contexts. Particular emphasis is placed on women's soccer and U19 female players, for whom the available evidence remains scarce and where applied protocols must be validated under realistic competitive or match-simulation conditions. While the findings of this thesis may help inform practice, larger-scale, replicated, and more controlled studies are still needed to consolidate sex and age-informed recommendations for halftime re-warm-up in soccer.

3.5. Readiness, Re-Warm-Up Approaches as a Multidimensional Process

Athletic readiness should be understood as a multidimensional and dynamic state that reflects the athlete's capacity to respond effectively to the demands of training or competition at a given moment. Rather than being determined solely by objective physical capacity, readiness emerges from the interaction between physiological status, neuromuscular function, perceived recovery, fatigue, motivation, attentional focus, and

cognitive-affective states (Saw et al., 2016; Summers et al., 2021). In elite sport, this concept is particularly relevant because performance capacity may fluctuate within short timeframes, especially during periods of accumulated fatigue, congested competition, or transitions between active and passive phases of play (Halson, 2014; Kellmann et al., 2018; Thorpe et al., 2017).

Within soccer, readiness is especially important during the halftime interval because players are required to transition from a demanding first half to a temporary period of reduced activity and then rapidly re-engage with high-intensity match demands. As discussed previously, this transition may involve changes in muscle temperature, heart rate, neuromuscular activation, perceived freshness, alertness, and cognitive focus (Lovell et al., 2013; Mohr et al., 2004; Russell et al., 2015). Therefore, second-half performance should not be interpreted only through isolated physiological or neuromuscular markers, but rather within the broader physical, perceptual, and contextual dimensions of readiness.

Subjective measures may provide complementary information in this context. Self-report measures have been shown to be sensitive tools for monitoring athletes' responses to training and competition, especially because they may capture changes in perceived well-being, fatigue, recovery, and preparedness that are not always fully reflected by objective performance measures alone (Saw et al., 2016). Within selected studies of the present thesis, the ARMS was used as a secondary measure to assess athlete's immediate perceptions of physical and mental readiness alongside objective indicators such as Sprint and Jump performance (Summers et al., 2021). The use of ARMS in the context of half-time re-warm-up allows subjective states to be interpreted alongside objective performance measures, such as sprinting and jumping outcomes. This complementary approach may contribute to a broader interpretation of athlete's responses to short-duration re-warm-up interventions.

Active re-warm-up may therefore function not only as a physiological stimulus, while potentially supporting perceptual and cognitive re-engagement before second half re-entry. By increasing physical activation, restoring attentional focus, and reintroducing players to task-specific movement demands, re-warm-up may help regulate the transition from passive halftime routines to the dynamic demands of match play (Lovell et al., 2013; Mohr et al., 2004; J. R. Silva et al., 2018). Recent studies have also suggested that brief

re-warm-up routines may influence attentional focus and decision-making under time pressure, although the available evidence remains limited and should be interpreted cautiously (González-Fernández et al., 2025; Nourshahi et al., 2024).

Taken together, the literature suggests that halftime represents a transitional period in which physiological deactivation, neuromuscular decline, perceptual changes, cognitive engagement, and tactical reorganization may interact (Mohr et al., 2004; Russell et al., 2015; Towlson et al., 2013). Active re-warm-up strategies may offer a practical means of regulating some of these responses, but the magnitude and direction of the effect likely depend on contextual factors such as protocol content, intervention duration, competitive level, sex, age, accumulated fatigue, and the specific demands of the match (Gonzalez-Devesa et al., 2021; Hammami et al., 2018; L. M. Silva et al., 2018). Therefore, rather than assuming that a single re-warm-up protocol will universally enhance performance, the present thesis adopts a cautious and exploratory perspective. Re-warm-up is interpreted as a potential strategy for regulating second-half readiness under ecological constraints. Within this framework, SPBP, SSP, and IRW-Soccer are examined as different practical approaches that may influence performance-related and match-related responses in distinct and context-dependent ways.

3.6. Purpose of the Thesis

The theoretical and empirical evidence reviewed in this chapter supports the central rationale of the present doctoral thesis: to explore whether short-duration, feasible, and soccer-specific re-warm-up strategies can contribute to the maintenance or regulation of readiness during the transition from halftime to the early stages of the second half. This rationale is based on the premise that halftime should not be interpreted solely as a passive recovery period, but also as a critical transitional phase in which recovery, tactical reorganization, physiological reactivation, and preparation for second half match demands must coexist within a limited time window.

Accordingly, the present thesis focused on the development and evaluation of 3-minute active re-warm-up strategies that could be implemented within the practical constraints of the halftime interval. These strategies were designed to examine whether different combinations of neuromuscular activation, power-oriented exercises, and soccer-specific stimulation could influence physical performance indicators, and match-

related responses, while selected studies also considered perceived readiness as a complementary outcome. This perspective also provided the foundation for the development of a broader conceptual model of dynamic halftime readiness regulation in soccer.

The empirical component of the thesis was organized into four experimental studies. These studies progressively examined: (i) the comparison between power-based and soccer-specific re-warm-up strategies in senior female players; (ii) the application of the integrated IRW-Soccer protocol compared with passive rest in senior female players; (iii) the feasibility and effects of IRW-Soccer in U19 female players; and (iv) the comparison between power-based and soccer-specific re-warm-up strategies in senior male professional players, including match-related external-load responses. Together, these studies were designed to address the identified gaps in the literature, particularly the limited evidence regarding short-duration, ecologically valid, and sex and age-informed re-warm-up strategies in soccer. By integrating objective physical performance indicators, selected subjective readiness measures, and match-related responses, this thesis aims to contribute to a more comprehensive understanding of how different halftime re-warm-up strategies may regulate readiness and support second half performance in applied soccer contexts.

Chapter 2 - Original Research Articles

Paper I - Warm-Up Strategies at Halftime: A Pilot Randomized Controlled Trial in a Professional Women's Soccer Team

Paper II - Should Soccer Players Re-Warm-up at Half-Time? An Exploratory Randomized Controlled Trial in a Professional Women's Team

Paper III - Effects of an Integrated Half-Time Re-Warm-Up Protocol (IRW-Soccer) on Neuromuscular Performance in U19 Women's Soccer Players: An Exploratory Study

Paper IV - Neuromuscular and High-Intensity Match Performance Responses to Re-Warm-Up Protocols at Halftime: A Pilot Randomized Trial in Professional Male Soccer Players

Paper I - Warm-Up Strategies at Halftime: A Pilot Randomized Controlled Trial in a Professional Women's Soccer Team

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Article

Warm-Up Strategies at Halftime: A Pilot Randomized Controlled Trial in a Professional Women's Soccer Team

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Abstract

Objectives: We compared the effects of two active re-warm-up protocols applied during halftime's last three minutes, after a warm-up, testing, and a simulated first-half match. **Methods:** Twenty-two professional players from a first Portuguese division club were randomized into two re-warm-up protocols during a simulated match interval: (i) a strength, plyometrics, and balance protocol (SPBP); and (ii) a soccer-specific protocol (SSP). Players were assessed for a 20-m linear sprint and countermovement jump (CMJ) after the warm-up and the re-warm-up. Descriptive statistics and mixed ANOVA were performed, with effect size assessed using partial eta-squared. The Acute Readiness Monitoring Scale (ARMS) questionnaire was administered after the simulated match and re-warm-up and was analyzed using a multifactorial ANOVA. **Results:** No significant interaction effects were observed ($p > 0.05$). Comparing pre-match to post-re-warm-up, there was a slight decrease in sprint (significant) and jump performance (non-significant). Additionally, there were no between-protocol differences in perceived readiness (ARMS). **Conclusions:** After the three-minute re-warm-up protocols, similar results were observed in the 20-m sprint performance, CMJ, and perceived readiness when comparing SPBP and SSP. These re-warm-up protocols (SPBP and SSP) are practical to implement within a 3-min time window, and, given their apparent lack of differences, players' preferences could be considered. However, the SSP is currently subject to restrictions that limit teams' access to the field during this period. Future research should compare active re-warm-up protocols with passive controls to more clearly assess their effectiveness.

Keywords: re-warm-up; halftime; rest period; jump; sprint; performance

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1. Introduction

Warm-up practices are fundamental in team sports, offering physiological and physical benefits [1], preparing athletes for optimal performance [2]. They enhance athletic performance by increasing muscle temperature, accelerating metabolism, optimizing force/power output, and neuromuscular activation [3,4]. Warm-ups accelerate and optimize VO_2 kinetics to more efficiently meet exercise demands [5,6], activate the central nervous system [7], and improve performance in sprinting and changes of direction (COD) tasks [8]. Warm-ups

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1. Introduction

Warm-up practices are fundamental in team sports, offering physiological and physical benefits (Towlson et al., 2013), preparing athletes for optimal performance (L. M. Silva et al., 2018). They enhance athletic performance by increasing muscle temperature, accelerating metabolism, optimizing force/power output, and neuromuscular activation (Faulkner et al., 2013; McGowan et al., 2015). Warm-ups accelerate and optimize VO_2 kinetics to more efficiently meet exercise demands (Bishop, 2003; M. Pernigoni et al., 2024), activate the central nervous system (Blazevich et al., 2018), and improve performance in sprinting and changes of direction (COD) tasks (Taylor et al., 2013). Warm-ups are applied in various contexts: pre-training, pre-match, halftime, and during the match (Ribeiro, 2017). While the traditional focus has been on pre-training or pre-match warm-ups, increasing attention is now being paid to re-warm-up strategies during halftime.

Prolonged passive breaks during halftime can negatively affect second-half performance due to decreases in body and muscle temperature (Hammami et al., 2018), leading to reduced physical output (Lovell, Barrett, et al., 2013; Mohr et al., 2004). The ability to perform high-intensity activities is essential in team sports (Hammami et al., 2018). Reductions in muscle temperature have been found to cause declines in high-intensity running in elite players, negatively impacting sprint and jump performance post-halftime (Edholm et al., 2014; Mohr et al., 2004). Similarly, Russell et al. (Russell et al., 2015) and Lovell et al. (Lovell, Midgley, et al., 2013), reported diminished physical performance and match intensity early in the second half due to physiological deactivation, characterized as the decline in physiological readiness during the half-time break, including reductions in muscle temperature, heart rate, and neuromuscular activation.

Active re-warm-up interventions can mitigate these effects (Gonzalez-Devesa et al., 2021), helping to preserve muscle temperature and neuromuscular function (McGowan et al., 2015; J. R. Silva et al., 2018). Studies suggest that protocols lasting 5 (Lovell, Midgley, et al., 2013; Lovell et al., 2007) to 7 minutes (Mohr et al., 2004; Yanaoka, Hamada, et al., 2018), improve second-half performance compared to passive rest (Ltifi et al., 2023), especially in the initial 15 minutes of the second half

(Lovell, Midgley, et al., 2013; Mohr et al., 2004). These re-warm-up interventions, often related to post-activation performance enhancement (PAPE), aim to optimize performance in high-intensity actions, such as jumping, sprinting, and changes of direction by incorporating strength and power exercises (Petisco et al., 2019; L. M. Silva et al., 2018).

Such findings highlight the importance of exploring halftime re-warm-up strategies that help maintain player readiness for soccer-specific high-intensity activities, including running and changes of direction (Abade et al., 2017; Mohr et al., 2004; Yanaoka, Hamada, et al., 2018). However, despite the growing evidence supporting these interventions, a systematic review by Hammami et al. (Hammami et al., 2018), emphasizes the lack of consensus on the most effective protocols. Variables such as activity type, intensity, and break duration appear to influence the effectiveness of these strategies, highlighting the need for further research to determine optimal re-warm-up approches, particularly regarding PAPE based methods and their impact on early second-half performance.

Several studies have documented the detrimental effects of passive halftime rest on performance, especially on sprinting and vertical jump height (Bang & Park, 2022; Christaras, 2023), primarily due to reduced muscle temperature, which impairs explosive force generation (Christaras, 2023; Mohr et al., 2004). Re-warm-ups help preserve muscle temperature and neuromuscular function, thereby enhancing second-half performance (Gonzalez Fernandez et al., 2023). Meta-analyses confirm the negative effects of passive halftime rest on vertical jump performance (Gonzalez Fernandez et al., 2023), while subjective assessments (e.g., ARMS) indicate reduced perceived muscular readiness (Summers et al., 2021). These effects are most prominent in the first 15 minutes of the second half (Russell et al., 2015), reinforcing the necessity of effective halftime re-warm-up strategies to prevent performance declines in soccer (Edholm et al., 2014). Although re-warm-up strategies enhance second-half performance (Edholm et al., 2014; Towlson et al., 2013; Yanaoka, Hamada, et al., 2020; Yanaoka, Iwata, et al., 2020), implementation in professional environments is often hindered by time constraints and coaching preferences (Towlson et al., 2013).

Therefore, it is recommended to explore high-intensity, short-duration (≈3 minutes) exercises (Yanaoka, Hamada, et al., 2018). Christaras et al. (Christaras, 2023)

found that a three-minute re-warm-up maintained core temperature and preserved high-intensity performance, specifically in jumping and sprinting in youth soccer players. These results suggest that short-duration, low-to-moderate intensity protocols (~3 min) may be practical and effective (Yanaoka, Hamada, et al., 2018), especially when time is limited, to help maintain body temperature and improve sprint performance post-halftime, showing comparable effects to longer protocols (Lovell, Midgley, et al., 2013; Lovell et al., 2007; Mohr et al., 2004).

Additionally, a major gap in the literature is the underrepresentation of female athletes in studies on warm-up and re-warm-up interventions (Gonzalez Fernandez et al., 2023). The predominance of male-focused research is problematic given the rapid growth of women's soccer (Smith et al., 2022). Female athletes exhibit distinct physiological characteristics, such as muscle composition, thermoregulation, and hormonal profiles, that may influence their responses to re-warm-up strategies (Datson et al., 2014). Recent studies (Emmonds et al., 2019; J. R. Silva et al., 2018; Zylberberg et al., 2024), show that females respond differently to potentiation-based warm-up protocols, suggesting that male-derived findings may not be directly transferable. A systematic review by Silva et al. (J. R. Silva et al., 2018) emphasize that most current knowledge is based on male cohorts, limiting applicability to female players. The lack of validated, female-specific protocols restricts the development of effective interventions. Recent reviews (Elliott-Sale et al., 2021) emphasize the urgent need for sex-specific research, making this scientific gap a core motivation for the development and design of the present study.

This study aims to investigate the effects of two distinct halftime re-warm-up protocols on performance in a professional women's soccer team: a strength-plyometrics-balance protocol (SPBP) and a soccer-specific protocol (SSP). The SPBP integrates neuromuscular exercises designed to induce (PAP), which enhances performance in activities requiring strength, speed, and power. The SSP, in contrast, focuses on soccer-specific movements, including small-sided games (SSG), and can be completed within a three-minute timeframe, making it a practical option for match settings. By focusing on female-specific responses, this research intends to fill the gap in the literature by providing evidence-based recommendations for re-warm-up

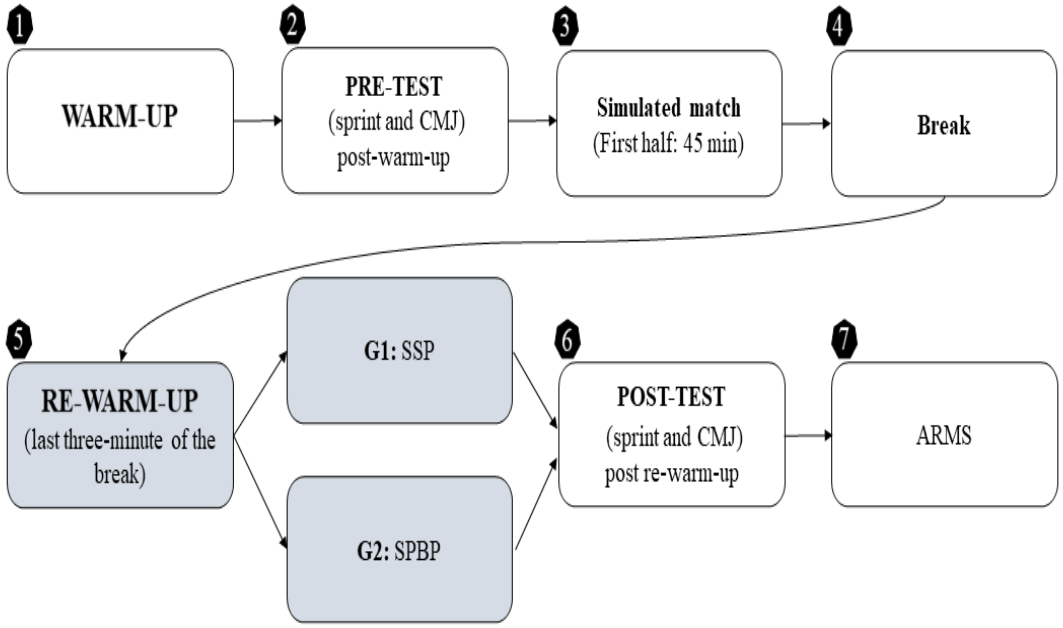
protocols tailored to female athletes, thereby contributing to the development of more effective and practical strategies for improving second-half performance.

2. Materials and Methods

2.1. Study design

A randomized trial with two parallel groups, was conducted to compare the effects of two active re-warm-up protocols at halftime on physical performance and perception of readiness in women's soccer players. The re-warm-up protocols (SPBP and SSP) were randomly assigned using simple randomization. However, the testing procedures followed a fixed order for all participants to ensure standardization and minimize variability. Following randomization, no relevant differences were observed between the groups. Research has demonstrated that the FIFA 11+ program can elicit acute improvements in performance, including a reduction in 20 m sprint time, an increase in jump height, and enhanced agility compared to other dynamic warm-ups (Bizzini et al., 2013). The FIFA 11+ protocol was chosen for its simplicity and speed, with six exercises feasible within the three-minute re-warm-up period, aligning with practical competition settings. Consequently, we included a protocol comprising (i) an SPBP integrating a segment of FIFA 11+ and (ii) an SSP featuring a small-sided game (i.e., 5 vs. 5 + Floater). The evaluation focused on performance in a 20-meter sprint test and CMJ (Figure 1). The study's objectives and procedures were explained to the players, who then signed an informed consent form. All procedures complied with the Declaration of Helsinki (updated version of 2013, Fortaleza).

Figure 1. Diagrammatic representation of the randomized trial. Note: CMJ, countermovement jump; min, minutes; G1, Group 1; G2, Group 2; SSP, soccer-specific protocol; SPBP, strength, plyometrics, and balance protocol; ARMS, acute readiness monitoring scale.



2.2. Participants

We recruited a purposeful, convenient sample of 22 professional women's soccer players of 23.4 ± 3.4 years; height:168 ± 6.6 cm; body mass: 60.1 ± 6.0 kg (mean ± standard deviation), representing the entire roster of a club participating in the 2023/2024 Portuguese Women's National Soccer Championship season. Prior to recruitment, approval was obtained from the team's technical staff. Players who met the selection criteria were randomly assigned to the study groups. The study included female soccer players with no limitations on match participation. Exclusion criteria were: (i) recent injury within the week prior to evaluations affecting match performance, (ii) players in the process of returning to match play, and (iii) individuals with pre-existing physical limitations before the evaluations

The team coach, under the supervision of the study's lead author, randomly assigned the 22 players into two groups using a balanced randomization method. Players were first paired based on specific characteristics, such as prior performance, and then randomly allocated within each pair, ensuring that both groups had a similar

composition with respect to these key variables. This ensured a fair and unbiased assignment. Following randomization, each group consisted of 11 participants (Figure 2).

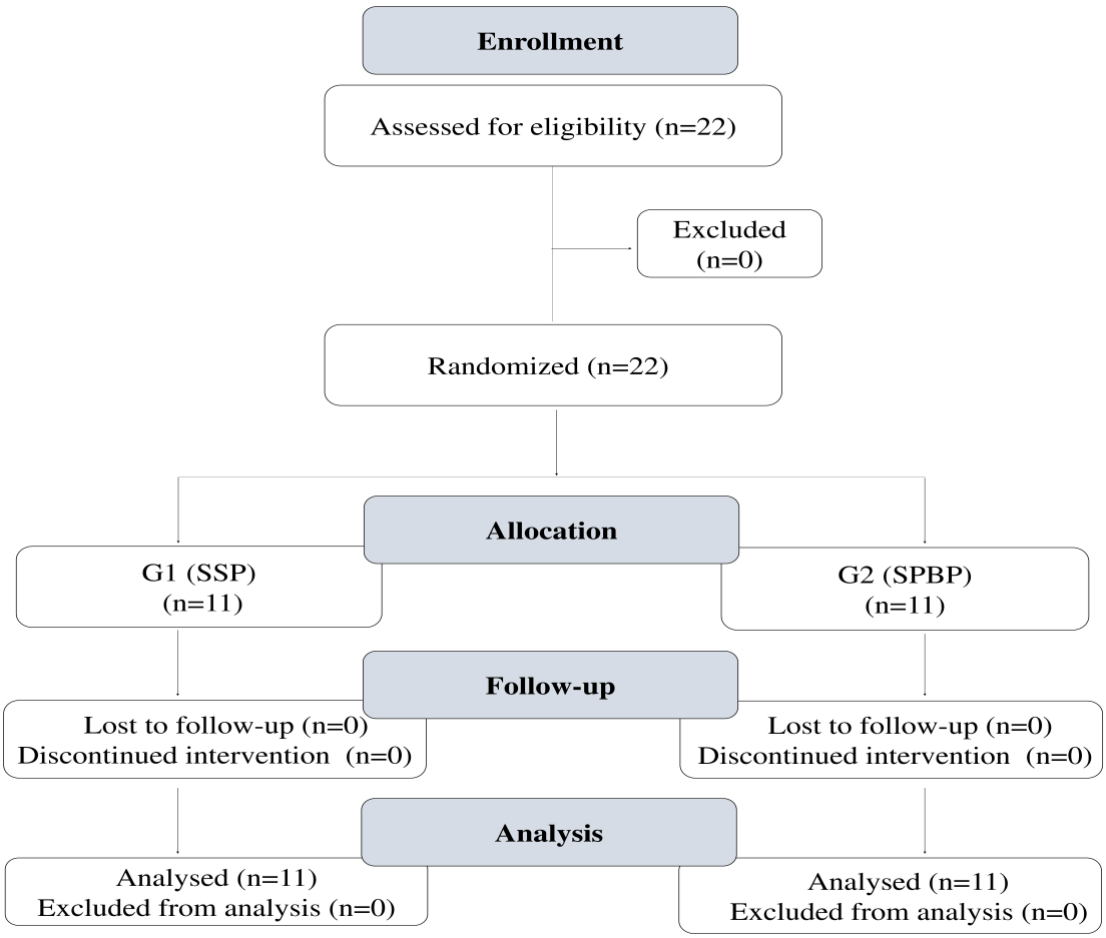


Figure 2. Flowchart of study participants. Note. SSP, soccer-specific protocol; SPBP, strength, plyometrics, and balance protocol.

2.3. Interventions

2.3.1. Familiarization session

Before the start of the study, players participated in a familiarization session to become accustomed to the re-warm-up protocols and the tests designed to assess sprint performance and lower limb power. This session was conducted under conditions identical to those of the experimental session, including the use of GPS tracking to ensure

consistency in data collection and monitoring. Players followed the exact same procedures, ensuring complete familiarity with all components of the protocol. The session began with a standardized warm-up identical to that performed before official matches. After the warm-up, players moved to the center of the field (with a maximum transition time of one minute to simulate halftime constraints) and performed a linear sprint, followed after an equivalent rest period by a CMJ. The first 45-minute half of the simulated match then commenced.

During the final three minutes of the simulated halftime interval, players completed both re-warm-up protocols as instructed. At the end of this period, they returned to the center of the field (again within a one-minute transition window), performed the sprint test, followed by the CMJ, and then began the second 45-minute half. At the end of the second half, while in the locker room, participants completed a post-exercise questionnaire. This familiarization process ensured that players were thoroughly prepared for each stage of the experimental protocol, reducing variability and enhancing the reliability of the performance and perceptual data collected.

2.3.2. Data Collection Procedures

After completing the full familiarization session, participants returned on a separate day for the simulated first-half match, during which all procedures were reviewed again. In this initial phase, players performed their usual pre-match warm-up under the guidance of the technical staff, following the recommendations of the FIFA 11+ Program. This standardized warm-up lasts approximately 15 to 20 minutes and consists of three main parts:

(1) running and dynamic mobility exercises to raise body temperature and activate the cardiovascular system;

(2) strength, balance, plyometric, and neuromuscular control exercises aimed at improving motor control and reducing the risk of muscular and ligament injuries;

(3) running with accelerations and changes of direction to prepare athletes for explosive actions during the match.

This protocol has been shown to improve balance, eccentric strength, and neuromuscular control and is recommended for athletes aged 14 years and older (Bizzini et al., 2013; Soligard et al., 2008).

At the end of the warm-up, players performed the pre-test to assess sprint speed and lower limb power using the 20-meter sprint test and CMJ, respectively. The tests were initiated immediately after the warm-up without any rest period in order to preserve the temporal effect of the warm-up, as per the established protocol. To ensure this, the investigative team and technical staff supported the process, and players were previously instructed to ensure an efficient and delay-free transition between the warm-up and the tests.

Next, participants played a simulated 11-a-side mach, consisting of two 45-minute halves and a 15-minute halftime break, in accordance with the official rules of the Fédération Internationale de Football Association (FIFA). During the halftime break, athletes remained in passive rest in the locker room and were instructed not to engage in any physical activity that could affect the study's outcomes. They were allowed to perform typical halftime activities such as using the restroom, listening to the coach’s instructions, and hydrating, but no additional physical exertion was permitted. Any deviation from these instructions was recorded and considered during data analysis.

In the last three minutes of the break, the SSP protocol was applied to 11 players, while the other 11 performed the SPBP, according to prior randomization. The post-test was then conducted to assess sprint speed and power, using the same procedures as the pre-test. Finally, the Acute Readiness Monitoring Scale (ARMS) questionnaire (Keegan et al., 2021; Pomares-Noguera et al., 2018) was administered to evaluate players' readiness and ability to perform tasks during the second half (Figure 1).

This structure is commonly used in soccer to replicate competitive match conditions and to allow for performance-related data collection under ecologically valid circumstances. Implementing the intervention in this context ensured that players were in a physical and mental state comparable to official competition, while allowing for controlled application of the re-warm-up protocols. This approach has been adopted in previous studies, such as those by Edholm et al. (Edholm et al., 2014), who conducted their interventions during competitive periods, and Yanaoka et al. (Yanaoka, Iwata, et al., 2020), who simulated match-play environments to improve ecological validity.

2.3.3. Strength, plyometrics and balance protocol (SPBP)

The SPBP protocol consisted of six exercises based on Part 2 of the FIFA 11+ Program: specifically designed to develop lower-limb strength, neuromuscular control, and dynamic balance and to reduce and improve the performance of soccer players through specific strength, balance, and running exercises (Barengo et al., 2014). The selected exercises were: (i) squats with toe raise jumping, (ii) walking lunges squats, (iii) one-leg squats jumping, (iv) vertical jumps, (v) lateral jump squats, and (vi) box jumps. Using this re-warm-up protocol, players performed two sets of eight repetitions of each exercise three minutes before starting the aforementioned sprint and jump tests. The protocol was designed to fit within three minutes, as the six exercises are simple, expeditious, and do not require equipment. This enables efficient execution within the time constraints of a real competitive context. This approach aligns well with the practical constraints of halftime in soccer and enhances the ecological validity of the study.

2.3.4. Soccer-specific protocol (SSP)

The SSP consisted of a small-sided game (5 vs. 5 + floater) aimed at maintaining ball possession on a 15 × 15m field (Zois et al., 2013). Players were randomly assigned to teams by the coaching staff, and the only rule was that each player was only allowed to touch the ball twice without other strategic focuses, in order to reduce variables that could influence performance. The goalkeeper acted as the floater and was allowed to play with both feet and hands. The utilization of a floater is a common practice in small-sided games within the context of soccer, facilitating match dynamics. Researchers and technical staff positioned themselves along the sidelines with replacement balls to ensure continuous play and prevent interruptions when the ball went out of bounds. The intervention was continuous and lasted for three minutes, and the players performed both tests immediately after the re-warm-up, without any rest period prior to the test, to maintain the time window for the effects of the re-warm-up. All procedures of both protocols were strictly controlled by the research team.

2.4. Performance Assessment

After the warm-up and re-warm-up, players completed two physical tests to assess performance: a 20-m sprint and a CMJ test. Sprint performance was recorded using the WIMU PRO™ device from RealTrack Systems (Almería, Spain). The analysis was based on the average speed recorded during the 20-meter sprint test. Each player was assigned an individual GPS device, which was positioned at midfield, activated 30 minutes before the initial warm-up, and placed in an adjustable vest worn on the player's back. This GPS monitoring system reliably collects movement data during training and matches (ICC > 0.93) (Balsalobre-Fernandez et al., 2014). After the simulated match, the devices were removed, and the data were transferred to the proprietary S-PRO™ analysis software.

To ensure accuracy, the start and end points of each 20-meter sprint were identified using the GPS tracking data, and each sprint was individually isolated through the S-PRO™ software. This procedure enabled the precise calculation of the average speed over the exact 20-meter distance for each athlete. The same methodology was applied at both evaluation time points (i.e., post-warm-up and post-re-warm-up), allowing for a direct and reliable comparison of performance across conditions for each player.

Following the sprint test, after a one-minute rest, players performed a CMJ to assess lower limb power. The CMJ height was measured using the My Jump 2 (MJ2) application, which has demonstrated nearly perfect agreement with force plate measurements (ICC = 0.997, 95% CI: 0.996–0.998). This application has been employed in other sports (Gallardo-Fuentes et al., 2016; Yingling et al., 2018) and has shown nearly perfect agreement (ICC = 0.997, 95% CI: 0.996–0.998) compared to the gold standard method for estimating CMJ height (i.e., force plate) (Balsalobre-Fernandez et al., 2015).

Players were instructed to stand upright with their hands on their hips and maintain this position throughout the test. When ready, they performed a downward movement until their knees reached a 90-degree angle, then immediately executed a rapid and explosive vertical jump to achieve maximum height. All Jumps were recorded on video and later analyzed using the MJ2 app. Takeoff was defined as the moment both feet left the ground, and landing as the moment at least one foot touched down (Balsalobre-Fernandez et al., 2014). Each athlete performed one jump and repeated the movement if

incorrectly executed. Only one sprint and one CMJ were performed to avoid compromising match readiness (Sanchez-Sanchez et al., 2024) and to maintain the time-sensitive blinding needed to assess the warm-up and re-warm-up effects on performance.

Although relying on a single sprint and jump trial may be viewed as a potential limitation given that multiple attempts are often recommended to ensure maximal effort all athletes in the present study underwent a familiarization session and were clearly informed in advance that only one attempt would be permitted. This likely enhanced their focus and execution. Considering the athletes' professional status and the limited time available during the re-warm-up window, this approach is methodologically justified and consistent with previous research conducted in elite sport settings (Moir et al., 2004; Wisløff et al., 2004).

2.5. Secondary outcomes

Following the physical tests, the players completed the Acute Readiness Monitoring Scale (ARMS) questionnaire (Summers et al., 2021), which consists of 32 items encompassing nine factors: general readiness, physical readiness, physical fatigue, cognitive readiness, cognitive fatigue, readiness for threat challenges, readiness for skills and training, group/team readiness, and equipment readiness (Keegan et al., 2021). To explore the implications of re-warm-up on players' performance in the second half of the match, we selected items from the ARMS, which we considered most directly relevant to our goals: (i) physical readiness (three questions:1, 14 and 16); and (ii) cognitive readiness (three questions: 26, 27 and 28) (Keegan et al., 2021). We acknowledge that this means the data are not validated, so we refrained from analyzing composite scores and instead examined each item separately, with the discussion of these results necessarily being cautious. The questionnaire utilized a scale from zero (did not apply) to six (fully applied) and was completed in the locker room. Players were instructed on completion and assured of response confidentiality. They were told not to communicate with teammates while filling out the questionnaire to ensure individual completion without external influence.

2.6. Statistical analyses

The Kolmogorov-Smirnov test was used to analyze the data distribution, which followed the normal distribution. Therefore, means and standard deviations (SD) were reported. We used mixed ANOVA (within- and between-factors) to compare the group*time interaction for the primary outcomes (CMJ and 20-m sprint test). Multifactorial ANOVA was used to compare the responses of the ARMS questionnaire. The magnitude of the effect was assessed using partial eta squared (η_p^2) and classified as small (≥ 0.01), moderate (≥ 0.06), and large (d ≥ 0.14) (Richardson, 2011). The level of statistical significance was set at 5%. All analyses were performed in IBM SPSS software version 27.0 (Chicago, IL, US.

3. Results

3.1. Main outcomes: Interaction between protocols on players' sprint and CMJ

The interaction between protocols showed no significant differences in sprint ($p = 0.68$, $\eta_p^2 = 0.008$) or CMJ ($p = 0.07$, $\eta_p^2 = 0.004$) performances (see Table 1). Players were slower at post-re-warm-up compared to post-warm-up, with an effect of large magnitude ($p < 0.001$, $\eta_p^2 = 0.79$).

Table 1. Descriptive statistics and interaction effects for sprint and CMJ, post-warm-up and post-re-warm-up.

Protocol		Mean± SD	*F*	*p*	η_p^2
	Sprint		73.1	0.001*	0.790
	Sprint x Protocol		0.17	0.684	0.008
SSP	Pre-test: Sprint post-warm-up (s)	3.51± 0.15			
	Post-test: Sprint post-re-warm-up (s)	3.86 ± 0.15			
SPBP	Pre-test: Sprint post-warm-up (s)	3.50± 0.10			
	Post-test: Sprint post-re-warm-up (s)	3.88 ± 0.26			
	CMJ		3.54	0.074	0.151
	CMJ x Protocol		0.85	0.773	0.004
SSP	Pre-test: CMJ post-warm-up (cm)	32.3 ±3.93			
	Post-test: CMJ post re-warm-up (cm)	31.1 ± 4.27			
SPBP	Pre-test: CMJ post-warm-up (cm)	36.3 ±4.88			
	Post-test: CMJ post re-warm-up (cm)	34.7 ± 5.94			

Note. * Statistically significant ($p < 0.05$). *Abbreviations*: CMJ, counter-movement jump; SD, standard deviation; SSP, soccer-specific protocol; SPBP, strength, plyometrics, and balance protocol.

There was no significant difference in CMJ ($p = 0.07$, $\eta_p^2 = 0.151$) between post-warm-up and post-re-warm-up. In the inter-group analysis, no significant differences were observed between the protocols in sprint ($p = 0.88$,

$\eta_p^2 = 0.001$) or in CMJ ($p = 0.06$, $\eta_p^2 = 0.162$), indicating that both rewarming methods produced similar responses; (Figure 3)

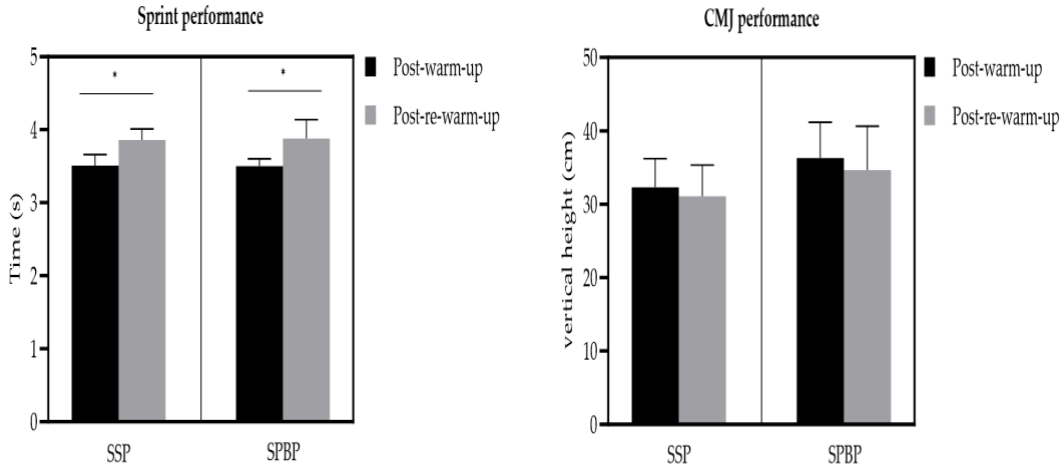


Figure 3. Effects of different protocols on sprint and countermovement jump performance.

Sprint performance (left panel): Sprint times (in seconds) post-warm-up and post-re-warm-up for two protocols: a SSP, soccer-specific protocol, and SPBP, a strength, plyometrics, and balance protocol. ***** Significant difference ($p < 0.001$). CMJ, Countermovement jump performance (right panel): jump height (in centimeters) measured post-warm-up and post-re-warm-up under the same protocols. Data are presented as mean ± SD.

3.2. Secondary outcomes

There were no significant differences in responses to the ARMS questionnaire ($p = 0.481$, $\eta_p^2 = 0.27$) between players who performed the SSP and those who completed the SPBP protocol (Table 2).

Table 2. Acute readiness monitoring scale questionnaire.

ARMS	SSP	SPBP	*p*
Physical Readiness			
I am physically fit	4.27 ± 1.27	4.72 ± 1.19	0.397
I am physically prepared	4.63 ± 1.36	4.63 ± 1.20	1.000
I am physically fresh	3.63 ± 1.28	3.90 ± 1.22	0.616
Cognitive Readiness			
I can focus well	4.63 ± 0.50	5.09 ± 0.94	0.174
I am mentally prepared	4.36 ± 1.36	5.09 ± 1.22	0.202
I am thinking clearly	5.00 ± 1.09	5.00 ± 0.89	1.000

***Abbreviation**:* SSP, soccer-specific protocol; SPBP, strength, plyometrics, and balance protocol ARMS, Acute readiness monitoring scale.

4. Discussion.

Our aim was to investigate and compare the effects of two active re-warm-up protocols (SSP and SPBP), applied during the last three minutes of halftime, on players' physical performance, specifically sprint and CMJ, measured at two-time moments: post-warm-up and post-re-warm-up. Both protocols were designed to be feasible within the short halftime re-warm-up window and resulted in no significant interaction effects on sprint or CMJ performance, nor on perceived readiness as assessed by the ARMS questionnaire.

The underlying mechanisms of the SSP and SPBP protocols provide valuable insights into their effects on performance enhancement. A detailed analysis of these

mechanisms, as highlighted in the review by McGowan et al. (McGowan et al., 2015), reveals that strength-related and plyometric exercises primarily promote benefits through post-activation potentiation (PAP) or post-activation performance enhancement (PAPE), whereas small-sided games (SSGs) mainly increase muscle temperature and neuromuscular readiness. This distinction offers a clearer understanding of how each re-warm-up protocol may differentially influence athlete performance. Our findings can be contextualized by comparing the characteristics of re-warm-up interventions used in previous studies. Variations in re-warm-up duration, intensity, and exercise modality (e.g., cycling, running, resistance exercises) can explain discrepancies in outcomes across the literature.

The temporal pattern of match intensity deserves particular attention, as the first 15 minutes of the second half represent a unique period often characterized by lower physical output despite the accumulated fatigue expected in the later stages of the match. Evidence from Mohr et al. (Mohr et al., 2004), Russell et al. (Russell et al., 2015), and Lovell et al. (Lovell, Midgley, et al., 2013), demonstrates that reductions in high-intensity running and sprint performance during this period are likely related to physiological factors such as decreased muscle temperature and neuromuscular deactivation during the passive half-time interval. Re-warm-up protocols can mitigate these declines by maintaining muscle temperature and neuromuscular readiness, as supported by Silva et al. (L. M. Silva et al., 2018) and McGowan et al. (McGowan et al., 2015), which demonstrated the benefits of re-warm-up protocols in minimizing this effects focused specifically on physical performance.

In this context, the present investigation contributes to the development of evidence in this field by highlighting the importance of re-warm-up strategies in mitigating the performance declines typically observed after half-time. It offers a deeper understanding of their role in optimizing match intensity during the early stages of the second half, particularly in relation to sprinting, jumping actions, and attentional focus on task execution assessed through the application of the ARMS questionnaire. These considerations strengthen the interpretation of our results and better situate our findings within the existing literature on re-warm-up effects and match performance dynamics.

The discussion was structured to emphasize the comparative analysis between the two re-warm-up protocols, aligning with the study's primary objective, rather than

providing an exhaustive examination of each protocol in isolation. The data showed that sprint times significantly increased (indicating a decline in performance) after the re-warm-up in both protocols (SSP: +0.35 s; SPBP: +0.38 s; $p = 0.001$), with a large effect size. CMJ height decreased slightly (SSP: -1.2 cm, $p = 0.074$; SPBP: -1.6 cm, $p = 0.074$), suggesting small magnitude effects without statistical significance. These findings align with some previous studies (Edholm et al., 2014), although other research has reported improved jumping and sprinting performance following re-warm-ups (Fashioni et al., 2020; Ltifi et al., 2023; Yanaoka, Iwata, et al., 2020), highlighting the variability depending on protocol design and context.

Although sprint performance declined after the re-warm-up protocol, it is unlikely that protocol-specific fatigue was the cause. The protocols involved short-duration activities (3 minutes) at moderate to low intensities, which are generally designed to maintain or enhance neuromuscular readiness rather than induce fatigue. It is possible that for some participants, particularly those less accustomed to such protocols, the re-warm-up may have contributed to transient fatigue and, consequently, affected sprint performance, but we consider this to be unlikely. Still, future studies could incorporate a subjective rating of perceived exertion (RPE) scale to assess the impact of the protocol on fatigue induction in athletes. Similar findings have been reported by other authors, for example, Hammami et al. (Hammami et al., 2018) and Edholm et al. (Edholm et al., 2014), also observed reductions in sprint performance following certain re-warm-up strategies, suggesting that suboptimal intensity, accumulated fatigue, or insufficient recovery time could attenuate the expected benefits of re-warm-up protocols. It is conceivable that the accumulated fatigue from the first half of the match simulation may have contributed to the decline in sprint performance, regardless of the re-warm-up intervention, as fatigue has been shown to impair neuromuscular function and sprint capacity during match-play (J. R. Silva et al., 2018).

Given this context, our primary objective was not solely to determine whether sprint performance improved after re-warm-up, but rather to compare the **magnitude of performance decline** between protocols, examining **which protocol better attenuated the performance drop** both in sprint and jump performance we aimed to identify the most effective strategy to preserve physical output during halftime. Moreover, the lack of significant differences in jump performance (CMJ) post-intervention suggests that fatigue

effects, if present, were limited in scope and did not broadly impair explosive lower-limb power. These findings underscore the importance of balancing the intensity and duration of re-warm-up protocols to avoid inducing additional fatigue while preserving performance benefits, but fatigue accumulated during the first half of the match will still likely play a role. Future research could incorporate measures of fatigue, such as subjective ratings and biochemical or neuromuscular markers, to better understand its potential confounding role in performance outcomes.

The similar effects observed between the SSP and SPBP protocols reinforce the practical implication that short, feasible re-warm-up routines can be integrated into soccer halftimes despite time and logistical constraints. Both protocols demonstrated comparable impact on performance and perceived readiness, we prioritized presenting these overall comparative results to maintain a clear and focused narrative aligned with the study's primary aims.The inclusion of a control group with passive rest could have strengthened the analysis of the absolute effectiveness of each protocol, however, the primary objective of this study was to compare two re-warm-up protocols that are already supported by previous literature for their ability to mitigate performance decline after halftime, although they operate through distinct mechanisms.

The SPBP protocol is grounded in neuromuscular and proprioceptive stimulation principles (Bizzini et al., 2013; Ekstrand et al., 2011; Tillin & Bishop, 2009), while the SSP protocol is based on the contextual specificity of match demands (Abade et al., 2017; Hill-Haas et al., 2011; Zois et al., 2013). Therefore, our focus was to investigate which of these two approaches would prove more effective within the practical constraints of a competitive halftime period, particularly considering the very limited time available (≤3 minutes). We chose not to include a passive control group, as several studies have consistently shown the detrimental effects of passive rest on both physical and technical-tactical performance at the beginning of the second half (Hammami et al., 2018; Mohr et al., 2004; Weston et al., 2011). This allowed us to concentrate our efforts on directly comparing the two active re-warm-up protocols under ecologically valid conditions.

The environmental factors, such as ambient temperature, humidity, and playing surface conditions, could potentially influence the magnitude of body temperature fluctuations during the half-time interval and subsequently affect performance parameters in the second half. Previous research has demonstrated that environmental conditions can

significantly impact thermoregulatory responses in athletes (Racinais et al., 2015; Taylor & Rollo, 2014), potentially modulating the effectiveness of re-warm-up interventions. Future studies should consider incorporating systematic measurement of environmental variables and potentially explore how different re-warm-up protocols might be optimized for specific environmental conditions, particularly in women's soccer where research on environmental influences on performance remains limited.

Both re-warm-up protocols (SSP and SPBP) were feasible considering the short three-minute time window, and there were no significant interaction effects regarding sprint, CMJ performance, or between-group differences in perceived readiness to perform. Comparing pre-match to post-re-warm-up values for both protocols (SSP and SPBP), significant increases were observed in sprint times, with variations of +0.35 and +0.38 ($p = 0.001$), respectively, indicating a large magnitude effect for both. Similar effects were noted for the CMJ; however, these did not reach statistical significance (SSP: -1.2 cm, $p = 0.074$; SPBP: -1.6 cm, $p = 0.074$), suggesting a small magnitude effect for both.

It was shown previously that re-warm-up strategies could mitigate the negative impact of passive halftime practices on physiological measures (heart rate and core temperature) and on players' performance (jump, sprint, and distance covered) (Hammami et al., 2018). However, the available time for a re-warm-up in soccer is estimated to be under three minutes (Towlson et al., 2013), so longer protocols may not be as easily implemented in real-world contexts (Russell et al., 2018). The SSP and SPBP protocols were designed to be implemented within the available re-warm-up time window (approximately three minutes). In the case of SPBP, the selection of only six exercises from FIFA 11+ was strategically made to ensure its feasibility and practical application in a soccer context. The simplicity of both protocols facilitated their efficient execution within the limited time frame. This suggests that re-warm-up protocols can be effectively implemented in practical contexts, even when time is constrained.

Although the intervention was carried out in a simulated match environment, the protocols were carefully designed to replicate the constraints and demands of an official soccer match, thereby enhancing ecological validity and facilitating the applicability of findings to real-world settings. Utilizing experimental conditions that closely mirror actual game scenarios is essential to ensure that research outcomes are relevant and

transferable to practical performance contexts. (M. Pernigoni et al., 2024). Despite the temporal limitations imposed by soccer regulations on re-warm-up during halftime, our findings indicate that short and feasible re-warm-up protocols can be implemented within a 3-minute halftime window. However, given that sprint performance declined compared to the post-warm-up condition, it is not possible to assert positive effects on performance. Rather, the implementation of such protocols may help attenuate performance losses typically observed after passive halftime periods.

Considering that current regulations restrict access to the field before the start of the second half in official matches, and that the space available outside the playing field is often inadequate, this situation **could** pose a challenge to the implementation of the re-warm-up protocols.

However, the adaptation of the SSP protocol exercises, based on FIFA 11+ Program, proved to be highly feasible without compromising its execution and ensuring its viability in real scenarios. The findings encourage potential changes to match regulations, considering the positive effects of SSP on performance. The two protocols had similar effects on sprint and CMJ performance, with no significant interaction effects. The average SSP performance decreased from 32.3 cm to 31.1 cm (mean difference: -1.2 cm; $p = 0.074$), while the SPBP performance decreased from 36.3 cm to 34.7 cm (mean difference: -1.6 cm; $p = 0.074$). This corresponds to a percentage decline in CMJ performance of 3.72% for SSP and 4.41% for SPBP following the re-warm-up.

This suggests that CMJ performance slightly decreased after the re-warm-up in both protocols, although differences did not reach statistical significance, with a slightly larger decrease in the SPBP protocol compared to the SSP protocol. This decline aligns with findings by Edholm et al. (Edholm et al., 2014), who reported a decrease of 7.6% in the control group and 3.1% in the re-warm-up group. However, research has also shown improved jumping performance after a re-warm-up (Yanaoka, Kashiwabara, et al., 2018).

These discrepancies in the literature can be attributed to various methodological factors. Variations in duration, exercise type, and intensity of re-warm-up protocols appear to be determinant factors for the observed outcomes. For instance, while Yanaoka et al. (Yanaoka, Hamada, et al., 2018), demonstrated benefits with short-duration re-warm-up protocols (3 minutes) at both moderate intensity (60% VO_2max) and low intensity (30% VO_2max), Hammami et al. (Hammami et al., 2018), reviewed studies

employing re-warm-up protocols lasting between 5 and 7 minutes at varying intensities, highlighting their significant impact on maintaining or enhancing physical performance after the half-time break. Similarly, Mohr et al. (Mohr et al., 2004), found that a 7-minute moderate-intensity re-warm-up improved sprint performance by 2.8% compared to passive rest. Additionally, participant characteristics, such as fitness level, sport-specific training background, and physiological adaptations, may contribute to variable responses to re-warm-up protocols, as highlighted in a recent systematic review by Zois et al. (Zois et al., 2013). For instance, Sanchez-Sanchez et al. (Sanchez-Sanchez et al., 2024) demonstrated that using elastic bands during half-squats as a re-warm-up improved strength, power, and speed in youth soccer players.

Other factors explaining conflicting results include the diverse dependent variables and assessment methods employed across studies. While some researchers focused on specific physical performance measures (single vs. repeated sprints, vertical jump, agility), others also included physiological parameters such as muscle temperature or metabolic responses. Russell et al. (Russell et al., 2018), demonstrated that a 2-minute re-warm-up attenuated the decline in core temperature by 0.5°C and improved repeated sprint ability immediately after half-time in professional rugby players. This finding suggests that short re-warm-up protocols can be effective in maintaining muscle temperature and enhancing physical performance during rest periods in sports. Whereas Lovell et al. (Lovell, Midgley, et al., 2013), found improvements primarily in muscle glycogen resynthesis rather than performance metrics. Environmental conditions (temperature, humidity) and the precise timing of re-warm-up during the interval (beginning, middle, or end) also significantly affect protocol efficacy and contribute to the variability of results reported in the literature. A recent meta-analysis (Jeffreys, 2017), identified timing as a critical factor, with re-warm-ups performed within the final 3 minutes of half-time showing greater efficacy than those performed earlier. This complexity underscores the importance of considering multiple factors when interpreting and comparing results from different studies on re-warm-up protocols.

Our results indicated a significant decline in sprint performance following the re-warm-up protocols. Specifically, sprint times were longer after the re-warm-up compared with post-warm-up (SSP: 3.86 ± 0.15 s vs. 3.51 ± 0.15 s; SPBP: 3.88 ± 0.26 s vs. 3.50 ± 0.10 s). Conversely, Yanaoka et al.(Yanaoka, Hamada, et al., 2018), investigated two

distinct 3-minute re-warm-up protocols, rather than a single protocol with variable durations. Specifically, these protocols consisted of: (1) 3 minutes of cycling at 60% of VO_2max (moderate intensity) and (2) 3 minutes of cycling at 30% of VO_2max (low intensity). Both protocols were compared to the control condition (passive rest), reported improvements in sprint performance following re-warm-up protocols involving either one minute of cycling at 90% VO_2max or three minutes at 30% VO_2max. Notably, in their study, sprint performance following the re-warm-up was superior to that observed after passive rest during halftime. These differences may reflect variations in the re-warm-up protocols used and participant characteristics.

Furthermore, Ltifi et al. (Ltifi et al., 2023), investigated the impact of a brief re-warm-up activities on the sprint performance of youth soccer players. The intervention consisted of a re-warm-up protocol lasting only 3 minutes, during which players wore weighted vests corresponding to 5% and 10% of their body mass. The results demonstrated that this re-warm-up approach, using weighted vests, significantly improved 20-meter sprint performance. Performance measurements were compared between two time points: after the initial warm-up and after the re-warm-up intervention, allowing for a direct assessment of the effect of this "micro-dose" re-warm-up on subsequent performance. The study concluded that three-minute re-warm-up with a vest weighing 10% of body mass yielded the highest RPE and notable improvements in 20-meter sprint performance, suggesting that young elite soccer players should incorporate 10% body mass vests into their re-warm-up routines to enhance sprint performance after halftime.

Overall, these studies highlight the importance of effective re-warm-up strategies in maintaining and improving sprint performance in soccer. By optimizing these protocols, coaches and trainers can better prepare players for the demands of the match, particularly during critical moments such as the start of the second half. Our results therefore suggest that both protocols produced similar outcomes on sprint and CMJ performance and perceived readiness; which directly addresses the main research question, however, no passive control group was available to better frame the relevance of these findings. From a perceptual standpoint, the two protocols (SSP and SPBP) resulted in similar perceived readiness as assessed through six questions from the ARMS

questionnaire. It is important to consider that the duration of the re-warm-up may have influenced our results.

While a 3-minute protocol is more feasible in real competitive contexts, the literature suggests that longer periods of 5 to 8 minutes may be necessary to achieve an adequate re-warm-up (L. M. Silva et al., 2018), future research should investigate the optimal balance between the physiological benefits and the practical feasibility of re-warm-up strategies, particularly in light of the limited halftime period, often constrained by coaching practices as noted by Towlson et al. (2013). Moreover, studies should consider additional contextual factors aligned with the specific needs of each team, including competition level, environmental conditions, and individual athlete profiles, to ensure the development of tailored and effective interventions. The protocols applied in the present study—both the SPBP and the SSP—may serve as foundational models for the design of practical re-warm-up strategies adapted to various sporting contexts.

4.1. Limitations

The small sample size, which also resulted in the absence of a passive control group, limits the ability to assess the effectiveness of the two proposed re-warm-up protocols in comparison to rest. However, as demonstrated by the literature, a significant decline in physical performance occurs following a passive halftime period (Gonzalez-Devesa et al., 2021; Lovell, Barrett, et al., 2013; Yanaoka, Hamada, et al., 2020), with documented reductions in muscle temperature, sprint capacity, and lower-limb power (Russell et al., 2015), which reinforces the importance of re-warm-up strategies to mitigate these negative effects and optimize subsequent performance.

The variation in methodologies across studies prevents more direct comparisons, and it is possible that dose-response relationships mediate the results, which should be explored in future research. While a comparison with a control group would have provided a clearer reference point to isolate the specific effects of the re-warm-up interventions, the study design still offers meaningful insights into the relative effectiveness of the two protocols.

To preserve the ecological validity of the study, we deliberately chose not to assess performance at the end of the first half of the simulated match. In real-world scenarios, coaches typically use this moment to communicate with players, and conducting

performance tests at this time could interfere with this essential process. Additionally, any performance decline observed after halftime could be largely attributed to accumulated fatigue during the match (Marco Pernigoni et al., 2024; J. R. Silva et al., 2018), without providing insights into the effectiveness of the re-warm-up protocols.

Beyond the limitations previously identified (i.e., passive control groups and larger samples), future research should consider incorporating additional performance metrics, as relying solely on sprint and CMJ tests provides a limited view of overall athletic performance. Although all participants underwent a familiarization session and were professional athletes, the use of a single trial for sprint and CMJ assessments may reduce measurement reliability. Multiple attempts are typically recommended in similar studies to better capture maximal performance and minimize variability.

Moreover, there is a need to develop instruments capable of assessing perceived readiness to perform that are straightforward and can be applied quickly. Practical constraints inhibited the implementation of crossover design. Specifically, it would require greater interference with the team's natural training process. Therefore, we decided not to use a crossover design, despite the limitations of doing so.

5. Conclusions

This study provides insights into the effects of a short-duration re-warm-up protocol (3 minutes) on the physical performance of soccer players. While this duration may be more feasible in real competitive contexts, our results indicate that it may not be entirely effective in restoring all aspects of physical performance, particularly sprint times. These findings highlight the need to balance practical considerations with physiological requirements when designing re-warm-up protocols for sports competitions. Both re-warm-up protocols (SSP and SPBP) produced similar effects, specifically increases in sprint times and non-significant reductions in jump performance compared to post-warm-up. The lack of a control group precludes us from stating whether the investigated protocols could mitigate the performance decrement related to fatigue accumulation. Nonetheless, our results show that SSP and SPBP did not have differential effects on the readiness of players to start the second half of the match. Coaches and fitness trainers should consider these findings when planning re-warming sessions, adjusting protocols as necessary to balance potential benefits and adverse effects on

athletic performance. However, the implementation of re-warm-up protocols in official matches will require regulatory changes, particularly for those involving tactical and technical actions on the field, which remains a key consideration for future application.

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ORIGINAL INVESTIGATION

Should Soccer Players Re-Warm-up at Half-Time? An Exploratory Randomized Controlled Trial in a Professional Women's Team

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ABSTRACT

Purpose: This exploratory study investigated the effects of a 3-minute re-warm-up (RWU) protocol implemented during halftime on sprint and jump performance in female soccer players. **Methods**: Twenty-two professional female soccer players from two Portuguese clubs from First and Second Divisions were randomly assigned to either a control group (G1: passive rest) or an experimental group (G2: RWU). The Integrated Re-warm-up soccer protocol (IRW-soccer), performed by G2, consisted of six FIFA 11+ power exercises and a small-sided game (SSG). Performance was measured using a 20-meter sprint and countermovement jump (CMJ) at baseline (post-warm-up) and after the halftime intervention. A two-way ANOVA (group × time), was conducted for analysis, with effect sizes reported as partial eta squared (η_p^2). **Results**: A time × group interaction was found for sprint performance ($F = 6.66$, $p = 0.019$, $\eta_p^2 = 0.27$), favoring the experimental group (G1: -0.25 s vs. G2: -0.40 s). For CMJ performance, no time × group interaction was observed ($F = 2.66$, $p = 0.483$, $\eta_p^2 = 0.02$), although a main effect of time effect was detected ($F = 10.34$, $p = 0.005$, $\eta_p^2 = 0.36$); both groups showed a decrease in jump height, but to a lesser extent in the re-warm-up group (G1: -2.85 cm vs. G2: -1.82

cm). **Conclusions**: A brief 3-minute re-warm-up protocol implemented at halftime improved sprint performance compared to passive rest. These findings suggest that time-efficient re-warm-up protocols, combining FIFA 11+ power exercises and SSGs may be useful during the halftime interval in female soccer players.

Keywords: re-warm-up; halftime, warm-up, jump and sprint performance.

1. INTRODUCTION

In soccer, halftime interval is typically characterized by activities focused on rehydration, energy replenishment, and tactical discussions.[1,2] However, passive rest can lead to a 1.5–2.0°C decline in muscle temperature,[3] negatively impacting physiological functions and performance.[4,5] A 1°C increase in muscle temperature has been shown to result in a 2–5% improvement in muscle power,[6] which is often compromised by passive halftime routines.[3,7] This potential performance decline at the start of the second half of the game is particularly relevant for high-intensity tasks,[8,9] such as sprinting and jumping.[10,11] During the initial minutes of the second half, soccer players perform the greatest number of high-intensity actions,[12] regardless of their field position,[13] and this period is also associated with a spike in injury rates.14 This underscores the need to investigate effective re-warm-up strategies to optimize performance and safety.

Re-warm-up activities during halftime may mitigate these negative effects,5,15 enhancing players' readiness for the start of the second half,1,9,16,17 and improving explosive performance during its initial minutes.2,5,18 Re-warm-up protocols have been shown to enhance performance in sprints, jumps, and rapid changes of direction.3,8,9

Although the effects are small (2–3%) compared with control conditions,8 they may still be relevant in balanced matches. Re-warm-up protocols may also enhance specific technical skills, including passing ability and ball possession, and reduce perceived fatigue levels despite increased physical output.3,5,8

The gap between scientific findings and practical application remains a significant challenge, while several studies have employed 6–7-minute re-warm-up protocols,3,8,19-21 their feasibility within the halftime constraints of a competitive match is remains questionable. In fact, the time realistically available for an active re-warm-up, after accounting for tactical briefings and rehydration, is approximately 3 minutes.7

Consequently, there is growing interest in developing shorter re-warm-up strategies that are both practical and effective.15,22,23 Such strategies have shown promise in sustaining or enhancing performance in constrained environments or under limited resources conditions.20,24

A 3-minute protocol during halftime could be effective, improving intermittent sprint performance by 1.4-2.1% in the 10 minutes following halftime, which is comparable to longer re-warm-up durations.22,25 In this context, FIFA 11+ exercises may be useful, as they improve neuromuscular control when incorporated into warm-up routines,17 while SSG provide sport-specific stimuli that can help to maintain physiological readiness.26 Both approaches are feasible within the realistic constraints of a soccer halftime. However, comparisons between structured re-warm-up protocols and passive rest strategies remain scarce.18,23

In this context, the Integrated Re-warm-up Soccer (IRW-Soccer) protocol was developed to be both time-efficient and scientifically grounded. It combines two distinct components: six exercises derived from Part 2 of the FIFA 11+ program and a 5v5 Small-Sided Game (SSG). The FIFA 11+ exercises include strength, plyometric, and neuromuscular activation drills that have been shown to acutely enhance neuromuscular performance and readiness for explosive actions such as sprinting and jumping.27 Simultaneously, previous studies have shown that SSGs increase heart rate, lactate concentration, distance covered at high intensity, sprints, and changes of direction, thereby maintaining physiological readiness and technical activity during training.28 This integrated approach ensures that the limited 3-minute window is maximized to mitigate performance decrements while directly addressing the demands of the second half of a soccer match.

Another relevant gap in the literature is the underrepresentation of female athletes in warm-up and re-warm-up research.5,10,29 This is particularly concerning given the rapid growth of women's soccer and the distinct physiological characteristics of female players, including differences in muscle composition, thermoregulation, and hormonal profiles, which may influence their responses to such interventions.30 Research suggests that female's players respond differently to potentiation-based warm-up protocols,[29,31,32] indicating that findings derived from male samples may not be directly transferable. These observations underscore an urgent need for sex-specific research.[33]

This randomized trial aimed to investigated the effects of a 3-minute halftime *Integrated Re-warm-up Soccer protocol* (IRW-Soccer), compared with passive rest on sprint and jump performance in professional female soccer players. The IRW-Soccer combines elements of the FIFA 11+ program and a 5 vs. 5 SSG, which have been implemented separately in previous studies.[23] As this is an exploratory study, no formal hypotheses were established.

2. METHODS

2.1. Participants

Twenty-two professional female soccer players (age: 24.31 ± 3.42 years, height: 168.0 ± 5.73 cm, body mass: 61.13 ± 6.25 kg) were recruited from two distinct clubs in the Portuguese First and Second Divisions. Prior to recruitment, approval was obtained from the team's technical staff. Players who met the selection criteria (female soccer players without limitations regarding match participation) were assigned to the study groups. Exclusion criteria included: (i) recent injury affecting match performance, and (ii) pre-existing physical limitations that could affect the assessments. Under the supervision of the study's lead author, the team randomly assigned the 22 players into two groups using a 1:1 allocation ratio (11 players per group). Players were first paired based on specific characteristics, such as prior performance, including position and physical, technical, and tactical attributes, to ensure balanced groups, and then randomly allocated within each pair, ensuring that both groups had a similar composition in terms of these key variables. Although allocation sequence was not concealed, the lead researcher ensured that no player changed groups after the randomization. Figure 1 presents the participant flow.

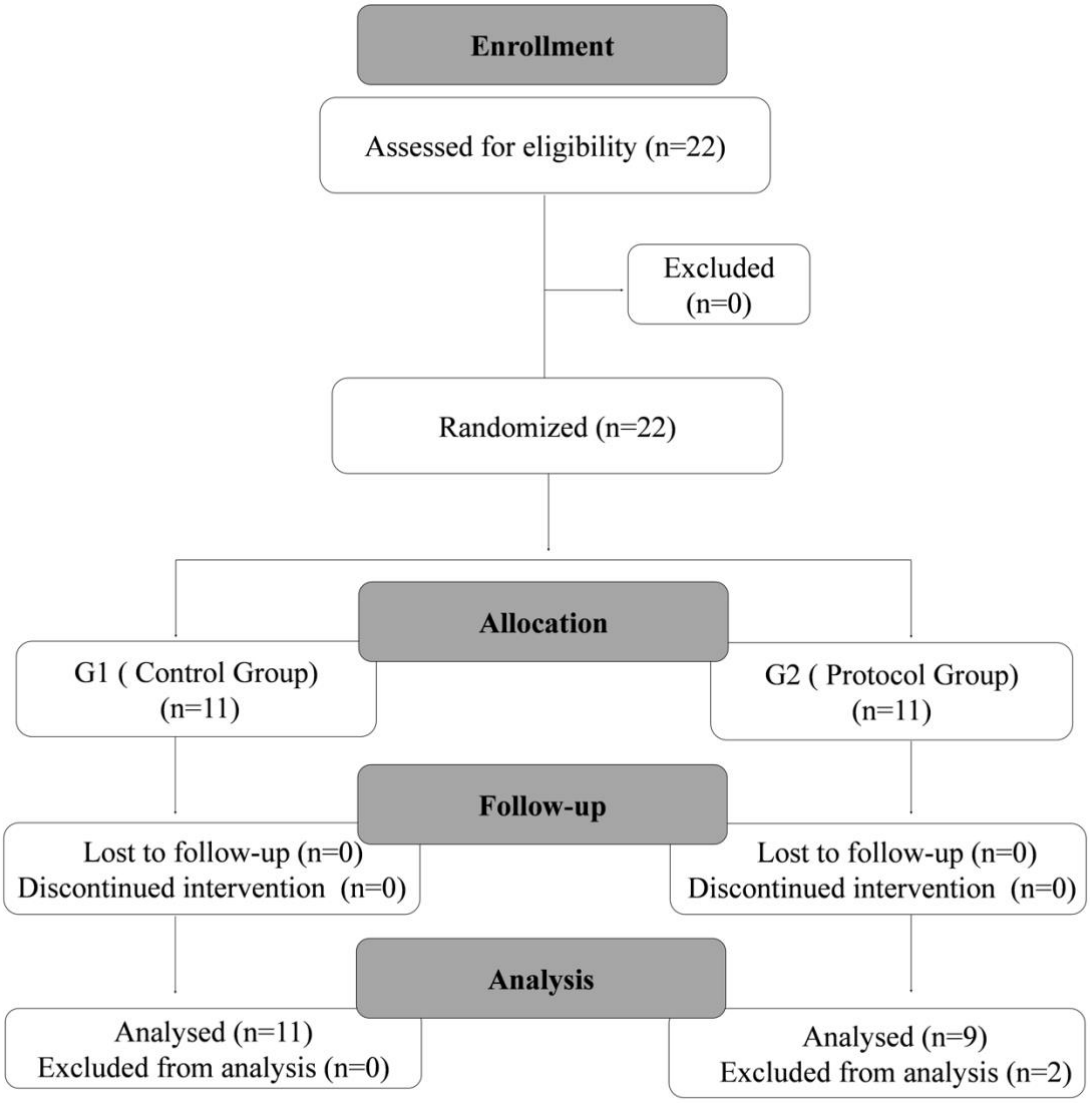


Figure 1. Flowchart of study participants. The reason for exclusion was the lack of valid data recordings due to unsuccessful data capture or technical issues with the monitoring equipment.

2.2. Design

A randomized controlled trial was conducted to compare the effects of the IRW-Soccer, a 3-minute re-warm-up protocol, on physical performance. Twenty-two professional female soccer players from First and Second Division clubs in the Portuguese Women's Soccer Championships were randomly allocated to a Control Group (G1, n=11) and an Experimental Group (G2, n=11). The experimental group performed

the structured IRW-Soccer protocol during the final 3 minutes of the halftime interval, while the control group underwent passive rest.

Following the initial pre-match warm-up, and again upon completion of the IRW-Soccer or passive rest period, players immediately underwent performance assessments, consisting of a 20-meter linear sprint test and a CMJ test (Figure 2).

All procedures were conducted in accordance with the Declaration of Helsinki (2013 update, Fortaleza revision) and were approved by the Ethics Committee of the Faculty of Sport, University of Porto (CEFADE_37_2022). Informed consent was obtained from all participants after they received detailed information about the study's purpose, procedures, potential risks, and benefits. Participants were informed of their right to withdraw from the study at any time without any penalty.

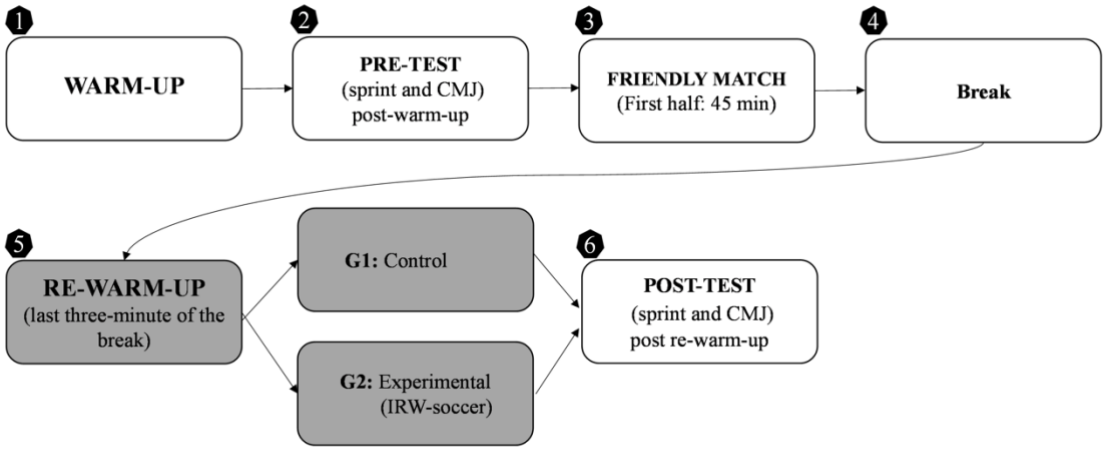


Figure 2. Diagrammatic representation of the randomized trial. *Legend*: CMJ, countermovement jump; min, minutes; G1, Group 1; G2, Group 2.

2.3. Procedures

2.3.1. Familiarization session

Before the start of the study, players from the First Division team participated in a familiarization session to become accustomed to the re-warm-up protocols and the performance tests. This session was conducted under conditions identical to those of the experimental session, including the use of GPS-based tracking. It began with a

standardized warm-up identical to that performed prior to official matches. Within one minute of completing the warm-up, players performed a linear sprint, followed by another one-minute rest, before performing a CMJ. The first 45-minute half of the simulated match then commenced. During the final three minutes of the simulated halftime interval, players completed the re-warm-up protocols as instructed. Subsequently, they repeated the testing protocol.

Prior to data collection, all participants received a comprehensive briefing to ensure full understanding and informed consent. This session was conducted by the lead researcher, with the support of the teams' coaching staff to foster a familiar and trusted environment. The briefing detailed the study's objectives, the sequence of tests, and the specific requirements of the re-warm-up protocols, and included a dedicated question-and-answer period to address all participant queries. To compensate for the lack of a separate familiarization session for the Second Division team, this briefing was extended and particularly detailed, ensuring their procedural understanding was equivalent to that of the familiarized First Division team.

2.3.2. Data Collection Procedures

On the day of the trial, all procedures were reviewed once again. Players performed their usual pre-match warm-up under the guidance of the technical staff, following the recommendations of the FIFA 11+ Program. The warm-up lasted 15-20 minutes and comprised three parts: (i) running and dynamic mobility exercises; (ii) strength, balance, plyometric, and neuromuscular control exercises; and (iii) running with accelerations and changes of direction. At the end of the warm-up, players performed the pre-tests as described for the familiarization session.

Next, participants played a friendly 11-a-side match, consisting of two 45-minute halves and a 15-minute halftime break. During the halftime, players were allowed to perform typical halftime activities such as using the restroom, listening to the coach’s instructions, and hydrating, but no additional physical exertion was permitted. In the final three minutes of the halftime, the experimental group performed the IRW-Soccer protocol, while the control group remained at passive rest. Immediately following the halftime, players completed the Post-test as described. All testing procedures were

supervised by the same research team members to ensure standardization and were conducted on the same playing surface as the match to maintain consistent environmental conditions.

2.4. IRW-soccer Protocol

The IRW-Soccer consisted of two sequential components: (1) FIFA 11+ exercises focusing on strength, plyometrics, and balance, and (2) a small-sided game, with each component lasting (±1.5 minutes). The combination of neuromuscular training (FIFA 11+) and sport-specific activity aligns with current recommendations. [20,34] The first component incorporated six exercises derived from Part 2 of the FIFA 11+ program, which has been shown to be effective for acute performance enhancement in female soccer players.[17] Players performed one set of eight repetitions of each exercise in sequence: (i) squats with toe raise jumping; (ii) walking lunges; (iii) one-leg squats with jumping; (iv) vertical jumps; (v) lateral jumps; and (vi) Box jumps. The second component consisted of a 5v5 small-sided game conducted on a 15 m × 15 m field, designed to maintain sport-specific movement patterns and physiological readiness.

Players were randomly assigned to teams by the coaching staff, with a two-touch restriction per player to promote quick decision-making and ball circulation. To maximize continuous play and minimize interruptions, researchers and technical staff were positioned along the sidelines with replacement balls to immediately return the ball that went out of bounds.

2.5. Outcomes

All testing procedures were conducted in the same sequence, whit the 20-meter linear sprint (Sprint) performed first, followed by the CMJ. The 20-meter linear sprint was selected for its validity in assessing soccer-specific explosive capabilities and its sensitivity to halftime-induced performance decrements. [3]

The test has shown high test-retest reliability and sensitivity in detecting acute changes in neuromuscular readiness.[15] Athletes started from a stationary position and performed one maximal trial, with conditions kept constant Pre- and Post-intervention.

Sprint performance was recorded using WIMU PRO™ devices (Real Track Systems, Spain). Devices were activated 30 minutes before the warm-up to ensure satellite connection and system stability. They were positioned in vests on each player's upper back. These 10 Hz GPS units, which integrate accelerometers, gyroscopes and magnetometers, have demonstrated high reliability for sprint testing (ICC > 0.93). Data were analyzed using S-PRO software with a timing precision of 0.01 s.

The CMJ was used to assess lower limb power and neuromuscular fatigue, as it is a key performance indicator in soccer,[29,35] and is a reliable and sensitive measure of neuromuscular readiness.[35] Jump height was measured using the My Jump 2 mobile application (version 5.0.5; My Jump Team, developer; iOS, Apple Inc., USA), which employs high-speed video capture (120 Hz) to calculate flight time and derive jump height. This method has been validated against force plate measurements, showing near perfect agreement (ICC = 0.997, 95% CI: 0.996–0.998) and has demonstrated excellent inter-and intra-rater reliability (ICC > 0.95). Players performed the CMJ from an upright position with hands on hips to eliminate the arm swing influence. From this posture, they executed a rapid downward movement to approximately 90° knee flexion followed by a maximal vertical jump. Full extension during the flight and landing in the same position were required. Each player performed a single jump; if the attempt was technically incorrect, the test was repeated (up to two consecutive trials), with 30 seconds of passive recovery between attempts. The highest valid jump was recorded. A single jump was employed to ensure assessment occurred within the effective temporal window of the re-warm-up response.

2.6. Statistical Analysis

The Kolmogorov-Smirnov test with Lilliefors correction confirmed that all dependent variables followed a normal distribution ($p > 0.05$). Levene's test was used to assess homogeneity of variances, and sphericity was evaluated using Mauchly's test for the repeated-measures analyses. Descriptive statistics, were presented as means and standard deviations (M ± SD) for all performance variables. However, for the physical load variables, descriptive statistics were presented as medians and interquartile ranges (Median IQR) due to non-normal distribution.The primary analysis employed a 2 × 2

mixed analyses of variance (mixed-design ANOVA) with one between-subjects factor (Group: Control vs. Experimental) and one within-subjects factor (Time: Post-warm-up vs. post-re-warm-up) to examine the effects of the re-warm-up protocol on CMJ height and 20-meter sprint performance. Additionally, the Mann–Whitney U test was used to compare the baseline physical load metrics (total distance covered, high-speed running distance, maximum speed, sprints, accelerations, and decelerations) between the control and experimental groups during the first half of the friendly match. The alpha level for statistical significance was set at $p < 0.05$ for all analyses but, being an exploratory study, we avoided a rigorous interpretation of *p*-values. Additionally, following a significant time × group interaction, simple main effects tests were conducted to determine the specific differences between groups at post-re-warm-up and the changes over time within each group. The alpha level for statistical significance was set at $p < 0.05$ for all analyses but, being an exploratory study, we avoided a rigorous interpretation of p-values.

Effect sizes for the mixed ANOVA were quantified using partial eta squared (η_p^2), with values interpreted according to the following guidelines: small ($\eta_p^2 = 0.01$), medium ($\eta_p^2 = 0.06$), and large ($\eta_p^2 = 0.14$) effects. Additionally, for pairwise comparisons, Cohen's d was calculated with 95% confidence intervals, with values interpreted as small ($d = 0.2$), medium ($d = 0.5$), and large ($d = 0.8$) effects. All statistical analyses were performed using IBM SPSS Statistics for Windows, version 27.0 (IBM Corp., Armonk, NY, USA).

3. RESULTS

The analysis of the physical load recorded during the first half of the friendly match revealed no statistically significant differences between the control group (G1) and the experimental group (G2) in the high-intensity workload metrics, including high-speed running ($p = 0.310$), maximum speed ($p = 0.238$), sprints ($p = 0.395$), accelerations ($p = 0.310$), and decelerations ($p = 0.177$). However, a statistically significant difference was observed in the total distance covered ($p = 0.041$), with G2 covering a greater distance (median: 4554.5 m) than G1 (median: 4220.0 m). These results are detailed in Table 2. Despite the difference in total distance, the comparability of the high-intensity metrics

suggests that the groups experienced a similar level of physiological stress and fatigue prior to the intervention, this supporting the internal validity of the study regarding the most demanding physical actions.

Table 1. First-half match physical performance: Comparison between Control (G1) and Experimental (G2) groups.

	G1 (n = 11)	G2 (n = 9)		
Physical performance	**Median [IQR]**	**Median [IQR]**	***p-value***	***Effec Size (***
Total Distance (m)	4220.0 [866.0]	4554.5 [840.0]	0.041*	0.47
High-Speed Running (m)	497.0 [396.0]	656.7 [597.3]	0.310	0.25
Maximum Speed (km·h⁻¹)	23.0 [4.0]	24.5 [1.8]	0.238	0.29
Sprints (n)	6.0 [9.0]	6.5 [10.3]	0.395	0.21
Accelerations (n)	1357.0 [127.0]	1314.5 [131.0]	0.310	0.25
Decelerations (n)	1356.0 [131.0]	1316.0 [144.7]	0.177	0.31

Legend. IQR – interquartile range.

There was a significant time-by-group interaction effect for the 20-meter sprint test ($p = 0.019$, $\eta_p^2 = 0.27$), indicating a large effect size (Table 1). Although both groups improved sprint times from pre- to post-test, the improvement was greater in the experimental group (G2: -0.40 s) compared to the Control group (G1: -0.25 s). No significant time-by-group interaction ($p = 0.483$, $\eta_p^2 = 0.02$) was detected for the CMJ. Both groups experienced a decrease in performance from pre- to post-test (Control: -2.85 cm; Experimental: -1.82 cm).

Simple Main Effects tests confirmed that the improvements in the 20-meter sprint were significant within each group, and the main effect of time was also significant ($F = 123.6$, $p < 0.001$, $\eta_p^2 = 0.87$), indicating a substantial overall increase in sprint performance. For the CMJ, although no significant time-by-group interaction was detected ($p = 0.483$, $\eta_p^2 = 0.02$), the main effect of time was significant ($F = 10.34$, $p = 0.005$, $\eta_p^2 = 0.36$), reflecting an overall reduction in jump height.

Table 2. Mean (SD) of Performance in the Countermovement Jump (CMJ) and 20-m Sprint Test, with Main Effects and Interactions for Control (G1) and Experimental (G2) Groups, Evaluated Post-Warm-Up andPost-Re-Warm-Up.

Variable Effect	Group	Post-warm-up (M ± SD)	Post-re-warm-up (M ± SD)	Change (↓)	F	*p*	η_p^2
Sprint test (s)	G1	3.84 ± 0.15	3.59 ± 0.17	−0.25			
	G2	3.87 ± 0.17	3.47 ± 0.12	−0.40			
Time x Group					6.66	0.019	0.27
Time					123.6	<0.001	0.87
CMJ test (cm)	G1	34.35 ± 3.63	31.50 ± 4.09	−2.85			
	G2	33.94 ± 6.24	32.12 ± 4.49	−1.82			
Time x Group					2.66	0.483	0.02
Time					10.34	0.005	0.36

Legend: CMJ, countermovement jump.

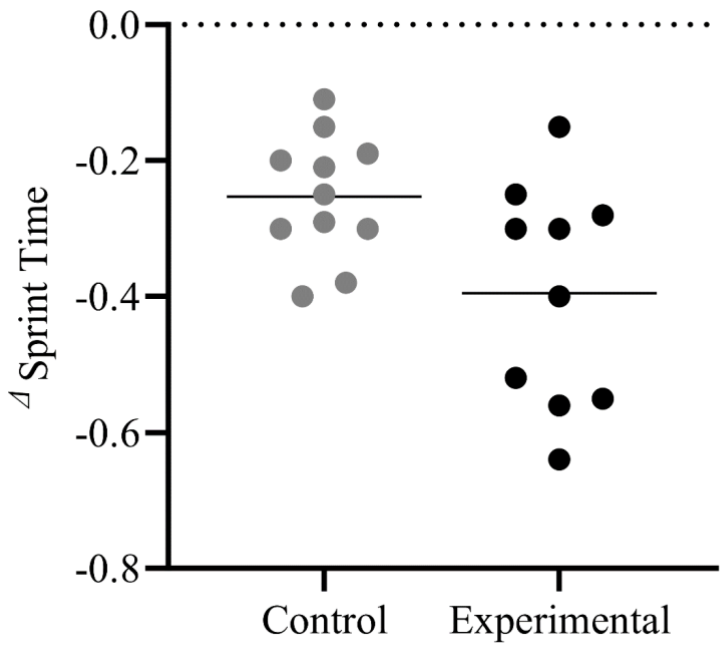


Figure 3: Individual variation in 20-m sprint time (post-pre half-time test) in the control (G1) and experimental (G2) groups. Each point represents one player, and horizontal lines represent group means. Negative values indicate improvements in sprint performance (i.e., faster times).

4. DISCUSSION

The main finding of this exploratory study suggests that a short 3-minute integrated re-warm-up (IRW-Soccer), performed at halftime may help improve sprint performance in the second half of the game in professional female soccer players compared to passive rest. Although both groups showed a decline in CMJ performance, the decline was smaller in the experimental group. These findings suggest that even a short and practical re-warm-up routine, well-structed can help players and may be an effective strategy to counteract the performance decline typically associated with the halftime interval, maintain their explosiveness particularly in high-speed actions and power.

In terms of sprint performance, results suggested post-halftime improvements in both groups. This finding contrasts with most previous research, which tend to report performance maintenance or even declines following passive rest.[1,3,9] For example, Mohr et al.[3] observed a 2.4% sprint performance reduction after passive halftime rest. In contrast, the significant group × time interaction ($p = 0.019$) observed in the present study, suggests that the IRW-Soccer protocol led to greater performance enhancement compared to passive rest.

Our results are in line with previous research demonstrating the benefits of a short, active halftime routines. Several studies have consistently shown that short re-warm-ups, lasting between 1 and 7 minutes, can enhance intermittent sprint performance by 1.4-2.1% and improve both muscle power and explosive strength.[21,24] Our findings are consistent with Ltifi et al.[36], who found that incorporation routines involving plyometric or sprint-specific drills help to preserve neuromuscular function. Moreover the inclusion of FIFA 11+ exercises in our protocol is supported by evidence indicating their positive effects to improve sprint performance [17] and reactive strength,[18] reinforcing the value of this type of targeted re-warm-up,[15] for female soccer players.

In contrast, CMJ performance declined in both groups, highlighting the sensitivity of the vertical jump to fatigue [37]. However, the results suggested an attenuated decline in the re-warm-up group (G2: –1.82 cm; –5.4%) compared to the larger decline observed in the control group (G1: –2.85 cm; –8.3%), which should be explored in future confirmatory studies. These results align with previous research reporting CMJ reductions of 2.6-5.8% after passive rest[8,38] and supports the notion that active re-warm-

ups provide a protective, albeit incomplete, effect on explosive vertical jump performance.[39,40]

The application of the IRW-Soccer protocol appears to attenuate the decline in sprint performance and reduce CMJ decrements. The inclusion of power-based exercises from the FIFA 11+ may have elicited Post-Activation Performance Enhancement (PAPE), which is predominantly associated with increases in muscle temperature, neuromuscular activation, and muscle-tendon stiffness.[41] Active re-warming likely contributed to the maintenance of muscle temperature and neuromuscular function, helping to mitigate the negative effects of passive recovery. [6] Together, these factors may explain the reduced performance decline observed in the experimental group, consistent with previous re-warm-up findings.[10]

Elite female soccer players differ from male players in muscle mass, strength, and neuromuscular characteristics, which may influence their capacity to perform explosive actions such as sprints and jumps.[42-44] In addition, the high-intensity demands at the start of each half and potential menstrual cycle related effects on thermoregulation and fatigue may further affect performance in women's soccer.[45] Despite these sex-specific physiological and contextual factors, there is a scarcity of studies examining structured halftime re-warm-up protocols in soccer players, particularly in female athletes and using objective measures such as sprint and jump performance. These considerations provide a plausible framework for interpreting the current findings and reinforce the relevance of exploring time-efficient, soccer-specific re-warm-up strategies in female athletes.

5. PRACTICAL APPLICATIONS

Reflecting on the current findings, it suggests that integrating a short re-warm-up (IRW-Soccer), routine combining FIFA 11+ exercises with small-sided games, can genuinely help female soccer players maintain their physical performance during halftime. The protocol's simplicity and flexibility make it a practical option, particularly in high-pressure match environments where time and resources are limited.

In contexts with restricted pitch access or strict turf protection policies, the SSG component may potentially be replaced with high-intensity change of direction and

acceleration drills performed in the technical area or along the side-line, enhancing neuromuscular activation while adapting to logistical constraints.

For example, in situations where a team relies heavily on quick sprints and rapid transitions, incorporating elements like gentle plyometrics or reactive drills immediately before returning to the pitch could provide a subtle but meaningful performance advantage. It's important to note, though, that the players involved in this particular study came from only two professional squads, which calls for some caution when generalizing these results to other populations such as male, youth, or amateur players.

Furthermore, the data primarily reflect immediate, short-term effects and questions remain regarding how long these benefits persist and the underlying physiological mechanisms involved. Uncontrolled variables, such as ambient temperature and humidity may have influenced some outcomes.

A limitation of this study is the absence of menstrual cycle-related data. Due to the exploratory nature of the field-based design, logistical constraints during the competitive season, and the lack of prior ethical authorization, menstrual phase information was not collected. Therefore, potential variability associated with menstrual cycle status cannot be excluded and should be considered when interpreting the findings. Another limitation of the study was that temperature and humidity values were not collected during halftime because, although both groups were exposed to the same environmental conditions, these variables were not within the scope of the present investigation.

There is a clear need for future studies consider larger and more diverse populations, employ designs that account for environment variations and include physiological markers to better understand the effects of re-warm-up protocols and routines in players on second half performance.

For coaches, adapting warm-up routines to the physical demands and game context of individual players may yield more pronounced benefits and results. Researchers are encouraged to explore variations in protocol content, mix and match different exercises of different protocols, modify duration and interaction with contextual factors, laying the groundwork for evidence based in guidelines that are applicable across diverse players profiles and real-world competitive scenarios.

6. CONCLUSION

A 3-minute halftime re-warm-up (IRW-Soccer), combining FIFA 11+ exercises with a small-sided game, may represent a practical and time-efficient strategy to enhance sprint performance and attenuate the decline in jump ability. Consequently, it could serve as an effective approach to counteract the well-documented halftime-induced reductions in neuromuscular function and the associated risk of injury.

Based on our findings, we propose an innovative regulatory adjustment: the formal implementation of a standardized, three-minute on-field re-warm-up immediately following the 15-minute halftime interval. This intervention is not merely a performance enhancement, *but a* strategic measure designed to maintain match intensity, optimize player readiness, support evidence-based approaches to player welfare and injury prevention, and modernize soccer, taking into account current scientific evidence.

From a strategic perspective, this three-minute re-warm-up period could also be leveraged for live tactical commentary, advanced analyses, or targeted sponsor activations, creating a novel opportunity within the game. By proposing a formal change in FIFA regulations to include the re-warm-up period, the approach represents an integrated solution that simultaneously improves player performance and safety, enhances the quality of play, and opens new avenues for commercial value, highlighting the potential of evidence-based practices to optimize both sport and spectacle.

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Effects of an Integrated Half-Time Re-Warm-Up Protocol (IRW-Soccer) on Neuromuscular Performance in U19 Women's Soccer Players: An Exploratory Study

Original Investigation

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ABSTRACT

Objectives: To investigate the effects of a 3-minute halftime Integrated Re-Warm-up Soccer protocol (IRW-Soccer) on physical performance (sprinting and jumping) and self-reported readiness of U19 women soccer players. **Methods:** Twenty-two players (n=22) were divided into control (G1; n=11; passive rest) and experimental (G2; n=11; IRW-soccer: 1'30" FIFA 11+ and 1'30" small-sided game) groups. Performance was assessed the 20 m sprint and countermovement jump (CMJ) post-warm-up and post-re-warm-up. Readiness was assessed via the Acute Readiness Monitoring Scale (ARMS) at the end of the training session. A two-way ANOVA (group × time) was conducted for physical performance, with effect sizes reported as partial eta squared (η_p^2). Nonparametric analysis (Mann-Whitney U test) was used for ARMS data, with effect size reported as Rosenthal's *r*. **Results**: No significant time × group interaction was found for 20-m sprint ($F = 1.428$, $p = 0.247$, $\eta_p^2 = 0.070$) or CMJ ($F = 0.614$, $p = 0.442$, $\eta_p^2 = 0.030$). A significant large effect of time was detected for the sprint ($F = 95.34$, $p < 0.001$, $\eta_p^2 = 0.834$), with both groups improving sprint times post-warm-up and post-re-warm-up (G1: -0.339 s vs. G2: -0.434 s). No main effect of time was detected for CMJ ($F = 0.881$, $p = 0.359$, $\eta_p^2 = 0.042$). ARMS analysis revealed no differences between groups ($p>0.05$). **Conclusion:** The 3-minute IRW-Soccer protocol did not significantly affect physical performance or perceived readiness in U19 women players. Despite this, the protocol was feasible within 3 minutes and can be applied according to individual preferences.

Keywords: female football; half-time; perceived readiness; youth athletes; small-sided games

3. INTRODUCTION

Warm-up strategies are implemented to optimize neuromuscular function, joint range of motion, and core temperature, achieving the ergogenic state required for peak athletic performance.[1] In professional soccer, however, the halftime interval is traditionally a passive recovery period.[2,3] Passive rest can induce a 1.5–2.0 °C decrement in muscle temperature, with every 1 °C decrease resulting in a 3% reduction in lower-body power output [4], potentially impairing physiological function and athletic performance.[5,6] This decline is particularly deleterious for high-intensity actions like sprinting and jumping during the initial phases of the second half,[7,8] underscoring the imperative for effective RWU strategies. [9,10]

Active halftime RWU strategies can mitigate these effects, enhancing players' readiness for the second half.[10-12] Beyond the physiological and athletic performance improvements observed at the onset of the second half, RWU protocols may help maintain physiological function and performance during the initial minutes of the subsequent match period.[12,13] Active RWU protocols may also confer psychological benefits, including enhanced motivation, concentration, task focus, and overall mental readiness,[14] while improving attention network activity and neuromuscular coordination.[15] However, further exploration in ecologically valid competitive settings remains necessary.[13]

Despite growing evidence supporting the benefits of RWU interventions, their translation into practice remains limited. Time-efficient protocols represent a practical alternative to passive rest in competitive settings.[9,10] However, systematic reviews indicate that many studies have tested RWU protocols lasting 6–7 minutes. [13,16] surpassing the 3-minute window typically available after tactical briefings and rehydration.[17] Consequently, recent research has focused on shorter, practical strategies such as power exercises, plyometrics, change of direction, and small-sided games lasting 3 minutes or less.[9,10]

In this context, the IRW-Soccer protocol was developed as a time-efficient intervention combining FIFA 11+ power exercises and small-sided games.[18] This specific 3-minute protocol has been shown to improve sprint performance compared to passive rest, suggesting that such integrated strategies are effective in maximizing the limited halftime window to address the physical and multidimensional demands of the second

half in female soccer players.[17-19] Furthermore, self-reported readiness can modulate an intervention's effectiveness, as players who “feel” ready may perform better.

The ARMS is a validated tool that provides valuable insight into a player's immediate perception of their capacity to perform.[20] Integrating such subjective measures alongside objective tests (sprinting and jumping) offers a more holistic evaluation of RWU protocols, especially given that these interventions may reduce enhance perceived readiness despite increased physical output.[2,12]

Despite the rapid professionalization of women's football, a significant gap remains in the literature regarding the underrepresentation of female athletes in RWU research.[21] Evidence supporting halftime RWU strategies for female players is still critically scarce, which is concerning as physiological differences suggest that findings from male samples are not directly transferable.[9,21]

Therefore, this study aimed to investigate the effects of the 3-minute halftime IRW-Soccer protocol compared with passive rest on sprinting performance, jumping performance, and self-reported readiness ARMS in players from the Portuguese Under-19 Women's club league. By integrating both objective and subjective measures, this research seeks to provide a more comprehensive understanding of time-efficient re-warm-up strategies in a competitive female youth setting.

4. METHODS

2.1. Study Design

A randomized controlled trial was conducted to examine the effects of a 3-minute Integrated RWU (IRW-Soccer) protocol, performed during halftime, on physical performance and self-reported readiness in female players competing in the Portuguese Under-19 Women’s club league. Twenty-two players from a U19 women’s team were randomly assigned to a passive rest group (G1; n = 11; Control Group) or an experimental group (G2; n = 11; IRW-Soccer).

The experimental group performed the structured IRW-Soccer protocol during the final 3 minutes of the halftime interval, while the control group underwent passive rest. Following the initial pre-match warm-up, and again upon completion of the IRW-Soccer or passive rest period, players immediately underwent performance assessments,

consisting of a 20-m linear sprint test and a countermovement jump (CMJ) test (Figure 1). At the end of the session, players completed the ARMS questionnaire, which had been previously explained regarding its objective and completion method.

All procedures adhered to the Declaration of Helsinki (2013, Fortaleza Revision) and received approval from the Ethics Committee of the Faculty of Sport, University of Porto (CEFADE_37_2022). Informed consent was obtained from all participants following a comprehensive briefing on the study's purpose, procedures, potential risks, and benefits. Participants were explicitly informed of their right to withdraw at any time without any prejudice.

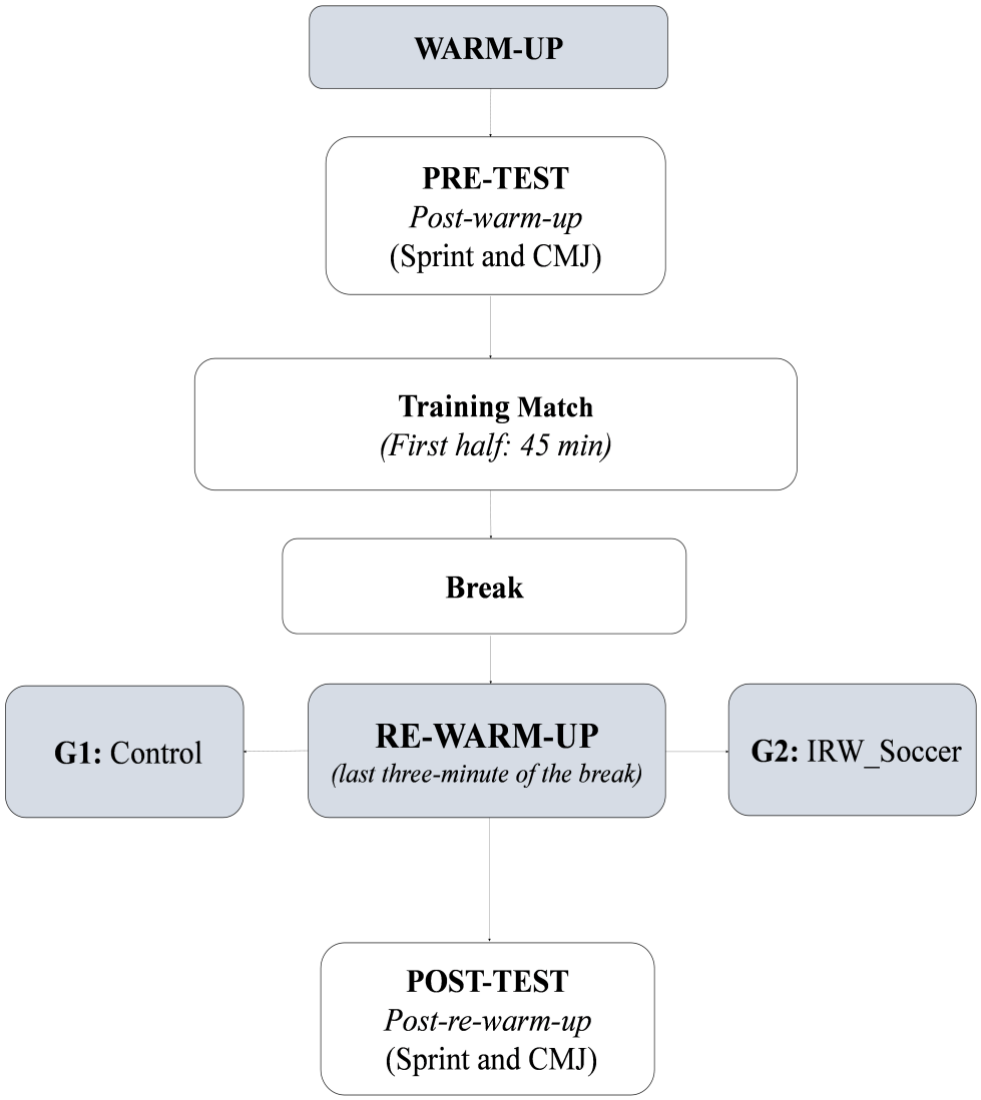


Figure 1. Diagrammatic representation of the randomized trial. *Legend*: CMJ, countermovement jump; G1, Group 1; G2, Group 2.

2.2. Participants

Twenty-two female soccer players (Table 1) competing in the Portuguese U19 Women's First Division Soccer Championship, were recruited from a single U19 team using a purposeful and convenience sampling. Prior institutional approval was obtained from the team's technical staff. The Inclusion criteria were: (i) active participation in competitive matches without medical restrictions, and (ii) no recent injuries affecting performance capacity. Exclusion criteria: (i) acute or subacute injury within 6 months, and (ii) physical limitations affecting sprinting or jumping assessments.

Table 1. Participant characteristics.

Group	Age (years)	Body Mass (kg)	Height (cm)
Control (*n*=11)	**15.27 ± 1.56**	**51.6 ± 6.5**	**162.1 ± 3.**
IRW-Soccer (*n*=1	**16.55 ± 0.93**	**56.6 ± 6.8**	**163.6 ± 5.5**
Total (*n*=22)	**15.91 ± 1.34**	**54.1 ± 7.2**	**162.9 ± 4.6**

Note: Values represent mean ± standard deviation. Independent t-tests showed no significant baseline differences between groups ($p > 0.05$).

Participants were randomly allocated using stratified-paired randomization supervised by the team coach and lead researcher. Players were matched by playing position, prior sprinting and jumping performance, and physical attributes, then randomly assigned within pairs (coin toss method; 1:1 allocation). Post-randomization integrity measures prevented group changes. Participant flow is shown in Figure 2.

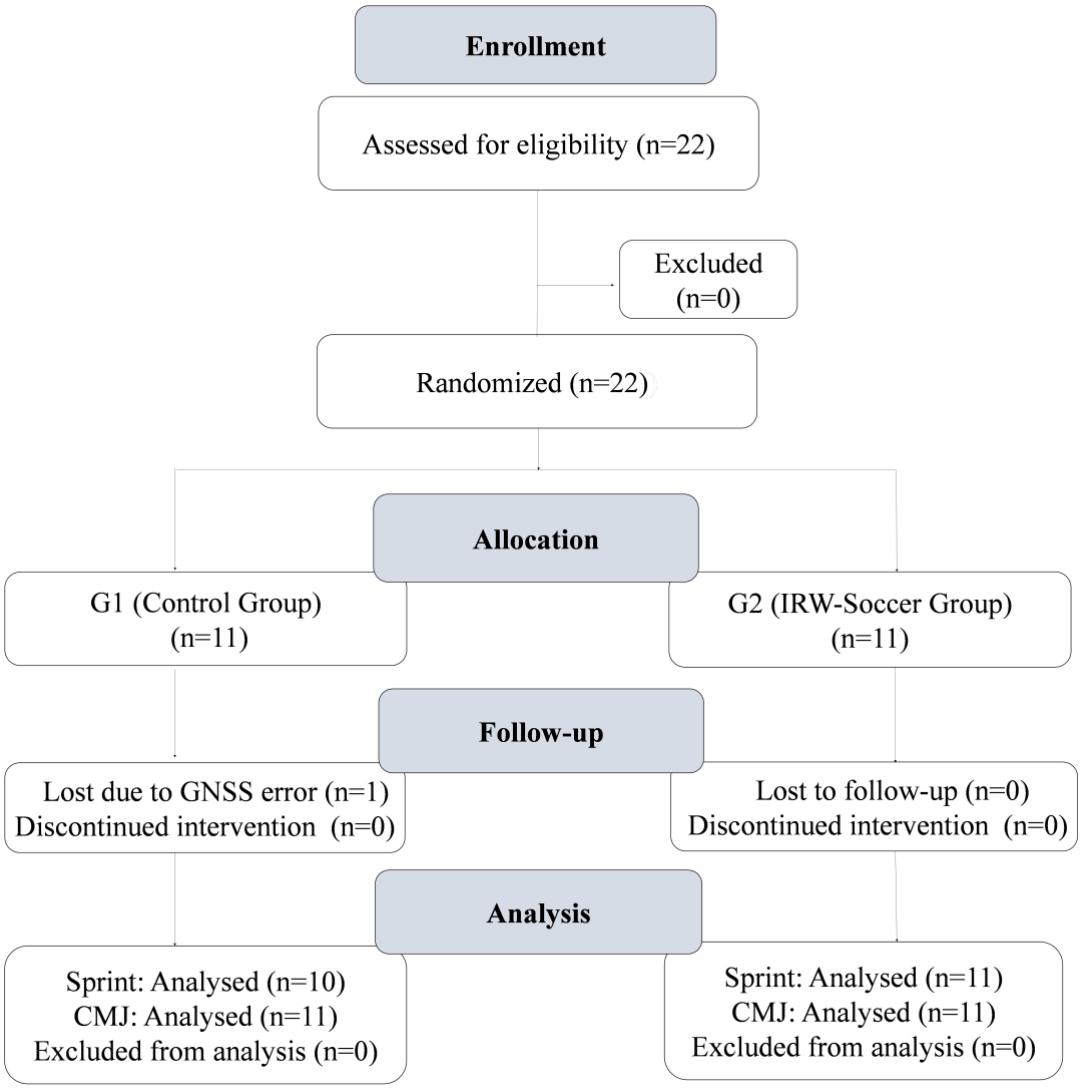


Figure 2. Flowchart of study participants.

2.3. Procedures

2.3.1. Explanatory Session

Prior to data collection, players attended an introductory session where the research team detailed the study's objectives, rationale, and experimental procedures. This included a comprehensive overview of the testing protocols and the data collection process using Global Navigation Satellite System (GNSS) units. The session concluded with an open discussion to clarify any queries from the athletes and technical staff, ensuring a full understanding of all experimental procedures

2.3.2. Data Collection Procedures

Immediately before data collection, a briefing session reviewed the study's objectives and procedures with players and staff. Participants then performed a 15–20-minute pre-match warm-up based on the FIFA 11+ program, followed by baseline neuromuscular tests (sprint and jump). Subsequently, players participated in a standardized 11-a-side friendly match (two 45-minute halves) with a 15-minute halftime. During the first 12 minutes of halftime, players engaged in typical match-related activities without additional exertion. In the final three minutes, the control group (G1) remained in passive rest, while the experimental group (G2) performed the IRW-Soccer protocol. Post-intervention, both groups repeated the neuromuscular tests. All procedures were conducted by the research team on the same playing surface under consistent environmental conditions to ensure standardization. Finally, participants completed the ARMS questionnaire via a digital link in the locker room to assess immediate self-reported readiness before the second half.

2.4. IRW-Soccer Protocol

The IRW-Soccer protocol followed the 3-minute halftime methodology previously described and validated.[18] Briefly, it consisted of two consecutive 1.5-minute components: (1) six adapted FIFA 11+ exercises (Part 2) performed for one set of eight repetitions each (squats with toe-raise, walking lunges, single-leg squats, vertical, lateral, and box jumps); and (2) a 5v5 small-sided game (SSG) on a 15 × 15 m pitch (Figure 3). To maintain high-intensity dynamics, the SSG included a two-touch restriction and neutral floater, with replacement balls positioned around the sidelines to ensure uninterrupted play. Post-intervention tests were conducted immediately after the SSG to preserve the acute re-warm-up window.[18]

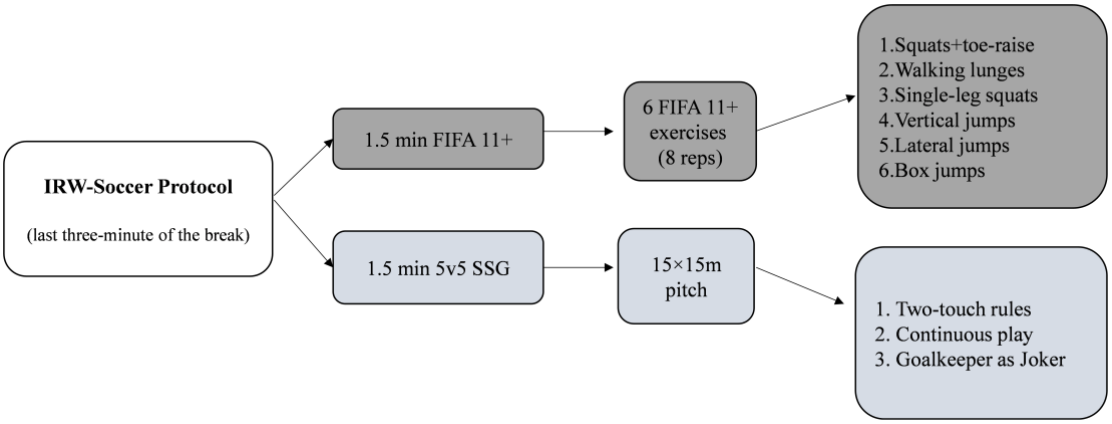


Figure 3. Timeline of the IRW-Soccer protocol applied during the final 3 minutes of the half-time break: 1.5 min of FIFA 11+ exercises followed by 1.5 min of 5v5 small-sided games (SSG) performed on a 15 × 15 m pitch. *Legend.* min = minutes; m = meters; reps = repetitions; SSG = small-sided games.

2.5 Outcomes

All testing sessions followed a standardized sequence, with the 20-m linear sprint performed first, followed by the CMJ, during both pre- and post-intervention assessments to ensure methodological consistency and minimize potential order effects. This testing order aligns with previous re-warm-up (RWU) studies investigating post-halftime performance outcomes,[16] and reflects the validity of the 20-m sprint in assessing soccer-specific explosive capabilities, as well as its sensitivity to performance decrements induced by the halftime.

2.5.1. 20 m Sprint Test

The 20-m linear sprint was used to assess acceleration, given its ecological validity and sensitivity to fatigue in soccer contexts. This measure is particularly relevant, as most high-intensity match actions occur within short distances 10–20 m, and sprint performance is known to be affected by the halftime interval and responsive to re-warm-up strategies.[16,18]

2.5.2 Countermovement Jump Test

The CMJ served as a sensitive indicator of post-halftime neuromuscular readiness (Silva et al., 2018). Passive rest typically impairs jump height through reduced muscle temperature and neural drive, whereas active RWUs can counteract these effects (Russell et al., 2015). Jump height was measured using the My Jump 2 app (v5.0.5) from 120-Hz video, a method previously validated against force plates.[22] Players executed one maximal CMJ with hands on hips and a rapid countermovement to ~90° knee flexion. Invalid trials allowed one re-attempt after 30 s recovery, with the highest valid height retained for analysis.

2.5.3 Acute Readiness Monitoring Scale

The ARMS questionnaire, which consists of 32 items distributed across nine factors: general readiness, physical readiness, physical fatigue, cognitive readiness, cognitive fatigue, readiness for threat challenges, readiness for skills and training, group/team readiness, and equipment readiness.

Three items from each of two ARMS factors were selected, as they were considered the most relevant for determining the implications of re-warm-up on the players' readiness for the task in the second half of the match: (i) physical readiness (three questions: 1, 14, and 16); and (ii) cognitive readiness (three questions: 26, 27, and 28).

The questionnaire uses a scale ranging from zero (did not apply) to six (fully applied). Players were previously instructed on how to complete the questionnaire and were assured of the confidentiality of their responses. The questionnaire was completed individually, and players were asked not to share information with their teammates during the process.

2.5.4 - External Load Monitoring

In addition to timing the 20-m sprint, external load during matches was monitored using the same 10-Hz WIMU PRO™ GNSS units with integrated accelerometers.

Locomotor activity was categorized using predefined thresholds applied consistently across all participants: high-speed running (HSR > 11.0 km·h^{-1}), sprint (> 21.0 km·h^{-1}), accelerations (ACC > 3.0 m·s^{-2}), and decelerations (DCC > 2.0 m·s^{-2}). These metrics were subsequently used to compare groups and control for potential confounding effects of match-induced fatigue (see Section 2.6 Statistical Analysis).

2.6. Statistical Analysis

Normality was assessed using Shapiro-Wilk tests: CMJ data violated normality ($p < 0.05$ in 3/4 conditions), whereas sprint data met this assumption ($p > 0.05$). Despite partial non-normality, a 2 × 2 mixed ANOVA was used to examine the effects of Group (Control vs. IRW_soccer) × Time (Post-warm-up vs. Post-RWU) on the primary outcomes (20-m sprint, CMJ), justified by the study's exploratory design and the robust properties of ANOVA. Partial eta squared (η_p^2) was interpreted as small (≥ 0.01), medium (≥ 0.06), or large (≥ 0.14), according to Cohen. [23] Levene's test (homogeneity of variance) and Mauchly's test (sphericity) were non-significant ($\alpha = 0.05$). ARMS data (ordinal Likert scale) were analysed using Mann-Whitney U tests (n = 11/group), reporting Rosenthal's r effect sizes (small: r ≥ 0.1; medium: r ≥ 0.3; large: r ≥ 0.5)[24]. Pairwise comparisons used Cohen's d, interpreted as small (≥ 0.2), medium (≥ 0.5), and large (≥ 0.8)[23]. Analyses were conducted in IBM SPSS Statistics (v27.0). As an exploratory study using a small sample, p-values were interpreted cautiously, prioritizing descriptive patterns and effect sizes.

In addition, to ensure that observed differences in primary outcomes were not confounded by variations in in-game physical demands, the physical load metrics recorded during the match were compared between the Control and IRW-Soccer groups. An independent samples Mann-Whitney U test was used to analyse differences for total distance, high-speed running, maximum speed, number of sprints, accelerations, and decelerations. Rosenthal's r was calculated as the effect size. This analysis aimed to verify the internal validity of the study by confirming a comparable physical load between groups.

3. RESULTS

3.1. Game Load Control Analysis

Before analysing the primary outcomes, the external physical load experienced during the match was compared between groups to control for potential confounding variables. There were no significant differences for any of the load metrics (Table 2), supporting the internal validity of the study by suggesting that subsequent findings on primary outcomes (sprint and CMJ) are not attributable to variations in match-induced fatigue.

Table 2. First-half match physical performance: Comparison between Control (G1) and IRW-Soccer (G2) Groups

Physical performance	G1 (n = 11) Median [IQR]	G2 (n = 11) Median [IQR]	*P*	Effect Size (r)
Total Distance (m)	4588.8 [295.1]	4656.6 [813.3]	0.673	0.090
High-Speed Running (HSR, m; >11.0 km·h^{-1})	1646.2 [480.6]	1697.3 [761.0]	0.888	0.030
Maximum Speed (km·h^{-1})	25.0 [3.3]	24.3 [3.4]	0.888	0.030
Sprints (n; >21.0 km·h^{-1})	5.0 [7.0]	5.0 [5.0]	0.644	0.098
Accelerations (ACC, n; >3.0 m·s^{-2})	1351.5 [124.3]	1343.0 [194.0]	1.000	0.000
Decelerations (DCC, n; >2.0 m·s^{-2})	1350.0 [150.0]	1343.0 [197.0]	0.944	0.015

Legend. ACC – Accelerations; DCC – Decelerations; HSR – High-Speed Running; IQR – Interquartile range;

3.2. Primary Outcomes: Sprint and Vertical Jump Performance

The changes in 20-m sprint and CMJ performance from post-warm-up to post-RWU are detailed in Table 3. For 20-m sprint performance, a significant improvement was observed in both groups (Control: from 4.32 ± 0.14 s to 3.98 ± 0.21 s, Δ = −0.34 s;

IRW-Soccer: from 4.49 ± 0.23 s to 4.06 ± 0.24 s, Δ = −0.43 s). There was a statistically significant main effect of time with a large effect size ($F = 95.34$, $p < 0.001$, $\eta_p^2 = 0.834$). However, no significant time × group interaction was observed ($F = 1.428$, $p = 0.247$, $\eta_p^2 = 0.070$), suggesting that the magnitude of improvement was comparable between groups. Regarding **CMJ height**, changes were minimal and non-significant (Control: from 27.82 ± 2.47 cm to 27.94 ± 3.29 cm, Δ = +0.12 cm; Experimental: from 25.87 ± 4.47 cm to 27.15 ± 2.62 cm, Δ = +1.28 cm). No significant main effect of time ($F = 0.881$, $p = 0.359$, $\eta_p^2 = 0.042$) or time × group interaction ($F = 0.614$, $p = 0.442$, $\eta_p^2 = 0.030$) was found. Additionally, the main effect of group was not significant ($F = 1.312$, $p = 0.266$, $\eta_p^2 = 0.062$).

Table 3. Physical performance outcomes (M ± SD) and mixed ANOVA results for 20-m sprint and CMJ tests.

Variable Effect	Group	Post-warm-up (M ± SD)	Post-RWU (M ± SD)	Change (↓)	F	*p*	η_p^2
Sprint test (s)	G1	4.32 ±0.14	3.98 ± 0.21	−0.34			
	G2	4.49 ± 0.23	4.06 ± 0.24	−0.43			
Time x Group					1.43	0.247	0.07
Time					95.9	<0.001	0.83
CMJ test (cm)	G1	27.82 ± 2.4	27.94 ± 3.29	0.12			
	G2	25.87 ±4.47	27.15 ± 2.62	1.28			
Time x Group					0.61	0.442	0.30
Time					0.88	0.359	0.42

Legend: CMJ, countermovement jump. M, Mean; SD, Standard Deviation.

3.3. Perceived Readiness and Recovery (ARMS)

No significant differences were found between the control group (G1) and the IRW-Soccer group (G2) for any of the physical or cognitive readiness items (Table 4). For physical readiness, the item “I am physically fresh” showed a moderate effect size ($r = 0.35$), although it was not significant ($p = 0.151$). The item “I am physically prepared” had a slightly higher median in the control group (5 (3–5) vs. 4 (2–5); $p = 0.332$, $r = 0.24$), while “I am physically fit” showed no relevant differences. Higher scores indicate better

physical readiness; thus, small descriptive differences slightly favoured the control group, without statistical significance. Regarding cognitive readiness, none of the items "I can focus well", "I am mentally prepared", and "I am thinking clearly", showed significant differences between groups ($r \leq 0.20$; $p > 0.05$), indicating similar responses to the protocol.

Table 4. Comparison of subjective physical and cognitive readiness between groups after the halftime interval.

ARMS	Control Group (G1)	IRW_soccer Group (G2)	Z	p	Effect Size (r)
Physical Readiness					
I am physically fit	4 (3-5)	4 (3-5)	-0.299	0.797	0,06
I am physically prepared	5 (3-5)	4 (2-5)	-1.132	0.332	0,24
I am physically fresh	4 (2-5)	4 (2-4)	-1.629	0.151	0,35
Cognitive Readiness					
I can focus well	4 (3-5)	4 (3-5)	-0.939	0.401	0.20
I am mentally prepared	4 (2-5)	4 (2-5)	-0.527	0.652	0.11
I am thinking clearly	4 (3-5)	4 (3-5)	-0.558	0.606	0.12

***Legend*:** Arms - Acute Readiness Monitoring Scale; IRW- Soccer - Integrated Re-warm-up soccer protocol

Note: *Data are presented as Median (Minimum–Maximum). G1: Control Group (passive rest); G2: IRW-soccer Group (3-minute re-warm-up protocol). Z: Mann-Whitney U test statistic; p: significance level ($p < 0.05$). Effect Size (r) interpreted as: small (0.10), medium (0.30), and large (0.50) according to Cohen (1988).*

4. DISCUSSION

This exploratory study examined the effects of a 3-minute re-warm-up protocol (IRW-Soccer),[9] combining FIFA 11+ exercises and SSGs, on 20 m sprint and CMJ in First Division U19 female soccer players. Both groups experienced comparable physical loads during the first half, suggesting that the findings were not differentially influenced by potential differences in match-induced fatigue. After the RWU, no significant interaction effects were found, with no differences between groups. Both groups improved sprint performance (Control: $\Delta = -0.34$ s; IRW-Soccer: $\Delta = -0.43$ s), potentially reflecting a potentiation effect from playing the 1st half of the match, although it is unclear why no effect was found for the CMJ. Our results diverge from studies

showing that passive halftime rest impairs explosive performance (~2.6% decrease in sprint and ~7.6% in jump),[25,26] while low-intensity RWUs generally attenuate these declines.[25] Previous studies have indicated that active re-warm-ups enhance physical performance in soccer, reducing losses in speed and power.[11,18,26]

The lack of significant differences between groups following the RWU, despite improvements in sprint performance for both, suggests that very brief interventions may not always outperform rest in young female players. This outcome may be attributed to the specific physiological profile of female soccer players, which includes lower muscle power development, [27] distinct thermoregulatory responses, and a higher susceptibility to injuries.[7,21]

Such characteristics limit the transferability of findings derived from male populations, emphasizing the need for re-warm-up protocols tailored to female specificities to optimize performance and mitigate injury risks during the second half of match play.

Even within women players, factors such as age, competitive level, and level of fatigue experienced during the 1st half of the match may interact with a RWU protocol, generating non-linear responses that may be sample- and context-specific. Comparisons with professional adult female players suggest that age and competitive level may influence RWU responses: adults showed significant sprint improvements with large interaction effects ($p = 0.019$, $\eta_p^2 = 0.27$; experimental: −0.40 s vs. controls: −0.25 s),[18] whereas U19 players achieved numerical gains that were not statistically significant (Time × Group: $F = 1.43$, $p = 0.247$, $\eta_p^2 = 0.070$).

The observed dissociation between sprint and CMJ has precedents in research: linear sprint seems more responsive to short RWUs, whereas vertical power requires longer or more specific stimuli.[4,28,29] The greater positive effect on sprint that we observed in the active RWU group may still confer a competitive advantage, and the lack of statistical significance may reflect either a true effect, or a false negative due to reduced statistical power.

ARMS results showed no differences between groups in physical or cognitive readiness ($Z = –0.299$ to $–1.629$; $p = 0.151–0.797$), with small-to-medium effect sizes ($r = 0.06–0.35$). These findings indicate that the intervention did not meaningfully alter players' perceived readiness compared with the control condition. Similar outcomes have

been reported in youth soccer, although slightly longer re-warm-up protocols may provide additional benefits. For example, a 7-minute half-time re-warm-up improved attention and reaction time in cognitive tasks such as the Psychomotor Vigilance Task (PVT) in U16 players.[30] However, official matches will rarely offer a time-window of 7 minutes for a RWU protocol to be performed.

Collectively, our findings suggest that the RWU intervention did not meaningfully alter players' explosive performance or perceived readiness compared with the control condition. The RWU was feasible within the limited 3-minute time-window, but the results diverge from previous similar studies and suggest the need to tailor protocols to the physiological and neuromuscular characteristics of young athletes and to explore future strategies regarding duration, intensity, and exercise composition,[7,21] as well as how the RWU protocol dose interacts with fatigue accumulated during the 1st half of the match.

Limitations and Future Directions.

The small sample size limits statistical power and generalizability of the findings. The absence of a formal familiarization session with the team may have increased performance variability and induced habituation effects. Moreover, assessing only acute responses leaves longer-term adaptations to re-warm protocols unexplored, while the lack of physiological measures (e.g., muscle temperature, blood lactate concentration) restricts mechanistic interpretations.

5. CONCLUSION

The 3-minute IRW-Soccer protocol did not differ from passive rest in physical performance or perceived readiness in U19 female soccer players. Both groups improved sprint times but not CMJ height, suggesting a similar response to the re-warm-up. Practically, the RWU may be sufficient to maintain or slightly enhance linear sprint capacity, whereas vertical power may require more specific or longer-duration stimuli. The effects of RWU protocols may vary depending on fatigue accumulated during the 1st half of the match and factors such as age and competitive level, demanding more research.

6. PRACTICAL APPLICATIONS

The practical aim of this study is to provide insights into the application of the IRW-Soccer protocol, previously implemented in professional adult athletes, in young female players, in order to optimize performance and readiness during the second half.

Differences in neuromuscular characteristics and muscle mass between young and adult players suggest that, although the protocol can be applied in this population, its effects may be more limited if adaptations are not made. The protocol may help maintain the ability to perform explosive actions and potentially enhance performance, although exercise intensity and content should be adjusted according to the players' physical and neuromuscular characteristics as well as their competitive level.

When access to the pitch or training area is restricted, the SSG included in the protocol can be replaced with high-intensity exercises, such as changes of direction, accelerations, light plyometrics, or short reactive circuits performed in confined spaces. These strategies allow neuromuscular activation to be maintained and effectively prepare players before returning to the second half, providing a practical and flexible approach for coaches and performance staff.

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Neuromuscular and High-Intensity Match Performance Responses to Halftime Re-Warm-Up Protocols: A Pilot Randomized Trial in Professional Male Soccer Players

Original Investigation

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ABSTRACT

Objectives: Halftime in soccer is typically passive and may impair second-half readiness. This study compared two 3-minute active re-warm-up protocols on neuromuscular performance and high-intensity match-running performance during the first 25-minutes of the second half. **Design:** Pilot randomized comparative study. **Methods**: Twenty-two male professional soccer players were randomized to a strength, plyometric, and balance protocol (SPBP) and a soccer-specific protocol (SSP). Countermovement jump (CMJ) and 20-m sprint test, were performed after the pre-match warm-up and immediately after the halftime re-warm-up protocol. Global Navigation Satellite System (GNSS), quantified match-running outcomes during the first 25-minutes of the second half. Mixed ANOVA examined neuromuscular outcomes, while Mann–Whitney U tests compared GNSS derived outcomes; effect sizes were expressed as partial eta squared (η_p^2) and Rosenthal´s (*r)*. **Results:** No significant time x group interaction was observed for CMJ ($p = .562$) or 20-m sprint performance ($p = .383$). During early second-half match play compared with SSP, SPBP showed higher total distance, sprint distance, high-speed running distance, and maximum speed, with small-to-moderate effects, although between-group differences were not statistically significant. **Conclusion**: The 3-minute halftime re-warm-up protocols (SSP and SPBP) produced similar acute neuromuscular responses (CMJ or 20-m sprint). However, SPBP showed more favorable match-running outputs during the first 25 minutes of the second-half for total distance, sprint distance, maximum speed, and maximum acceleration. Short duration halftime re-warm-up strategies may offer practical competitive benefits in professional male soccer players, but further studies including larger samples and passive-control conditions are required.

Keywords: male players; neuromuscular performance; small-sided games; sprint performance; countermovement jump.

INTRODUCTION

Studies in professional male soccer have consistently shown a decline in high-intensity running from the first to the second half of match play, particularly during the initial minutes, (Di Mascio & Bradley, 2013; Weston et al., 2011). Empirical evidence further indicates that high-intensity running and acceleration metrics are often reduced at the beginning of the second half, although isolated peaks corresponding to the most-demanding periods of play can still occur (Lino-Mesquita et al., 2025; Oliva-Lozano et al., 2021). This performance decrement has been associated with accumulated fatigue, reductions in muscle and core temperature during halftime, and lower physiological readiness to cope with the most demanding passages of play that may occur immediately upon halftime restart, (Dellal et al., 2015; Mohr et al., 2004; Oliva-Lozano et al., 2020). This period is particularly critical, as players may be required to perform frequent high-intensity actions immediately after the restart, regardless of playing position (Oliva-Lozano et al., 2023).

The halftime interval is typically used for rehydration, energy replenishment, and tactical adjustments (Carling et al., 2016; Russell et al., 2015). However, its predominantly passive nature may contribute to declines in neuromuscular performance during the early phase of the second half. The first 15 minutes after halftime have been consistently identified as a phase of reduced overall physical output (Lovell, Midgley, et al., 2013; Weston et al., 2011), possibly due to incomplete recovery from first-half. From a physiological perspective, passive halftime may result in reductions in muscle and core temperature of approximately 1.5-2.0 ºC (Hammami et al., 2018; Lovell, Barrett, et al., 2013; Mohr et al., 2004; West et al., 2013), negatively affecting sprinting, jumping, and high-intensity running performance during the early phase of the second half (Russell et al., 2015).

Implementing brief, high-intensity re-warm-up strategies could be an effective approach to attenuate halftime related performance decrements and support players' readiness for high-intensity actions at the beginning of the second half (Edholm et al., 2014; Yanaoka, Hamada, et al., 2018; Zois et al., 2013). Strength and plyometric based

protocols may provide a neuromuscular priming stimulus, whereas soccer-specific strategies, such as small-sided games, may simultaneously maintain technical-tactical engagement and physiological activation (Dellal et al., 2011; Impellizzeri et al., 2006). Although **post activation performance enhancement (**PAPE) was not directly assessed in the present study, these approaches may be conceptually related to PAPE mechanisms, whereby brief high-intensity conditioning activities can acutely support explosive performance when the balance between potentiation and fatigue is favorable (Blazevich & Babault, 2019; Seitz & Haff, 2016; Xu et al., 2025).

Given the practical time constraints of the halftime period, short re-warm-up strategies, lasting approximately 3 minutes, have been proposed as feasible alternatives to restore physiological and neuromuscular readiness without interfering with tactical instructions or recovery routines (Edholm et al., 2014; Yanaoka, Kashiwabara, et al., 2018; Zois et al., 2013). In our previous work with professional female soccer players, 3-minute strength, plyometric, and balance-based protocols and soccer-specific protocols elicited small and protocol dependent acute responses in sprint and countermovement jump performance, without clear superiority of one strategy over the other (Abreu et al., 2025). More recently, an integrated re-warm-up soccer protocol (IRW-Soccer), combining FIFA 11+ derived exercises and small-sided games, was shown to attenuate sprint and countermovement jump performance decrements in senior professional female players, when compared with passive halftime recovery (Abreu et al., 2026). However, in U19 female players, this integrated approach did not show clear advantages over passive rest, in the study by Abreu et al., (under review) suggesting that age, maturation, competitive level, and contextual match demands may influence the response to halftime re-warm-up strategies.

Despite these findings, previous studies have mainly focused on immediate neuromuscular responses assessed before and after halftime, whereas the potential transfer of brief re-warm-up protocols to subsequent match-running performance remains less understood. In particular, little is known about whether distinct 3-minute halftime re-warm-up protocols/strategies influence high-intensity running, sprint distance, accelerations, decelerations, maximum speed and total distance, during the early phase of the second half.

Therefore, this exploratory study aimed to compare the effects two re-warm-up protocols on neuromuscular performance and GNSS-derived match-running responses, during the first twenty-five minutes of the second half in professional male soccer players.

2. METHODS

2.1. Study Design

A randomized trial with two parallel groups was conducted to compare the effects of two active re-warm-up protocols at halftime on physical performance in professional male soccer players: a strength, plyometric, and balance protocol (SPBP; G1) and a small-sided game protocol (SSP; G2). Twenty-two players from a team competing in the Portuguese Professional League *(Tier 3: Highly Trained/National level)* were randomly allocated to G1 (n = 11) and G2 (n = 11). The intervention consisted of a brief protocol performed during the final 3-minutes of the halftime interval.

The data-collection session began with a standardized warm-up prescribed by the technical staff and supervised by the research team, in accordance with FIFA recommendations. Performance assessments were conducted immediately after the pre-match warm-up and immediately halftime re-warm-up (post re-warm-up), with no intervening rest to preserve the temporal window and included a 20-m linear sprint and a countermovement jump, (Figure 1). Match performance during the first 25-minutes of the second half was monitored using Global Navigation Satellite System (GNSS; WIMU PRO™; RealTrack Systems, Almería, Spain) technology, while first-half data were collected to provide a baseline for comparison. This approach allowed the evaluation of both acute neuromuscular responses and their transfer to match performance.

All procedures were conducted in accordance with the Declaration of Helsinki (2013 update, Fortaleza revision) and were approved by the Ethics Committee of the Faculty of Sport, University of Porto (CEFADE_37_2022). Informed consent was obtained from all participants after they received detailed information about the study's purpose, procedures, potential risks, and benefits. Participants were informed of their right to withdraw from the study at any time, without any penalty.

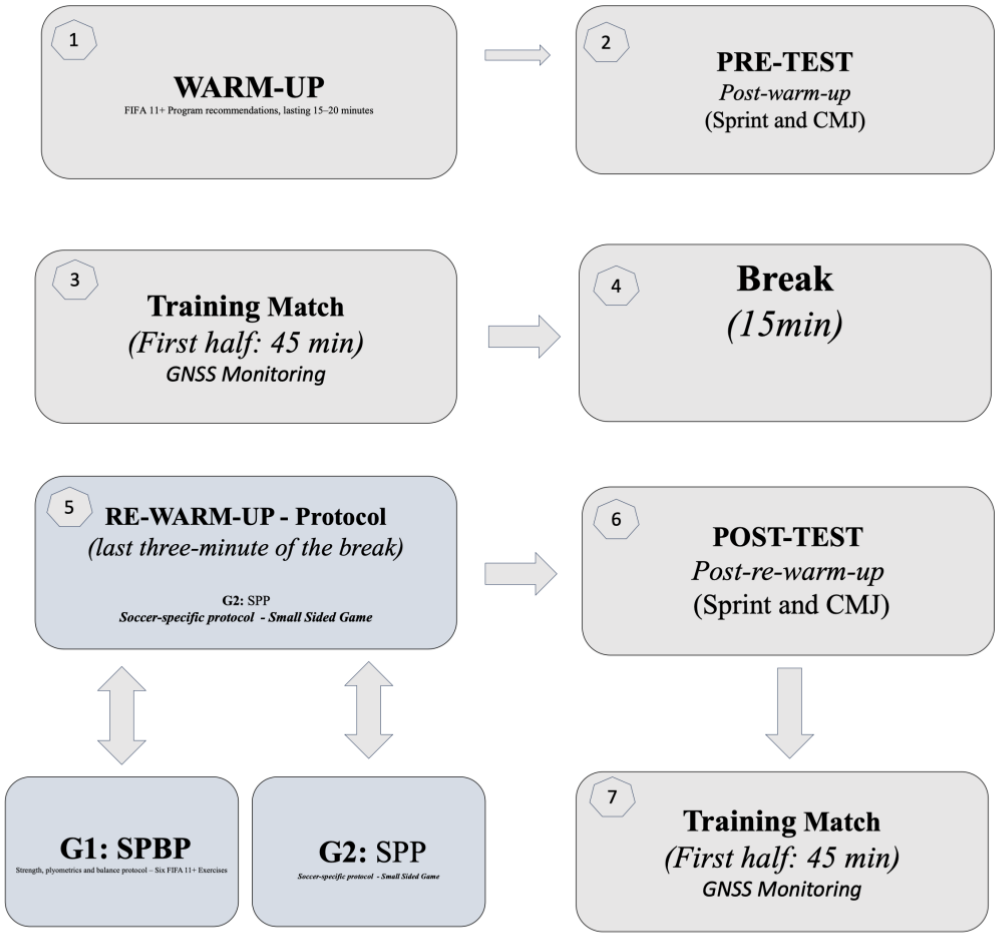


Figure 2. Diagrammatic representation of the randomized trial.

***Legend*:** *SPBP, small-sided possession-based protocol; SSP, small-sided protocol; GNSS, global navigation satellite system; CMJ, countermovement jump*

2.2. Participants

Twenty-two adult professional male soccer players were recruited from one team competing in the Portuguese Professional League, using a purpose and convenience sampling strategy. Details regarding participant recruitment and data exclusion due to technical Global Navigation Satellite System (GNSS; WIMU PRO™; RealTrack Systems, Almería, Spain) signal failures (G1: n = 1 excluded) and jump execution errors (G2: n = 1 excluded) are provided in the flowchart of study participants (Figure 2). Prior institutional approval was obtained from the team's technical staff. The inclusion criteria were: (i) current active participation in competitive matches without medical restrictions; and (ii) no recent injuries affecting performance. Exclusion

criteria were: (i) acute or subacute injury within the previous 6 months; and (ii) physical limitations affecting sprinting or jumping assessments. The two groups were comparable in their baseline anthropometric characteristics (Supplementary Table 1).

Supplementary Table 1. Participant characteristics.

Group	Age (years)	Body Mass (kg)	Height (cm)
SPBP (n = 11)	**23.6 ± 2.0**	**75.0 ± 7.4**	**182.5 ± 4.8**
SSP (n = 11)	**25.8 ± 6.0**	**75.6 ± 7.8**	**182.3 ± 5.9**
Total (n = 22)	**24.7 ± 4.5**	**75.3 ± 7.4**	**182.4 ± 5.2**

Note: Values are presented as mean ± standard deviation. Independent t-tests indicated no significant baseline differences between groups ($p > 0.05$).

Participants were randomly allocated using stratified paired randomization under the supervision of the team coach and lead researcher. Players were matched by playing position, prior sprinting and jumping performance, and physical attributes, and were then randomly assigned within pairs each par using a 1:1 allocation ratio. After randomization no group changes were permitted. Participant flow is shown in Figure 2.

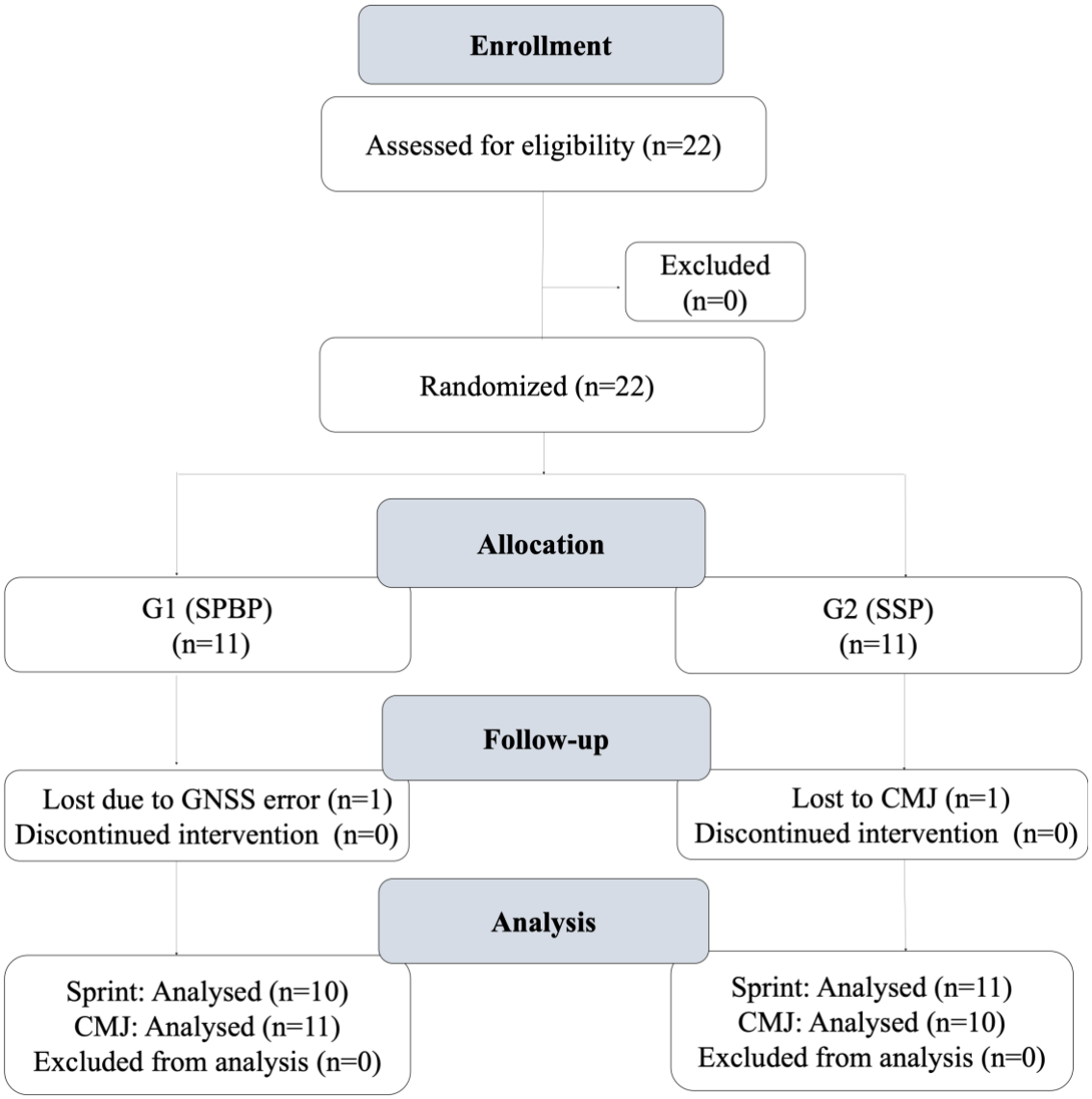


Figure 2. Flowchart of study participants.

Legend: *SPBP, small-sided possession-based protocol; SSP, small-sided protocol; GNSS, global navigation satellite system; CMJ, countermovement jump*

2.3. Procedures

2.3.1. Explanatory Session

Prior to data collection, the research team provided the coaching staff with all necessary information regarding the study's objectives, data collection procedures, data

processing, and confidentiality procedures. The coaching staff approved the study and allocated a training session for data collection. On the day of data collection, all players participated in an explanatory session conducted by the research team together with the coaching staff in the locker room. This session was designed to ensure a comprehensive understanding of the study's objectives, hypotheses, testing procedures, and monitoring processes. The research team once again explained in detail the purpose of the study, the specific physical tests to be performed, the use of portable GNSS units for external-load monitoring, as well as the data to be collected and analyzed. This system has demonstrated high test-retest reliability for mean velocity during locomotor tasks, expressed as an intraclass correlation coefficient (ICC = 0.951), and a low typical error of measurement for distance covered (TEM = 1.47%) (Bastida Castillo et al., 2018). The session concluded with an open discussion, allowing players to ask questions and ensuring full understanding of the procedures before proceeding with the experimental protocol.

No practical familiarization session was conducted, as the participants belonged to a professional team and such a session could interfere with their usual routines. Data collection was scheduled at a time when a team training session was already planned during a week of competition break, thereby minimizing disruption to the team and its programming. As all players were experienced professionals and familiar with sprint and jump testing, as well as with the regular use of GNSS systems by the technical staff for monitoring training load parameters, a prior familiarization session would likely not provide additional benefits to the study.

2.3.2. Data Collection Procedures

On the trial day, all procedures were reviewed with the participants during an explanatory session. Subsequently, the research team fitted the players participating in the study with the GNSS units, which had previously been placed at midfield for approximately 30-minutes to acquire a satellite signal.

The players completed the usual pre-match warm-up, prescribed by the technical staff and supervised by the research team. Before data-collection, the research team requested that this warm-up be adapted to align with FIFA 11+ recommendations while maintaining a duration of 15–20 min and **c**omprised three phases: (i) running and dynamic

mobility exercises; (ii) strength, balance, plyometric, and neuromuscular control exercises; and (iii) running with sprint accelerations and directional changes. Pre-intervention performance tests (20-m sprint and CMJ) were conducted immediately after the warm-up.

Participants then completed a standardized 11-a-side training match consisting of a 45-minutes first half and 25 minutes second half, separated by a 15-minutes halftime interval. During the first part of halftime (~11 min), players engaged in typical recovery activities, including restroom use, hydration, and coach instructions, with no additional physical exertion permitted.

During the final 3 min of halftime, participants in the intervention groups performed the structured RWU protocols: G1 performed the SPBP, and G2 performed the SSP.

Post-intervention performance tests (20-m sprint and CMJ) were conducted immediately after the respective halftime conditions, using the same protocols and equipment as in the pre-tests, without additional rest to preserve the acute re-warm-up effect. All assessments were performed on the same playing surface and under consistent environmental conditions and pitch surface conditions and were supervised by the same research team to ensure standardization.

2.4 Interventions

2.4.1. Strength, plyometric and balance protocol (SPBP)

The SPBP comprised six exercises: (a) squats with toe raises, (b) walking lunges, (c) single-leg squats, (d) vertical jumps, (e) lateral jumps (f) box jumps. The protocol was adapted from the FIFA 11+ warm-up programme, originally developed by FIFA to reduce injury risk and enhance performance in soccer players through a structured combination of strength, balance, plyometric, and running exercises (Barengo et al., 2014). Players performed two sets of eight repetitions of each exercise during the 3-minute re-warm-up period preceding the sprint and jump assessments.

2.4.2. Soccer-specific protocol (SSP)

The SSP consisted of a 5 vs. 5 plus goalkeeper small-sided game designed to maintain ball possession on a 15 m x15 m pitch. Players were randomly assigned to teams by the coaching staff, and a two-touch restriction was applied per possession to increase game intensity and decision-making demands. The goalkeeper acted as a neutral player and was allowed to use both feet and hands. The research team and technical staff strategically positioned replacement balls around the pitch to ensure uninterrupted play during the 3-minute bouts, whenever the ball went out of bounds. This format was designed to promote ball possession, rapid decision making, and high-intensity actions (Dellal et al., 2011; Neves et al., 2025; E. Rampinini et al., 2007).

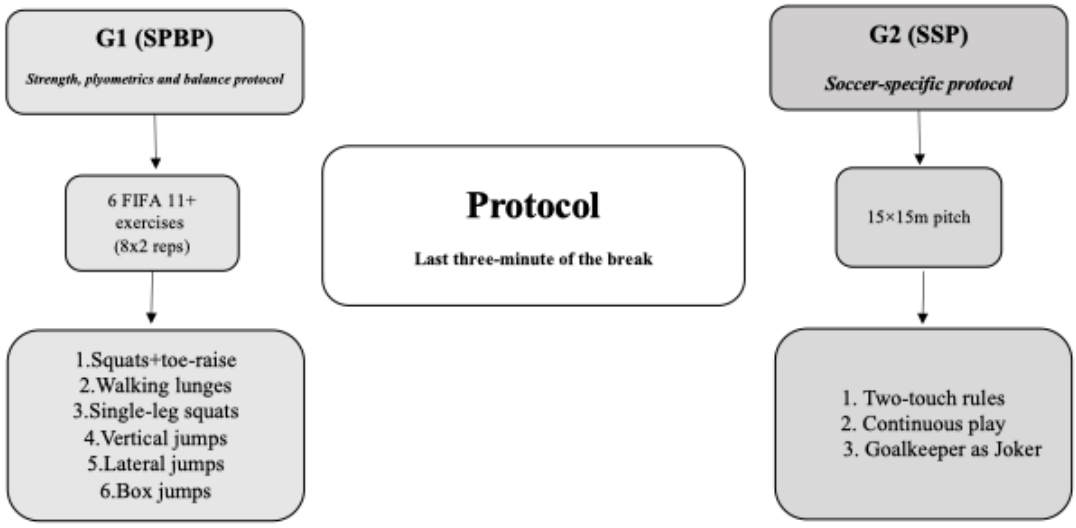


Figure 3. Experimental design of the SPBP and SSP protocols.

Legend: *SPBP, small-sided possession-based protocol; SSP, small-sided protocol; GNSS, global navigation satellite system; CMJ, countermovement jump*

2.5 Outcomes

The session was conducted in the same order for all participants, with the 20-m sprint test performed before the CMJ during both pre and post-intervention assessments, to ensure methodological consistency and reduce potential order effects (Edholm et al., 2014; Gonzalez Fernandez et al., 2023; Mohr et al., 2004).

2.5.1. 20-m Sprint Test

The 20-m sprint test was selected due to its ecological validity and sensitivity to fatigue in soccer (Mohr et al., 2004; Ermanno Rampinini et al., 2007). Players performed one maximal sprint from a standing start, timed using WIMU PRO™ GNSS units (10 Hz; RealTrack Systems, Almería, Spain) with integrated accelerometers (ICC > 0.90) (Bastida Castillo et al., 2018). Units were placed on the upper back, activated approximately 30-minutes before testing for satellite acquisition, and data were downloaded and processed using the S PRO™ software (version 1.0.0; RealTrack Systems, Almería, Spain).

2.5.2. Countermovement Jump Test

The CMJ assessed lower-limb power and neuromuscular readiness, serving as a valid and sensitive indicator of post-halftime fatigue in soccer (Loturco et al., 2020; Silva et al., 2018). Jump height was measured using the My Jump 2 app (version 5.0.5 IOS; developed by Carlos Balsalobre) from 120-Hz video, which has been validated against force plates (ICC = 0.997, 95% CI: 0.996–0.998; ICC > 0.95) (Balsalobre-Fernandez et al., 2015; Beato et al., 2018). This application has been employed in other sports (Gallardo-Fuentes et al., 2016; Yingling et al., 2018) and has shown nearly perfect agreement (ICC = 0.997, 95% CI: 0.996–0.998) compared with the gold standard method for estimating CMJ height (i.e., force plate) (Balsalobre-Fernandez et al., 2015). Players performed one maximal CMJ from an upright standing position, hands on hips, with rapid countermovement to ~90° knee flexion, full extension during flight, and controlled

landing. Invalid trials allowed one re-attempt after 30 s of recovery; the highest valid height was retained for analysis.

2.5.3. GNNS match-running data and high-intensity thresholds

As secondary outcomes, individual match-running data were collected using GNSS devices (sample rate: 10 Hz, update frequency: 10-Hz; WIMU PRO™, RealTrack Systems, Almería, Spain) worn in a vest positioned between the scapulae. Total distance, high-speed running (HSR >21 $km \cdot h^{-1}$), and sprint distance (≥24 $km \cdot h^{-1}$) were computed for each 15-s epoch and aggregated for the first 25 minutes of the second half. Acceleration and deceleration peaks (e.g., >3.0 $m \cdot s^{-2}$ and <–3.0 $m \cdot s^{-2}$, respectively) were also identified for each player to describe high-intensity neuromuscular load. All GNSS variables were exported and analyzed using proprietary software (version 1.0.0; RealTrack Systems, Almería, Spain), and any data loss during the first 25-minutes of the second half was excluded from the analysis. The data from the first half were utilized for the Game Load Control Analysis (Table 2), while the initial 25-minutes of the second half were specifically analyzed for primary outcomes related to neuromuscular performance (Table 4) presents the physical performance outcomes.

2.6. Statistical Analysis

Normality was assessed using the Shapiro-Wilk test. Descriptive statistics were reported as mean ± standard deviation (SD) for normally distributed variables and as median [interquartile range, IQR] for non-normally distributed variables. Primary neuromuscular outcomes (CMJ and 20-m sprint), were analyzed using a 2x2 mixed ANOVA, with Group (SPBP vs. SSP) as the between-subject factor and Time (post-warm-up vs. post-re-warm-up) as the within-subject factor. Effect sizes for ANOVA were quantified using partial eta squared (η_p^2), and interpreted as small (≥ 0.01), medium (≥ 0.06), or large (≥ 0.14) interpreted as small, medium, and large effects, respectively (Cohen, 1988).

For GNSS-derived physical performance variables, which did not meet normality assumptions, between-group comparisons were performed using the Mann-Whitney U test. Effect sizes were calculated as Rosenthal´s (r) from the standardized (z) statistic.

Rosenthal's r was interpreted as small (0.10 to < 0.30), medium (0.30 to < 0.50), or large (≥ 0.50).

To examine whether second-half responses during the first 25-minutes, could be influenced by prior match demands, first-half physical-load metrics were also compared between groups using the Mann–Whitney U test, with Rosenthal's r reported as the effect size. These variables included total distance, high-speed running distance, maximum speed, sprint distance, maximum acceleration, and maximum deceleration.

All analyses were conducted using IBM SPSS Statistics, version 27.0. Statistical significance was set at $p \leq .05$. Given the exploratory nature of this pilot study and the relatively small sample size, p-values were interpreted alongside effect sizes, with emphasis placed on the magnitude and practical relevance of the observed effects.

3. RESULTS

3.1. First-Half Game Load Control Analysis

During the first half, no significant between-group differences were observed for total distance, high-speed running distance, maximum speed, or sprint distance (all $p > .05$; Table 2). However, significant between-group differences were observed for maximum acceleration (medium effect) and maximum deceleration (large effect). The SPBP group showed lower maximum acceleration and deceleration values than the SSP group.

Table 1. First-half match physical performance: comparison between SPBP and SSP groups.

Physical performance	SPBP (n = 10) Median [IQR]	SSP (n = 11) Median [IQR]	*p*	Rosenthal's *r*
Total Distance (m)	4892 [1264.6]	4374.4 [890]	0.468	0.17
High-Speed Running (HSR, m; >21.0 km·h⁻¹)	214.1 [246.6]	288.8 [240]	0.282	0.25
Maximum Speed (km·h⁻¹)	28.6 [10.8]	29.3 [4.8]	0.468	0.17
Sprint Distance (m; >24.0 km·h⁻¹)	98.8 [156.1]	110.4 [133.3]	0.468	0.17
Maximum Acceleration (m·s⁻²)	4.5 [0.6]	5.2 [0.6]	0.036	0.45
Maximum Deceleration (m·s⁻²)	-5.4 [0.9]	-6.3 [1.3]	0.006	0.58

Legend. Values are presented as median [interquartile range]. SPBP: strength, plyometric, and balance protocol; SSP: soccer-specific protocol; HSR: high-speed running; IQR: interquartile range. Between-group comparisons were performed using the Mann–Whitney U test.d

3.2. ***Primary outcomes: Neuromuscular Outcomes (CMJ and 20-m Sprint)***

Analysis of CMJ revealed no significant main effect of time ($F(1, 19) = 0.08$, $p = .772$, $\eta_p^2 = .01$) and no significant time x group interaction ($F(1, 19) = 0.35$, $p = .562$, $\eta_p^2 = .02$). The SPBP group showed a small increase in CMJ height ($\Delta = +0.69$ cm; +1.64%), whereas the SSP group showed a trivial decrease ($\Delta = -0.23$ cm; −0.56%).

Similarly, 20-m sprint performance showed no significant time x group interaction ($F(1, 19) = 0.80$, $p = .383$, $\eta_p^2 = .04$). The SPBP group showed a trivial increase in sprint time ($\Delta = +0.013$s; +0.38%), whereas the SSP group showed a greater increase in sprint time ($\Delta = +0.077$s; +2.23%), indicating a small performance decrement in the SSP group. Descriptive data and mixed ANOVA results are presented in Table 3.

Table 2. Neuromuscular performance outcomes and mixed ANOVA results for CMJ and 20-m sprint performance.

Variable Effect	Group	Post-warm-up (M ± SD)	Post-RWU (M ± SD)	Change (↓)	F	*p*	η_p^2
Sprint test (*s*)	**SPBP**	3.37 ± 0.13	3.38 ± 0.16	0.01			
	SSP	3.45 ±0.09	3.52 ± 0.21	0.07			
Time x Group					0.80	0.383	0.04
Time					1.57	0.227	0.08
	SPBP	42.19 ± 5.10	42.88 ± 6.51	0.69			
CMJ test (cm)	**SSP**	41.50 ± 3.59	41.27 ± 5.13	-0.23			
Time x Group					0.35	0.562	0.02
Time					0.08	0.772	0.01

Legend: CMJ, countermovement jump. M, Mean; SD, Standard Deviation; G1 -SPBP; G2- SSP; RWU, re-warm-up

3.3. Secondary Outcomes: High-Intensity Match Performance During the First 25 Minutes of the Second Half

During the first 25-minutes of the second half, the SPBP group showed higher values than the SSP group across all GNSS-derived physical performance variables (Table 4). Although none of the between-group differences reached statistical significance, small-to-moderate effect sizes were observed for several outcomes.

Total distance covered was higher in SPBP than in SSP (2536.7 [857.6] m vs. 1878.8 [1135] m; p = .061; r = .41). Similar trends were observed for sprint distance (77.1 [48.4] m vs. 43.5 [49.0] m; p = .114; r = .36), maximum speed (26.6 [6.4] $km \cdot h^{-1}$ vs. 21.6 [10.0] $km \cdot h^{-1}$; p = .173; r = .31), maximum acceleration (4.25 [0.75] $m \cdot s^{-2}$ vs. 3.82 [1.38] $m \cdot s^{-2}$; p = .152; r = .32), maximum deceleration (−5.81 [1.28] $m \cdot s^{-2}$ vs. −4.80 [2.32] $m \cdot s^{-2}$; p = .223; r = .27), and high-speed running distance (167.5 [85.9] m vs. 110.7 [109.1] m; p = .251; r = .26).

Table 3. Second-half match physical performance (first 25 min): Comparison between SPBP and SSP groups.

Physical performance	SPBP (n = 10) Median [IQR]	SSP (n = 11) Median [IQR]	*P*	Rosenthal's *r*
Total Distance (m)	2536.7 [857.6]	1878.8 [1135.8]	0.061	0.41
High-Speed Running (HSR, m; >21.0 km·h⁻¹)	167.5 [85.9]	110.7 [109.1]	0.251	0.26
Maximum Speed (km·h⁻¹)	26.6 [6.4]	21.6 [10.02]	0.173	0.31
Sprint Distance (m; >24.0 km·h⁻¹)	77.1 [48.4]	43.5 [49.0]	0.114	0.36
Maximum Acceleration (m·s⁻²)	4.25 [0.75]	3.82 [1.38]	0.152	0.32
Maximum Deceleration (m·s⁻²)	-5.81 [1.28]	-4.80 [2.32]	0.223	0.27

Legend. HSR: high-speed running; IQR: interquartile range; SPBP: strength, plyometrics, and balance protocol; SSP: soccer-specific protocol. Values are presented as median [interquartile range]. Between-group comparisons were performed using the Mann–Whitney U test.

4. DISCUSSION

This exploratory study compared two 3-minute halftime re-warm-up protocols, SPBP and SSP, on neuromuscular performance and GNSS-derived match-running responses in professional male soccer players. The protocols did not produce significantly different acute effects on CMJ or 20-m sprint performance. However, SPBP was associated with higher GNSS-derived external-load values during the first 25-minutes of the second half, particularly in total distance, sprint distance, maximum speed, and maximum acceleration.

These second half findings should be interpreted in light of the first half game-load control analysis. Although total distance, high-speed running distance, maximum speed, and sprint distance were broadly comparable between groups, the SPBP group displayed lower maximum acceleration and deceleration values during the first half. Therefore, the higher second-half external-load outputs observed in SPBP cannot be attributed solely to the re-warm-up protocol and should be interpreted as preliminary associations rather than definitive intervention effects. Given the exploratory nature of the study and the small sample size, these findings should be considered preliminary and hypothesis generating.

The absence of significant time x group interactions for CMJ and 20-m sprint performance suggests that the two 3-minute re-warm-up protocols did not produce clearly different acute effects on maximal neuromuscular performance. Although the SPBP group showed a descriptive tendency toward better maintenance of CMJ and sprint performance, these findings should be interpreted again with caution, because the effect sizes were small and statistically non-significant. This pattern is consistent with previous research showing that brief halftime re-warm-up strategies may not always elicit measurable improvements in isolated sprint or jump tests, particularly when the intervention duration is short and the recovery to testing interval is limited (Edholm et al., 2014; Yanaoka, Kashiwabara, et al., 2018; Zois et al., 2013). Alternatively, the lack of clear differences may indicate that both active protocols were similarly effective or that neither protocol was sufficiently impactful to alter immediate neuromuscular outcomes under the present conditions.

From a mechanistic perspective, strength and plyometric-based activities may support neuromuscular readiness through PAPE-related mechanisms, including increased motor unit recruitment, enhanced musculotendinous stiffness, and improved calcium sensitivity (Blazevich & Babault, 2019; Seitz & Haff, 2016; Xu et al., 2025). However, the emergence of PAPE effects is likely dependent on the intensity, volume, and neuromuscular specificity of the conditioning activity, as well as the balance between potentiation and fatigue. In the present study, the short duration of the protocol and the practical constraints of the halftime context may have limited the intensity or total neuromuscular stimulus required to induce a robust PAPE response. Therefore, the present protocols may not have provided sufficient stimulus intensity to elicit clear improvements in CMJ or 20-m sprint performance.

The present findings should also be considered in relation to previous work from our research group examining halftime re-warm-up strategies in professional women's soccer. In a previous pilot randomized controlled trial, Abreu et al. (Abreu et al., 2025) showed that halftime re-warm-up strategies may help attenuate performance decrements after the interval, although the magnitude and consistency of the effects appeared to depend on the specific outcomes assessed and the competitive context. The current findings partially align with this evidence, as no clear between-protocol differences were

observed for isolated neuromuscular outcomes, whereas more favorable responses were found for selected GNSS-derived match-running variables after SPBP.

More recently, Abreu et al. (Abreu et al., 2026) introduced the IRW-Soccer protocol, which combines FIFA 11+ derived strength, plyometric, and balance exercises with soccer-specific small-sided games during a 3-minute short halftime window. Although the present study did not directly test the IRW-Soccer protocol, these findings support the rationale for further examining integrated protocols that combine neuromuscular activation with soccer-specific locomotor demands, technical-tactical components, and perceptual demands within an Integrated Model of Dynamic Performance framework.

Despite the absence of clear between-protocol differences in isolated neuromuscular tests, the analysis of secondary GNSS-derived variables suggested a different pattern during the first 25-minutes of the second half. The SPBP group showed higher values than the SSP group across all external-load variables, with the most relevant differences observed for total distance, sprint distance, maximum speed, and maximum acceleration. Nevertheless, none of these between-group differences reached statistical significance, and the effect-sizes were small-to-moderate. These findings should therefore be interpreted cautiously, as the higher second half values observed in SPBP may reflect a combination of protocol-related responses, match-context variability, and pre-existing differences in first-half match demands.

4.1 Limitations and Future Directions

This study has several limitations. First, the relatively small sample size and the use of multiple statistical comparisons may have limited the statistical power to detect significant interaction effects. Therefore, the findings should be interpreted primarily through descriptive patterns and effect sizes rather than through statistical significance alone.

Second, the single-match design limits the generalizability of the results and does not allow conclusions regarding the consistency of the observed responses across different competitive contexts. In addition, although first-half total distance, high-speed

running distance, maximum speed, and sprint distance were broadly comparable between groups, significant differences were observed in maximum acceleration and deceleration. This partial imbalance in first-half peak neuromuscular load may have influenced the second-half GNSS-derived outcomes.

Future studies should use larger samples, passive-control conditions, randomized cross-over designs, and repeated observations across multiple matches and also compare isolated and integrated halftime re-warm-up formats, incorporating neuromuscular, physiological, perceptual, and biochemical measures to better understand the mechanisms and practical relevance of these strategies in competitive soccer.

5. CONCLUSION

The absence of significant differences between the SPBP and SSP protocols regarding maximal neuromuscular capacity, suggests that both protocols may be implemented in elite settings without impairing performance, although comparisons with passive control conditions are necessary to establish whether they provide advantages. The SPBP protocol showed more favorable descriptive GNSS-derived responses, although these findings require caution due to the pilot design, small sample size, and first-half differences in peak acceleration and deceleration. Given the heterogeneity of findings across studies, including those from our own research group, the effects of halftime re-warm-up strategies may be sample and context-specific.

6. PRACTICAL APLICATIONS

Brief 3-minute halftime re-warm-up strategies appear feasible within the practical constraints of the halftime interval and may help coaches maintain player neuromuscular readiness before the second half. Although no clear superiority was observed between the strength, plyometric, and balance protocol and the soccer-specific protocol for CMJ or 20-m sprint performance, both approaches can be implemented without substantially disrupting halftime routines.

The strength, plyometric, and balance protocol may be particularly useful when the aim is to promote structured neuromuscular activation in a limited time window.

However, given the exploratory nature of the findings and the presence of first half differences in peak acceleration and deceleration demands, coaches should interpret the observed second half external-load advantages with caution.

In practice, halftime re-warm-up strategies should be adapted according to player characteristics, match context, tactical priorities, available space, and environmental conditions. Their effectiveness should be monitored using match-running, neuromuscular, and player-response data.

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Chapter 3: *Overall Discussion*

4. Overall Discussion

4.1. Overview of the Main Findings

The primary objective of this doctoral thesis was to explore the impact of short-duration (3-minute) re-warm-up protocols performed during the soccer halftime interval on neuromuscular and match-related performance outcomes, while selected studies also considered perceptual responses across different soccer populations. Through a series of four experimental studies, this thesis examined the effects of different re-warm-up stimuli, ranging from power-based and soccer-specific protocols to an integrated hybrid approach, while also considering the ecological constraints imposed by real and simulated soccer contexts. This objective aligns with previous research showing that passive halftime periods may reduce physiological readiness and impair explosive performance, while active re-warm-up strategies may help attenuate these decrements (Edholm et al., 2014; Fashioni et al., 2020; Gonzalez-Devesa et al., 2021; Lovell et al., 2013; Mohr et al., 2004).

Given the exploratory nature of the studies, the findings should not be interpreted as definitive evidence of the superiority of one specific re-warm-up protocol across all contexts. Rather, they provide preliminary and context-dependent evidence regarding how different short-duration re-warm-up strategies may influence second-half readiness and performance-related responses. This cautious interpretation is consistent with recommendations for exploratory research in sport and exercise science, in which ecological relevance, contextual variability, and hypothesis generation are central considerations (Ditroilo et al., 2025).

Table 2- Summary of the effects of different half-time re-warm-up protocols on 20-m sprint, CMJ, subjective readiness, and match-related outcomes across the four studies included in this doctoral thesis.

Study	Population	Protocol comparison	20-m sprint	CMJ height	ARMS / ecological outcome	Match simulation context
Study 1	Adult professional female players	SPBP vs. SSP	Sprint performance declined in both groups (+0.35–0.38 s; $p < 0.001$); no significant between-protocol difference	CMJ height declined slightly (−1.2/−1.6 cm; $p = 0.07$); no significant between-protocol difference	ARMS showed no significant between-protocol differences	Simulated internal match
Study 2	Adult professional female players / two-team context	IRW-Soccer vs. passive control	RW-Soccer improved sprint performance compared with passive rest (−0.40 s vs. −0.25 s; $p = 0.019$)	CMJ declined in both groups, with smaller decline in the RWU group (−1.82 cm vs. −2.85 cm)	ARMS not assessed	Two-team training match
Study 3	U19 female players	IRW-Soccer vs. passive control	Both groups improved sprint performance, with no significant group × time interaction	No significant protocol effect on CMJ	ARMS showed no significant between-group differences; response may be influenced by age, maturation, or competitive level	Simulated internal match

Study	Population	Protocol comparison	20-m sprint	CMJ height	ARMS / ecological outcome	Match simulation context
Study 4	Adult professional male players	SPBP vs. SSP	No significant group × time interaction; trivial immediate effect	No significant group × time interaction; trivial immediate effect	SPBP was associated with greater total distance, sprint distance, and high-speed running during the first 25 min of the second half	Simulated internal match

Note. SPBP = Strength-Power-Based Protocol; SSP = Soccer-Specific Protocol; IRW-Soccer = Integrated Re-Warm-Up Soccer; ARMS = Acute Readiness Monitoring Scale; CMJ = countermovement jump; RWU = re-warm-up.

Overall, the four studies suggest that a 3-minute halftime re-warm-up appears to be feasible and compatible with the practical constraints of soccer, but its effects appear to depend on the population assessed, the type of protocol used, and the outcome selected. In general, sprint performance appeared more responsive to re-warm-up than CMJ, particularly when active re-warm-up was compared with passive rest. However, the magnitude and direction of the response varied across studies, reinforcing the exploratory and context-dependent nature of the findings. This pattern is consistent with evidence indicating that sprint, jump, and match-running responses may be influenced by the specific content, timing, intensity, and context of the warm-up or re-warm-up stimulus (Abade et al., 2017; Gonzalez Fernandez et al., 2023; Hammami et al., 2018; L. M. Silva et al., 2018).

The initial study with professional female players compared a Strength-Power-Based Protocol (SPBP) with a Soccer-Specific Protocol (SSP). No significant differences were observed between protocols in 20-m sprint performance, CMJ, or ARMS scores, suggesting that, within a restricted 3-minute window, the specific content of the active stimulus did not clearly differentiate immediate performance or perceptual responses in this sample. By contrast, the second study, also conducted with senior female players, compared IRW-Soccer with passive rest. This study suggested that the integrated protocol may attenuate the performance decrement associated with passive recovery, particularly in sprint performance. The smaller decrement observed in the re-warm-up group indicates that combining neuromuscular activation with soccer-specific stimulation may provide advantages over passive rest, although the exploratory design and sample size require cautious interpretation.

The third study, conducted with U19 female players, tested the same IRW-Soccer protocol against passive rest. In this younger population, no significant group x time interactions were observed for sprint, CMJ, or ARMS responses. Both groups improved sprint performance, suggesting that factors such as test repetition, familiarity, residual warm-up effects, maturation, or differences in fatigue and recovery profiles may have influenced the results. This finding indicates that re-warm-up responses may not be directly transferable between senior and youth female players, even when the same protocol is applied.

The fourth study, conducted with professional male players, compared SPBP and SSP and extended the analysis beyond immediate performance testing by including GNSS-derived match-related external-load variables during the first 25 minutes of the second half. Although immediate CMJ and sprint responses did not differ significantly between protocols, the SPBP group covered greater total distance, sprint distance, and high-speed running distance during the early stages of second half. This finding is particularly relevant because it suggests that the potential effects of re-warm-up may emerge more clearly during match-related activity than during isolated post-re-warm-up performance respondes. The inclusion of GNSS-derived variables is important because external-load monitoring is widely used in soccer to quantify match demands and contextualize player responses during dynamic play (Bastida Castillo et al., 2018; Carling et al., 2016; Dalen et al., 2016).

Taken together, the findings suggest that short-duration re-warm-up protocols should not be interpreted as universally performance-enhancing interventions. Instead, they may be better understood as context-dependent strategies that can contribute to the regulation of second-half readiness under ecological constraints. This interpretation provides the basis for the following sections, which discuss the immediate neuromuscular responses, the role of population-specific factors, the transition from isolated testing to match-related performance, and the conceptualization of re-warm-up as a dynamic readiness-regulation strategy.

4.2. Immediate Neuromuscular Performance Responses: Sprint and CMJ

Across the four studies, the immediate neuromuscular responses to the 3-minute re-warm-up protocols were not uniform. Sprint and CMJ performance showed different response patterns, suggesting that these outcomes may reflect distinct neuromuscular demands and may not be equally sensitive to ultra-short halftime interventions. This distinction is relevant because sprinting and jumping, although both dependent on explosive lower-limb function, rely on partially different mechanical, coordinative, and task-specific determinants (Beato et al., 2018; Claudino et al., 2017; Haugen et al., 2019).

In the first study, conducted with professional female players, both the SPBP and SSP groups showed a significant decline in 20-m sprint performance after the halftime intervention, with no significant differences between protocols. This suggests that, when

two active protocols are compared directly, the specific nature of the stimulus may not be sufficient to clearly differentiate immediate sprint responses within a 3-minute window. One possible explanation is that the accumulated fatigue from the simulated first half may have limited the acute the acute effect of either intervention, particularly in a professional female cohort exposed to high physical demands. Another possibility is that both protocols provided a similar level of general activation, without producing clearly distinguishable immediate responses. Such an interpretation is consistent with previous evidence showing that fatigue, muscle temperature loss, and passive transition periods can impair sprint and jump performance after warm-up or halftime (Abade et al., 2017; Edholm et al., 2014; Galazoulas et al., 2012; Mohr et al., 2004).

In contrast, the second study showed that IRW-Soccer attenuated the decline in sprint-performance when compared with passive rest in senior female players. This finding suggests that the integrated combination of neuromuscular activation and soccer-specific stimulation may be more effective than passive recovery for preserving sprint capacity. Importantly, this does not necessarily indicate that IRW-Soccer enhances sprint performance beyond baseline levels, but rather that it may help reduce the negative impact of halftime inactivity. This interpretation is consistent with the broader literature showing that active re-warm-up strategies can attenuate reductions in sprint performance after passive halftime periods (Bang & Park, 2022; Edholm et al., 2014; Fashioni et al., 2020; Gonzalez-Devesa et al., 2021; Mohr et al., 2004).

The third study, conducted with U19 female players, revealed a different pattern: both the IRW-Soccer and passive-control groups improved sprint performance, with no significant group x time interaction. This suggests that, in younger players, sprint responses may be influenced by factors other than the re-warm-up stimulus itself, including familiarization, residual warm-up effects, motivational factors, lower first-half fatigue accumulation, or age-related recovery characteristics. Therefore, the same IRW-Soccer protocol that appeared beneficial in senior female players did not produce a detectable advantage in U19 players. This reinforces the idea that re-warm-up responses should not be generalized across age groups or competitive levels without considering maturational and contextual factors.

In the fourth study, involving professional male players, neither SPBP nor SSP produced significant immediate changes in 20-m sprint performance. However, the

absence of significant differences in isolated sprint testing contrasted with the later GNSS-derived findings, with the SPBP group covering greater total distance, sprint distance, and high-speed running distance during the first 25 minutes of the second half. This dissociation suggests that isolated post-re-warm-up sprint testing may not fully capture the functional effects of re-warm-up in match-like conditions. Sprint tests provide useful information about maximal linear acceleration capacity, but they may not reflect the repeated, intermittent, and context-dependent nature of high-intensity actions during soccer match-play (Bradley et al., 2009; Dalen et al., 2016; Di Mascio & Bradley, 2013).

Regarding CMJ, the findings were generally less pronounced than the sprint-related outcomes. Across the studies, CMJ either declined slightly or showed no significant protocol-specific response. This suggests that vertical jump performance may be less sensitive to 3-minute re-warm-up protocols than sprint performance, or that the stimulus required to preserve or enhance vertical power may differ from that needed to influence sprint capacity.

Previous studies have shown that vertical jump responses to re-warm-up can depend on the intensity, duration, and mechanical specificity of the conditioning activity (Gonz (Gonzalez Fernandez et al., 2023; L. M. Silva et al., 2018). Moreover, CMJ is widely used as a practical marker of neuromuscular status, but its interpretation should consider variability, testing context, and the specific neuromuscular qualities being assessed (Balsalobre-Fernandez et al., 2015; Claudino et al., 2017; Gallardo-Fuentes et al., 2016). In this thesis, the ultra-short duration of the interventions may not always have been sufficient to maintain general activation and to produce a measurable changes in CMJ performance.

The dissociation between sprint and CMJ may also reflect different neuromuscular and mechanical constraints. Sprinting involves horizontal force production, rapid acceleration, intermuscular coordination, and technical execution over distance, whereas CMJ primarily reflects vertical impulse production under more controlled conditions. Therefore, a given re-warm-up stimulus may influence sprint and jump performance differently depending on whether it preferentially effects horizontal force application, stretch-shortening cycle efficiency, muscle temperature, or general readiness. This interpretation is consistent with research showing that sprint, jump, and change-of-direction abilities can respond differently to training or acute activation strategies

depending on the specificity of the stimulus (Ayala et al., 2017; Beato et al., 2018; Dello Iacono, Vigotsky, et al., 2021).

From a physiological perspective, the inconsistent neuromuscular performance responses observed across studies may reflect the balance between fatigue and potentiation. Mechanisms associated with post-activation performance enhancement (PAPE) may contribute to improved explosive performance after conditioning contractions, but these effects depend on the athlete's training status, recovery time, stimulus intensity, and fatigue state (Blazevich & Babault, 2019; Hodgson et al., 2005; Seitz & Haff, 2016). In the context of halftime, this balance is particularly complex because players are not entering the intervention in a rested state, but after accumulated first-half load, tactical interruption, and partial physiological deactivation. Thus, the same re-warm-up protocol may produce potentiation in some players, maintenance in others, and insufficient recovery or residual fatigue in others.

Overall, the findings regarding immediate neuromuscular performance respondes suggest that 3-minute re-warm-up protocols may contribute more consistently to the attenuation of declines in sprint-performance than to the improvement of CMJ height. However, these effects should be interpreted cautiously because they were small, inconsistent across populations, and dependent on the comparison condition. Rather than demonstrating a universal neuromuscular performance benefit, the present findings suggest that short-duration re-warm-up may help regulate acute readiness in specific contexts, particularly when compared with passive rest. This interpretation supports the need to examine re-warm-up not only through isolated sprint and jump tests, but also through match-related performance indicators and individual readiness responses.

4.3. Context-Dependent Responses Across Populations

One of the central findings emerging from this doctoral thesis is that the effects of short-duration re-warm-up strategies appear to be strongly context-dependent. Across the four studies, the same or similar 3-minute interventions did not produce identical responses across populations, suggesting that re-warm-up effectiveness may be influenced by sex, age, competitive level, accumulated fatigue, training background, and the specific ecological conditions of the match or simulated match. This interpretation is consistent with previous evidence showing that warm-up and re-warm-up responses may

vary according to exercise mode, timing, player characteristics, and competitive context (Abade et al., 2024; Abade et al., 2017; Fradkin et al., 2010; Hammami et al., 2018).

In adult professional female players, the results suggest that active re-warm-up may be particularly relevant when compared with passive rest. In Study 1, both SPBP and SSP were associated with a decline in sprint performance, with no significant differences between protocols, whereas in Study 2, IRW-Soccer attenuated the decline in sprint performance deterioration compared with passive recovery. As these studies differed in design and comparison conditions, they should not be interpreted as providing a direct comparison between all three protocols. Nevertheless, the findings from Study 2 suggest that an integrated active stimulus may be beneficial relative to passive rest in senior female players. This interpretation is consistent with previous research showing that passive halftime periods can reduce muscle temperature and impair sprint and jump performance, while active re-warm-up may attenuate these effects (Edholm et al., 2014; Fashioni et al., 2020; Mohr et al., 2004).

The female professional context is especially relevant because women's soccer has historically been underrepresented in re-warm-up research, despite the rapid professionalization of the sport and the existence of physiological and performance-related characteristics that may influence acute responses to warm-up and re-warm-up strategies. Differences in muscle power, thermoregulatory responses, fatigue resistance, hormonal environment, and injury susceptibility have been reported between male and female players, suggesting that findings derived from male cohorts should not be automatically transferred to women's soccer (Cardoso de Araujo et al., 2020; Datson et al., 2014; Emmonds et al., 2019; Gagnon & Kenny, 2012).

In addition, match demands and physical performance profiles in elite female soccer may differ according to age, competitive level, and playing context, reinforcing the need for context-specific interpretation (Datson et al., 2017; Harkness-Armstrong et al., 2022). Therefore, the results obtained in the senior female cohorts provide exploratory evidence that short-duration re-warm-up may be practically relevant in professional women's soccer, particularly as a strategy to attenuate halftime-related performance decrements rather than to produce large acute performance enhancements.

The U19 female players in Study 3 displayed a different response pattern. Both the IRW-Soccer and passive-control groups improved sprint performance, and no

significant group x time interactions were observed for Sprint, CMJ or ARMS responses. This suggests that youth female players may not respond to halftime re-warm-up in the same way as senior professional players. Several explanations may account for this finding. First, younger athletes may accumulate less performance-related fatigue during a simulated first half due to lower absolute match demands or different pacing strategies. Second, they may recover more rapidly during the interval, reducing the potential observable benefit of an active re-warm-up intervention. Third, learning, familiarization, and motivation may have contributed to improved sprint performance in both groups. These explanations remain speculative and should be examined directly in future studies. Nerveless they highlight the importance of considering maturational status, training age, and competitive exposure when interpreting re-warm-up responses in youth players, as external and internal demands may vary substantially across youth age groups (Abade et al., 2014; Harkness-Armstrong et al., 2022).

The contrast between senior and U19 female players is particularly relevant for the development of sex and age- informed re-warm-up recommendations. Although the same IRW-Soccer protocol was feasible in both contexts, its detectable effects were not equivalent. This suggests that the dose, intensity, and exercise composition of re-warm-up may need to be adjusted according to the developmental stage and performance profile of the players. In youth female soccer, a 3-minute integrated protocol may provide a feasible form of ecological stimulation, but the present findings do not demonstrate a clear performance advantage over passive rest under all conditions. Future studies should therefore examine whether youth players require different re-warm-up durations, intensities, or exercise contents, and whether individual responsiveness varies according to maturation, position, fatigue, or baseline neuromuscular capacity.

In professional male players, Study 4 provided a different perspective. Although immediate sprint and CMJ responses were trivial and not significantly different between SPBP and SSP, the SPBP group displayed greater external-load outputs during the first 25 minutes of the second half, including total distance, sprint distance, and high-speed running distance. This suggests that, in male professional players, power-oriented re-warm-up may not necessarily produce immediate improvements in isolated neuromuscular tests, but may influence the expression of high-intensity actions during subsequent match-play. This finding is consistent with the idea that highly trained players

may require stimuli that are sufficiently intense and mechanically specific to influence match-related outputs, particularly when high-intensity locomotor actions are central to second-half performance demands and when match-running performance is shaped by repeated sprinting, accelerations, and high-speed running requirements (Bradley et al., 2009; Dalen et al., 2016; Di Mascio & Bradley, 2013).

The differences observed between male and female cohorts should be interpreted cautiously, as the studies differed in design, match context, and outcome measures. Accordingly, the findings should not be interpreted as evidence of sex-based differences in responsiveness. Nevertheless, the collective pattern suggests that re-warm-up responses may be moderated by physiological, competitive, and contextual characteristics. In female senior players, the integrated protocol appeared useful when compared with passive rest; in U19 female players, the same protocol did not clearly outperform passive recovery; and in male professional players, the power-based protocol appeared more strongly associated with subsequent high-intensity external-load responses. Rather than indicating that one protocol is universally superior, these findings suggest that re-warm-up should be individualized and contextually adapted.

Accumulated fatigue during the first half may be one of the most important moderators of re-warm-up effectiveness. A re-warm-up protocol is unlikely to operate in isolation; its effects depend on the player's physiological state at the time of the intervention. If first-half fatigue is high, a short re-warm-up may help counteract deactivation but may also add load to an already fatigued system. If fatigue is low, the same protocol may provide limited additional benefit because readiness has not substantially declined. This interaction may explain why similar protocols produced different responses across studies. Thus, re-warm-up effectiveness may reflect the balance between deactivation, fatigue, potentiation, and recovery, rather than the isolated effect of the protocol alone. This interpretation is consistent with the broader fatigue literature in soccer, where performance responses are shaped by the interaction between accumulated load, recovery status, and contextual match demands (Bangsbo et al., 2007; Dambroz et al., 2022; Greig & Siegler, 2009).

Overall, the present findings support the need to move beyond a one-size-fits-all approach to halftime re-warm-up. The same 3-minute time window may require different contents depending on population characteristics and match demands. Senior professional

players may benefit from structured interventions that attenuate performance decline, youth players may require protocols adjusted to maturational and fatigue profiles, and the findings from the professional male cohort suggest that power-oriented strategies may be relevant when match-related high-intensity actions are considered. This context-dependent interpretation reinforces the broader conceptual direction of the thesis: re-warm-up should be understood as a flexible, ecologically constrained strategy for regulating second-half readiness rather than as a fixed protocol expected to produce uniform effects across all players and contexts.

4.4. From Isolated Tests to Match-Related Performance

A key contribution of this doctoral thesis is the observation that immediate neuromuscular performance tests may not fully capture the potential effects of halftime re-warm-up strategies. Across the four studies, 20-m sprint and CMJ were useful indicators of acute neuromuscular performance, but their responses were not always consistent with the subsequent match-related outputs. This was particularly evident in Study 4, where no significant differences were observed between SPBP and SSP in immediate sprint or CMJ performance, yet GNSS-derived external-load data revealed differences during the first 25 minutes of the second half.

In Study 4, the SPBP group covered greater total distance, sprint distance, and high-speed running distance than the SSP group during the early stages of the second half. This finding suggests that the influence of a re-warm-up protocol may emerge more clearly during dynamic match play than during isolated post-intervention tests. While sprint and CMJ assessments provide valuable information about maximal linear acceleration and vertical power, soccer performance is expressed through repeated, intermittent, and context-dependent actions involving accelerations, decelerations, changes of direction, positional demands, tactical constraints, and decision-making (Bradley et al., 2009; Dalen et al., 2016; Di Mascio & Bradley, 2013). GNSS and related tracking systems have become widely used tools to quantify these external-load demands in soccer, although their interpretation should always consider measurement accuracy, context, and variability across match situations (Bastida Castillo et al., 2018; Carling et al., 2016). Therefore, isolated tests may underestimate the functional relevance of a re-warm-up stimulus when the aim is to understand second-half match readiness.

The apparent dissociation between immediate neuromuscular testing and match-related external load is particularly relevant for applied soccer contexts. A player may not demonstrate a clear improvement in a single sprint or jump test immediately after re-warm-up but may still express a greater volume of high-intensity actions during match play. This interpretation is consistent with the idea that performance in soccer is not determined solely by maximal isolated capacity, but also by the ability to reproduce high-intensity efforts within a complex, tactical, and fatigue-influenced environment. In this sense, the greater high-speed running and sprint distance observed after SPBP may be compatible with enhanced readiness, although the present findings do not allow this relationship to be established directly.

The SPBP protocol may have provided a neuromuscular priming stimulus that was more closely related to the expression of high-intensity locomotor actions during the early stages of the second half. Although this interpretation remains exploratory, it is consistent with the concept of post-activation performance enhancement (PAPE), whereby explosive or strength-oriented activities may transiently improve subsequent power-related actions when the balance between potentiation and fatigue is favorable (Blazevich & Babault, 2019; Hodgson et al., 2005; Seitz & Haff, 2016). In the present thesis, SPBP did not clearly improve isolated sprint or CMJ performance immediately after the intervention, but it was associated with greater external-load outputs during match play. This suggests that PAPE-related mechanisms, if involved, may have been expressed through a greater volume of high-intensity activity rather than through improvements in a single maximal test during the early stages of the second half.

This finding also aligns with previous research showing that high-intensity running and sprint actions are critical components of soccer performance and may influence decisive match moments (Bradley et al., 2009; Di Mascio & Bradley, 2013; Faude et al., 2012). Straight sprinting and high-speed actions are frequently involved in goal-scoring situations, defensive recovery runs, pressing actions, and transitional moments, making the early second-half period particularly important from a performance perspective. Therefore, even modest changes in the ability to sustain or express high-intensity activity after halftime may have practical relevance in elite soccer contexts.

At the same time, the interpretation of GNSS-derived differences should be cautious. External-load variables do not necessarily represent performance quality by

themselves. Greater total distance, sprint distance, or high-speed running may indicate increased physical output, but they may also be influenced by tactical organization, match scenario, player position, opposition behavior, and team strategy (Carling et al., 2016; Goncalves et al., 2018). In addition, match-to-match variability and congested competitive contexts can influence high-speed running and other external-load indicators, making it important to interpret these variables alongside tactical and contextual information (Carling et al., 2016; Dellal et al., 2015). Therefore, although the SPBP group displayed greater high-intensity external-load responses, this should not be interpreted as definitive evidence that SPBP is universally superior to SSP. Rather, these findings suggest that power-based re-warm-up warrants further investigation when the intended outcome is to support the expression of high-intensity locomotor activity during match re-entry.

The SSP protocol, despite not producing superior external-load outcomes in Study 4, should not be considered ineffective. Its potential value may lie less in maximizing high-intensity running output and more in preserving soccer-specific coordination, perceptual engagement, technical rhythm, and tactical reactivation. Small-sided games are known to reproduce important elements of soccer performance, including spatial awareness, decision-making, ball interaction, and representative movement patterns (Dellal et al., 2011; Dello Iacono, Beato, et al., 2021; Hill-Haas et al., 2011). Therefore, SSP may provide an ecological stimulus that is not fully captured by sprint, CMJ, or external-load volume alone. Future studies should incorporate technical-tactical indicators, decision-making measures, and contextual match variables to better determine whether soccer-specific re-warm-up protocols influence performance quality in ways that are not reflected by physical outputs alone.

The results of Study 4 therefore extend the interpretation of the previous studies by showing that the effects of re-warm-up may depend on the outcome used to assess them. In Studies 1–3, the main outcomes were immediate sprint, CMJ performance, while subjective readiness was also assessed in Studies 1 and 3. In Study 4, the inclusion of GNSS-derived match-related variables provided a broader ecological perspective. This progression is important because it suggests that re-warm-up research should move beyond isolated test outcomes and include match-related performance indicators when assessing the practical value of halftime interventions.

Overall, the findings suggest that the effectiveness of re-warm-up protocols should be evaluated across multiple levels: immediate neuromuscular performance, selected subjective readiness measures and match-related and match-related external-load responses. In this thesis, a particularly ecologically relevant finding emerged from the examination of early second-half external-load outputs rather than through isolated post-re-warm-up tests alone. This supports the broader conceptual direction of the thesis, in which re-warm-up is interpreted as a strategy for regulating second-half readiness under ecological constraints, rather than simply as a tool to acutely improve sprint or jump test performance.

4.5. SPBP, SSP, and IRW-Soccer as Complementary RWU Strategies

Across the studies included in this thesis, the SPBP, SSP, and IRW-Soccer protocols should not be interpreted as competing solutions with a single universally superior option. Instead, they may represent complementary re-warm-up strategies, each targeting different dimensions of halftime readiness. The SPBP was primarily designed to stimulate neuromuscular activation through strength-, power-, plyometric-, and balance-oriented exercises. The SSP emphasized soccer-specific movement, ball interaction, perceptual engagement, and decision-making through small-sided game formats. The IRW-Soccer protocol attempted to integrate both components neuromuscular activation and soccer-specific stimulation, within the same 3-minute window.

The SPBP protocol may be understood as a power-oriented stimulus aimed at counteracting the neuromuscular deactivation associated with halftime. By including explosive and strength-related exercises derived from FIFA 11+ components, SPBP may stimulate mechanisms associated with post-activation performance enhancement, provided that the balance between potentiation and fatigue is favorable (Blazevich & Babault, 2019; Hodgson et al., 2005; Seitz & Haff, 2016). This rationale is also supported by evidence showing that neuromuscular warm-up strategies, including FIFA 11+-based approaches, may improve components of balance, strength, injury prevention, and explosive performance in soccer players (Ayala et al., 2017; Barengo et al., 2014; Bizzini et al., 2013; Hammami et al., 2018). In this thesis, SPBP did not consistently improve

immediate sprint or CMJ responses when compared with SSP, but in Study 4 it was associated with greater high-intensity external-load outputs during the first 25 minutes of the second half. This suggests that the potential value of SPBP may be more evident in the expression of repeated high-intensity match actions than in isolated post-re-warm-up tests.

The practical relevance of SPBP is therefore related to its potential to stimulate neuromuscular readiness in a short and easily implementable format. Because the protocol does not require ball possession, large playing areas, or complex organization, it may be especially useful when teams have limited access to the field during halftime or when coaches require a highly controlled and time-efficient activation strategy. This aligns with the practical constraints described in previous research, in which the available time for physical reactivation during halftime is often limited by tactical instructions, hydration, nutritional strategies, and medical interventions (Carling et al., 2016; Russell et al., 2015; Towlson et al., 2013). However, the current findings do not allow SPBP to be considered universally superior, since its effects appeared dependent on the outcome assessed and the population studied.

The SSP protocol, in contrast, offers a more soccer-specific form of reactivation. By using small-sided game formats, SSP may help maintain technical rhythm, perceptual engagement, spatial orientation, decision-making, and tactical interaction. Small-sided games have been widely used in soccer because they reproduce several representative features of match play, including ball interaction, accelerations and decelerations, changes of direction, communication, and collective organization (Dellal et al., 2011; Dello Iacono, Beato, et al., 2021; Hill-Haas et al., 2011). In addition, SSG formats have been shown to manipulate physiological, technical, and tactical demands through changes in pitch size, player number, rules, and work-rest structure, making them highly adaptable for applied soccer settings (Dellal et al., 2011; Dello Iacono, Beato, et al., 2021; Hill-Haas et al., 2011). In the context of halftime re-warm-up, this ecological specificity may be particularly valuable because players may need not only physical reactivation but also perceptual and tactical re-engagement before returning to competition.

Nevertheless, the SSP did not clearly outperform SPBP in immediate neuromuscular performance outcomes or in match-related external-load responses in the present thesis. This does not necessarily mean that SSP is ineffective. Rather, it may

indicate that the selected outcomes sprint, CMJ, and external-load variables do not fully capture the potential benefits of soccer-specific reactivation. For example, SSP may influence technical accuracy, scanning behavior, collective synchronization, decision speed, or tactical organization, none of which were directly measured in the present studies. This interpretation is consistent with previous research suggesting that soccer performance is multidimensional and that physical outputs alone may not fully represent technical-tactical performance quality or collective organization (Bradley et al., 2009; Carling et al., 2016; Goncalves et al., 2018). Therefore, future research should include technical-tactical and perceptual-cognitive indicators to better understand the specific contribution of SSP-based re-warm-up strategies.

The IRW-Soccer protocol was developed as an integrated approach that combines the neuromuscular activation component with the ecological specificity of soccer-related stimulation. Its rationale is based on the assumption that halftime readiness is multidimensional and may require more than one type of stimulus. The first component, based on FIFA 11+ exercises, aims to stimulate strength, power, balance, and neuromuscular control. The second component, based on SSG, aims to preserve or restore soccer-specific engagement. This hybrid structure reflects the practical need to balance physiological activation with movement specificity within a very short time window, a challenge repeatedly highlighted in the halftime re-warm-up literature (Gonzalez-Devesa et al., 2021; Hammami et al., 2018; Russell et al., 2015; Towlson et al., 2013).

The findings from Studies 2 and 3 suggest that IRW-Soccer may have different effects depending on the population. In senior female players, IRW-Soccer improve sprint-performance compared with passive rest, while in U19 female players it did not produce a clear advantage over passive recovery. This contrast reinforces the idea that the integrated nature of the protocol is not sufficient by itself to guarantee a performance benefit across all contexts. Instead, its effectiveness may depend on the player's competitive level, fatigue state, maturation, and ability to respond to the selected stimulus. Such inter-individual and contextual variability is consistent with research showing that warm-up and re-warm-up responses are influenced by exercise mode, timing, training status, and athlete characteristics (Abade et al., 2024; Abade et al., 2017; Fradkin et al., 2010; Hammami et al., 2018).

From an applied perspective, IRW-Soccer may be considered a feasible and adaptable strategy rather than a fixed universal solution. Its value lies in its capacity to integrate two relevant dimensions of halftime preparation: neuromuscular reactivation and soccer-specific re-engagement. However, the exact proportion, intensity, duration, and sequencing of these components may need to be adjusted according to the competitive context. For example, the most appropriate protocol content may depend on players' accumulated fatigue, expected second-half demands, developmental stage, and competitive level. These possibilities should be examined directly in future studies before specific prescriptions are established.

Taken together, the three protocols can be conceptualized as different practical tools within a broader re-warm-up framework. SPBP may be particularly useful when the aim is to stimulate neuromuscular priming and high-intensity locomotor readiness. SSP may be useful when the priority is soccer-specific re-engagement and technical-tactical continuity. IRW-Soccer may represent an exploratory hybrid strategy attempting to combine both purposes within the practical constraints of halftime. Rather than asking which protocol is universally best, the present thesis suggests that practitioners should considerer which re-warm-up content best matches the player, the context, the expected second-half demands, and the available logistical conditions. This interpretation supports the broader conceptual direction of the thesis: short-duration re-warm-up should be understood as a flexible and context-sensitive strategy for regulating second-half readiness, rather than as a standardized intervention expected to produce identical effects across different populations and match situations.

4.6. Re-Warm-Up as a Dynamic Strategy Regulation of Second Half Readiness

The collective findings of this doctoral thesis suggest that halftime re-warm-up should not be interpreted merely as a short physical activation routine, but rather as a potential strategy for regulating second-half readiness under ecological constraints. Across the four studies, the effects of re-warm-up were not uniform across protocols, populations, or outcomes. This variability indicates that the halftime period may represent a dynamic transitional state, during which physiological deactivation, accumulated fatigue, neuromuscular readiness, perceptual readiness, and contextual match demands interact simultaneously.

From this perspective, the role of re-warm-up may be better understood as readiness regulation rather than simple performance enhancement. Passive halftime periods have been associated with reductions in muscle temperature, heart rate, neuromuscular activation, and explosive performance (Edholm et al., 2014; Lovell et al., 2013; Mohr et al., 2004; Russell et al., 2015). Active re-warm-up strategies may attenuate some of these decrements by maintaining physiological activation and supporting the transition back into high-intensity play (Fashioni et al., 2020; Gonzalez-Devesa et al., 2021; Hammami et al., 2018). However, the findings of this thesis suggest that the magnitude of the response depends on the balance between deactivation, fatigue, potentiation, and the specific demands imposed after re-entry into play.

This interpretation is particularly important because a 3-minute re-warm-up is unlikely to produce large, universal improvements in maximal neuromuscular performance. Instead, its value may lie in helping players maintain or restore an adequate state of preparedness before the second half begins. In this sense, re-warm-up may operate as a short, targeted stimulus that supports the athlete's transition from a passive or semi-passive interval state to a renewed state of competitive readiness. This interpretation is consistent with the literature showing that even brief re-warm-up interventions may help attenuate decrements in sprinting, jumping, and soccer-specific performance following halftime (Bang & Park, 2022; Fashioni et al., 2020; Gonzalez Fernandez et al., 2023; Yanaoka, Hamada, et al., 2018).

The present thesis also suggests that readiness should be understood as a multidimensional construct. Readiness is not limited to the expression of isolated sprint or jump performance, but may include neuromuscular activation, perceived freshness, cognitive engagement, tactical reorientation, and the capacity to respond to the immediate demands of match play. This interpretation is supported by the use of both objective outcomes, such as sprint, CMJ, and GNSS-derived variables, while selected studies also included the ARMS as a secondary measure of subjective readiness. Previous research has highlighted the relevance of perceived readiness and subjective monitoring in understanding athlete preparedness, fatigue, and performance responses (Saw et al., 2016; Summers et al., 2021).

A practical challenge remains the availability of brief and context-specific tools capable of assessing readiness immediately before match re-entry. Many existing

monitoring instruments evaluate readiness, recovery, wellness, or fatigue in a broader sense, often reflecting the athlete's general state across the day or training cycle rather than their immediate preparedness to perform in the next few minutes (Halson, 2014; Saw et al., 2016; Thorpe et al., 2017). In the specific context of halftime re-warm-up, this distinction is particularly relevant, because practitioners require brief and easily applicable measures that can capture the athlete's acute perception of readiness just before returning to play. In selected contexts, subjective tools such as the ARMS may complement objective performance or match-related indicators and contribute to a broader interpretation of second-half readiness regulation (Summers et al., 2021).

Although the present thesis did not directly test the Integrated Model of Dynamic Performance (IMDP), quantify Most Demanding Periods (MDPs), or measure PAPE-related mechanisms as primary constructs, the findings may be cautiously interpreted through an integrated and dynamic performance lens. Soccer performance emerges from the interaction between physical, technical, tactical, perceptual, and contextual factors. Therefore, a halftime re-warm-up may be seen as one practical way of influencing the player's readiness state before re-exposure to the complex demands of the second half. This interpretation is compatible with the idea that performance is not a static output of isolated physical qualities, but rather a dynamic process shaped by the interaction between the athlete, task, and environment (Asian-Clemente et al., 2021; Dellal et al., 2011; Hill-Haas et al., 2011).

Importantly, this does not mean that the present thesis validates the IMDP or directly demonstrates effects on MDPs or PAPE. Rather, these concepts provide useful conceptual lenses for interpreting why re-warm-up effects may not always appear in isolated neuromuscular performance tests but may become more visible during match-related activity. For example, in Study 4, the SPBP protocol did not produce significant immediate changes in sprint or CMJ, yet it was associated with greater total distance, sprint distance, and high-speed running distance during the first 25 minutes of the second half. This finding suggests that the functional effect of re-warm-up may emerge during the interaction between potential physiological priming effect and the external demands of play, rather than solely in controlled test conditions.

Therefore, re-warm-up may be conceptualized as a short-term regulatory strategy operating between first-half fatigue and second-half performance expression. During

halftime, players experience a reduction in physiological stimulation, but they are soon required to return to high-intensity actions such as sprinting, pressing, accelerating, decelerating, jumping, and changing direction. This creates a mismatch between the passive nature of the interval and the dynamic requirements of re-entry into play. A structured re-warm-up may help reduce this mismatch by providing a brief but targeted stimulus that supports thermal and neuromuscular reactivation while potentially contributing to perceptual and tactical re-engagement.

The findings also suggest that re-warm-up regulation is context-dependent. The same intervention may have different effects depending on the player's sex, age, competitive level, fatigue state, training background, and expected second-half role. This was evident in the different patterns observed across the senior female players, the U19 female players, and the professional male players. In senior female players, IRW-Soccer improved sprint performance when compared with passive rest. In U19 female players, the same protocol did not clearly outperform passive recovery. In professional male players, SPBP appeared more strongly associated with high-intensity match-related outputs than SSP. As these studies differed in design, context, and outcome measures, the findings should not be interpreted as direct evidence of sex-based differences in responsiveness. Instead, they reinforce the idea that re-warm-up should not be prescribed as a universal protocol, but rather adapted to the population and performance context.

This regulatory perspective also helps explain why sprint and CMJ responses were not always aligned. Sprint performance may be more sensitive to short-term thermal and neuromuscular reactivation, whereas CMJ may require a different mechanical stimulus, greater volume, or more recovery time to reveal measurable changes. Similarly, GNSS-derived responses may capture functional readiness in a more ecological way than isolated tests, particularly when players are required to repeatedly express high-intensity actions within a tactical environment (Bastida Castillo et al., 2018; Bradley et al., 2009; Dalen et al., 2016; Di Mascio & Bradley, 2013). These interpretations remain exploratory and should be examined directly in future studies. Thus, the effectiveness of re-warm-up may depend not only on the protocol, but also on the outcome used to evaluate it.

Taken together, the present findings support a shift in how halftime re-warm-up is conceptualized. Rather than asking whether re-warm-up universally improves performance, a more appropriate question may be how different re-warm-up strategies

contribute to the regulation of second half readiness in specific players, teams, and competitive contexts. This interpretation is aligned with the exploratory nature of the present thesis and with the need for ecologically valid research in applied soccer environments, where halftime routines are constrained by tactical, medical, nutritional, and logistical demands (Russell et al., 2015; Towlson et al., 2013). It also provides the conceptual foundation for the development of an exploratory model of dynamic halftime readiness regulation in soccer.

4.7. Practical and Conceptual Implications: Toward a Halftime Reactivation Period

The findings of this doctoral thesis have practical implications for the organization of the halftime interval in soccer. Traditionally, halftime is dominated by tactical communication, hydration, nutritional strategies, medical interventions, and passive recovery. Although these tasks are essential, they may reduce the opportunity for physiological and neuromuscular reactivation before the start of the second half (Carling et al., 2016; Russell et al., 2015; Towlson et al., 2013). In this context, the present findings support the consideration of a structured and time-efficient "Half-Time Reactivation Period as a practical strategy to facilitate the transition from passive recovery to renewed competitive readiness.

Under current match conditions, the proposed Halftime Reactivation Period should not be understood as a separate or additional interruption to the game, but rather as a brief and organized reactivation window integrated into the existing halftime routine. Based on the practical constraints described in the literature and the protocols tested in the present thesis, the final 3 minutes of half-time may represent a feasible opportunity to apply a brief re-warm-up stimulus without substantially interfering with tactical, medical, or nutritional priorities (Russell et al., 2015; Towlson et al., 2013). This 3-minute window appears particularly relevant because it is long enough to provide a targeted activation stimulus, yet short enough to remain compatible with elite match-day logistics. However, its practical implementation may depend on access to suitable spaces, team routines, and competition-specific organizational constraints.

From a physiological perspective, this reactivation period may help attenuate the reductions in muscle temperature, heart rate, neuromuscular activation, and explosive

performance typically associated with passive halftime periods (Edholm et al., 2014; Lovell et al., 2013; Mohr et al., 2004). Active re-warm-up strategies have previously been shown to reduce or attenuate decrements in sprinting, jumping, and soccer-specific performance after halftime (Bang & Park, 2022; Fashioni et al., 2020; Gonzalez Fernandez et al., 2023; Gonzalez-Devesa et al., 2021). The present thesis extends this applied rationale by showing that even ultra-short 3-minute protocols may be feasible and may influence sprint performance or match-related high-intensity outputs, depending on protocol content and population.

From a practical standpoint, the Half-Time Reactivation Period may be structured according to the intended performance objective. If the main aim is neuromuscular priming and high-intensity locomotor readiness, SPBP-like content may be prioritized. This may include short explosive, plyometric, balance, or strength-power exercises derived from neuromuscular warm-up approaches such as FIFA 11+ components (Barengo et al., 2014; Bizzini et al., 2013; Hammami et al., 2018). If the main aim is soccer-specific re-engagement, SSP-like content may be prioritized, using small-sided or possession-based activities that promote ball interaction, spatial orientation, decision-making, and tactical reactivation (Dellal et al., 2011; Dello Iacono, Vigotsky, et al., 2021; Hill-Haas et al., 2011). If the aim is to integrate both dimensions, IRW-Soccer may represent an exploratory hybrid option combining neuromuscular and soccer-specific stimuli.

However, the findings of this thesis also indicate that implementation should be flexible rather than standardized. The same 3-minute reactivation window may require different contents depending on the team, player profile, match context, and expected second-half demands. The most appropriate stimulus may depend on factors such as accumulated first-half fatigue, competitive level, developmental stage, positional demands, and logistical conditions. These possibilities should be examined directly in future studies before population or position-specific prescriptions are established. For example, professional senior players exposed to high first-half loads may require a carefully dosed stimulus that reactivates without adding excessive fatigue. Youth players may require a simpler or less intense format, particularly if their fatigue profile differs from senior players. Players expected to perform high-intensity actions immediately after halftime may benefit from power-oriented priming, whereas players requiring tactical

reorganization may benefit from more soccer-specific activity. Therefore, the Halftime Reactivation Period should be viewed as an adaptable framework rather than a fixed protocol.

The Half-Time Reactivation Period may also have implications for match dynamics. In Study 4, SPBP was associated with greater total distance, sprint distance, and high-speed running distance during the first 25 minutes of the second half. This suggests that a structured halftime reactivation stimulus may influence the physical expression of players during early second-half match play. However, external-load outputs do not necessarily represent performance quality by themselves, as they may be shaped by tactical strategy, opposition behavior, match status, player position, and collective organization (Carling et al., 2016; Dellal et al., 2015; Goncalves et al., 2018). Therefore, future evaluations of a Halftime Reactivation Period consider not only physical outputs, but also tactical, technical, perceptual, and contextual indicators.

Beyond its possible integration into existing halftime routines, the present thesis also raises a broader conceptual and organizational proposal for future consideration. This proposal would preserve the full official 15-minute halftime interval for passive recovery, tactical communication, hydration, nutritional strategies, and medical care, while introducing an additional standardized 3-minute on-field reactivation window immediately before the start of the second half. Importantly, this proposal should not be understood as reducing or replacing the existing 15-minute halftime period, which remains essential for recovery, tactical communication, hydration, nutritional strategies, and medical care. Rather, it represents a potential extension of the transition between the formal interval and second-half re-entry, allowing both teams to perform a brief and ecologically valid reactivation period on the pitch.

Such a structure could provide players with access to the full pitch, reducing the spatial restrictions often encountered when re-warm-up is performed in corridors, dressing-room areas, or limited sideline spaces. It could also allow substitute players preparing to enter at the beginning of the second half to warm up in a more integrated manner with the team. From a performance perspective, this may support a more gradual transition from passive recovery to high-intensity match demands. From an organizational perspective, the additional on-field window could potentially be integrated

into the broader match presentation without compromising the recovery, tactical, or medical functions of the formal halftime interval.

However, this proposal remains conceptual and should be interpreted cautiously. The additional standardized 3-minute on-field window was not directly tested in the present thesis. Its feasibility would require empirical validation and discussion with relevant stakeholders, including governing bodies, clubs, coaches, players, medical staff, broadcasters, and competition organizers. Table 3 presents a conceptual overview of the proposed Halftime Reactivation Period. This table should be interpreted as an applied synthesis derived from the exploratory findings of this thesis and the existing re-warm-up literature, rather than as a definitive intervention model. Future studies should therefore examine not only physiological and performance outcomes, but also logistical feasibility, stakeholder acceptance, match flow, regulatory implications, and the practical integration of the proposed additional on-field window into competition routines.

Table 3. Conceptual overview of the proposed Half-Time Reactivation Period.

Dimension	Description	Expected implications
Temporal structure	Brief active reactivation period lasting approximately 3 minutes. Under current match conditions, this period may be integrated into the final minutes of halftime. As a broader conceptual proposal, an additional standardized 3-minute on-field window could be considered immediately after the formal 15-minute interval.	May attenuate the decline in physiological and neuromuscular readiness typically associated with passive halftime routines
Timing	Immediately prior to the start of the second half	Provides a targeted pre-restart stimulus intended to support re-entry into match demands
Protocol content	Combination of neuromuscular activation exercises and/or soccer-specific activities	Allows adaptation according to performance objective: neuromuscular priming, soccer-specific re-engagement, or integrated readiness regulation
Physiological rationale	Based on re-warm-up principles, thermal maintenance, neuromuscular activation, and potential PAPE-related mechanisms	May support perceptual-cognitive engagement and tactical re-entry, although these effects require direct investigation
Perceptual-cognitive rationale	May include ball interaction, decision-making, spatial orientation, and tactical reactivation	May support cognitive engagement and tactical re-entry, although this requires direct investigation
Injury-related rationale	May reduce abrupt transition from passive rest to high-intensity match demands	May theoretically support safer re-entry, but potential injury-prevention relative effects require direct empirical investigation
Implementation context	Designed to fit within existing halftime routines or, conceptually, within an additional standardized on-field reactivation window, without replacing tactical, nutritional, or medical priorities	Practical feasibility depends on team logistics, access to field space, coaching priorities, stakeholder acceptance, and competition regulations
Research status	Exploratory conceptual proposal based on the present thesis and existing re-warm-up literature	Requires further validation in larger samples, repeated designs, official matches, and different competitive contexts

Within this conceptual framework, IRW-Soccer represents one possible operationalization of the Halftime Reactivation Period, combining neuromuscular exercises with a soccer-specific stimulus. The Halftime Reactivation Period, may be

understood as a broader applied concept that can include SPBP, SSP, IRW-Soccer, or other short re-warm-up strategies depending on the context.

Importantly, this proposal should not be interpreted as a recommendation to replace tactical communication or medical care during halftime. Rather, it suggests that the final minutes of the interval may be better organized to include a short, targeted, and context-sensitive reactivation stimulus. For coaches and performance staff, this means that re-warm-up should be planned in advance, matched to the team's tactical and physical needs, and adjusted according to player characteristics, environmental conditions, and first-half load. As discussed above, this framework may also inform future consideration of an additional standardized 3-minute on-field reactivation window immediately after the formal halftime interval, although this organizational extension requires empirical validation and stakeholder discussion.

In summary, the studies included in this doctoral thesis collectively suggest that a short and structured halftime reactivation strategy may constitute a pragmatic and physiologically coherent approach to preparing players for the second half in soccer. Rather than representing a universal solution, the Half-Time Reactivation Period should be understood as a flexible and exploratory framework that may help practitioners organize the transition from halftime recovery to second half performance demands. Its potential value lies in balancing neuromuscular readiness, ecological validity, and the practical constraints of the competitive environment.

4.8. Limitations

Our findings should be interpreted in light of several methodological and contextual limitations. Although the four studies provide ecologically relevant and practically applicable evidence regarding short-duration halftime re-warm-up strategies, they were exploratory in nature and were conducted with relatively small samples. This is a common challenge in applied soccer research, particularly when studies are conducted in elite or professional environments where access to players, match schedules, and experimental control may be limited. Therefore, the present findings should be interpreted as preliminary and hypothesis-generating rather than definitive evidence of protocol efficacy.

First, the sample sizes across the studies were relatively small. This may have limited the statistical power to detect small or moderate interaction effects, particularly for outcomes such as CMJ, sprint performance, and ARMS responses. Small samples also increase the possibility that individual variability may have influenced group-level results. In this context, non-significant findings should not necessarily be interpreted as evidence of the absence of an effect, but rather as indications that potential effects may be small, variable, or dependent on individual responsiveness. Future studies with larger samples are needed to determine whether the patterns observed in this thesis are robust and generalizable across broader soccer populations.

Second, the studies were conducted across different populations, including professional female players, U19 female players, and senior professional male players. Although this diversity is a strength from an ecological and exploratory perspective, it also limits direct comparison between studies. Differences in sex, age, training background, competitive level, maturation, and match demands may have contributed to the heterogeneous responses observed. Therefore, comparisons between groups and studies should be interpreted cautiously, as they reflect different soccer contexts rather than a single controlled experimental continuum. Accordingly, the findings should not be interpreted as direct evidence of sex- or age-based differences in responsiveness.

Third, not all studies included the same comparison conditions. Some studies compared two active re-warm-up protocols, whereas others compared an active protocol with passive rest. This methodological variation limits the ability to determine whether observed effects were due to the specific content of the protocol, the presence of any active stimulus, or the absence of passive recovery. For example, the absence of a passive control group in studies comparing SPBP and SSP makes it difficult to determine whether both active protocols were similarly effective, similarly ineffective, or equally affected by first-half fatigue. Future research should include passive control, active comparison, and integrated hybrid conditions within the same design.

Fourth, the use of simulated or training-match contexts should be considered. Although these contexts increased experimental feasibility and allowed greater control, they may not fully reproduce the psychological pressure, tactical complexity, competitive intensity, and emotional demands of official matches. As a result, the magnitude and direction of re-warm-up responses may differ in official competitive environments. This

is particularly relevant because halftime routines in official matches are influenced by scoreline, coaching decisions, substitutions, medical needs, environmental conditions, and competition regulations. Future studies should therefore examine re-warm-up protocols during official matches whenever ethically and logistically possible.

Fifth, the studies primarily assessed neuromuscular performance outcomes, such as 20-m sprint and CMJ, selected subjective readiness responses assessed using the ARMS, and GNSS-derived external-load variables. Although these measures provide valuable information, they do not fully capture the multidimensional nature of soccer readiness. Physiological measures such as muscle temperature, heart rate kinetics, oxygen uptake, blood lactate, or biochemical markers were not consistently included. Similarly, perceptual-cognitive and technical-tactical indicators such as decision-making speed, passing accuracy, scanning behavior, tactical synchronization, and positional organization were not directly assessed. This limits the ability to determine the precise mechanisms through which re-warm-up protocols may influence readiness and match performance.

Sixth, the studies did not directly measure PAPE-related mechanisms, muscle temperature changes, or neuromuscular activation through electromyography. Therefore, interpretations related to neuromuscular priming, thermal maintenance, or PAPE should be understood as theoretical explanations supported by previous literature, not as directly demonstrated mechanisms within the present thesis. Similarly, although the Integrated Model of Dynamic Performance and Most Demanding Period concepts were used as conceptual lenses in the discussion, they were not directly tested as empirical constructs. This distinction is important to avoid overinterpreting the findings beyond the measured variables.

Seventh, individual variability in re-warm-up responses was not examined in depth. Players may respond differently to the same protocol depending on position, baseline neuromuscular performance profile, fatigue state, fitness level, training history, perceived readiness, and expected tactical role. The group-based analyses used in the included studies may have masked meaningful individual responses. Future research should consider individual-response analyses, positional profiling, readiness-informed prescription, and individualized re-warm-up strategies. Repeated observations

within the same players may also help distinguish meaningful individual patterns from normal measurement variability.

Eighth, in the studies involving female players, biological and hormonal factors were not systematically monitored. Variables such as menstrual cycle phase, hormonal contraceptive use, maturation status, and individual thermoregulatory responses may influence fatigue, neuromuscular function, perceived readiness, and injury risk. Although the monitoring and interpretation of these factors remain challenging in applied team-sport settings, their potential influence should be considered in future research, particularly in studies involving female and youth female players.

Ninth, the duration of follow-up after re-warm-up was limited. In most studies, immediate neuromuscular performance responses were assessed shortly after the halftime intervention, while match-related data in Study 4 focused on the first 25 minutes of the second half. This limits the ability to determine whether any potential benefits were sustained throughout the entire second half or whether increased early high-intensity output may have influenced later fatigue. Future studies should monitor performance across the entire second half and examine whether early benefits are maintained, dissipate, or contribute to subsequent fatigue.

Finally, the ecological nature of the studies necessarily involved a trade-off between experimental control and applied relevance. The protocols were designed to fit within the real constraints of soccer halftime routines, which strengthens practical applicability but reduces the ability to isolate specific mechanisms. This limitation is inherent to applied sport science research and reinforces the need for complementary studies combining controlled laboratory designs, simulated-match protocols, and official-match observations.

In summary, the limitations of this thesis do not undermine the practical relevance of the findings, but they require a cautious interpretation. The present studies provide exploratory evidence that short-duration re-warm-up protocols may contribute to the regulation of second-half readiness, but further research is required to confirm their effectiveness, clarify underlying mechanisms, and determine how they should be adapted and individualized across different populations and competitive contexts.

4.9. Future Research Directions

The exploratory findings of this doctoral thesis open several directions for future research on halftime re-warm-up strategies in soccer. Although the present studies provide preliminary evidence regarding the feasibility and potential relevance of short-duration re-warm-up protocols, further research is required to confirm these findings, clarify underlying mechanisms, and determine how re-warm-up should be adapted and individualized across different populations and competitive contexts.

First, future studies should use larger samples and more robust experimental designs. Randomized crossover designs with repeated measures would be particularly valuable, as they would allow each player to be exposed to different re-warm-up conditions while reducing the influence of inter-individual variability. Such designs should ideally compare passive rest, SPBP, SSP, and IRW-Soccer within the same study, allowing researchers to determine whether integrated protocols provide additive or synergistic effects beyond isolated power-based or soccer-specific strategies. This would help clarify whether the benefits observed in the present thesis are related to the presence of active stimulation, the specific content of the protocol, or the interaction between neuromuscular and soccer-specific components.

Second, future research should examine re-warm-up protocols in official match contexts whenever feasible. Although simulated and training matches provide valuable experimental control, official matches impose unique psychological, tactical, emotional, and contextual demands that may influence re-warm-up responses. Match status, opposition level, substitutions, tactical adjustments, environmental conditions, crowd pressure, and coaching priorities may all shape how players respond to halftime reactivation. Therefore, testing re-warm-up strategies in official competition would strengthen the ecological validity and practical relevance of future findings.

Third, future studies should adopt a multidimensional assessment of readiness. Rather than relying exclusively on sprint and CMJ outcomes, future research should combine neuromuscular performance, physiological, perceptual, cognitive, technical-tactical, and match-related indicators. This may include muscle temperature, heart rate kinetics, oxygen uptake, blood lactate, electromyography, force-time variables from CMJ, sprint split times, repeated sprint ability, selected subjective readiness measures such as the ARMS, perceived fatigue, cognitive vigilance, decision-making tasks, passing

accuracy, scanning behavior, positional data, and GNSS-derived external-load variables. Such an approach would provide a more complete understanding of how re-warm-up influences second half readiness.

Fourth, future research should investigate the mechanisms underlying re-warm-up responses. In the present thesis, interpretations related to thermal maintenance, neuromuscular priming, and PAPE were based on previous literature rather than direct mechanistic measurements. Future studies should therefore include direct assessments of muscle temperature, neuromuscular activation, stiffness, rate of force development, and the balance between fatigue and potentiation. This would help determine whether short-duration re-warm-up protocols work primarily by maintaining thermal state, stimulating neuromuscular priming, supporting perceived readiness, preserving technical-tactical engagement, or through a combination of mechanisms.

Fifth, individual responsiveness should be explored in greater depth. Not all players are likely to respond in the same way to the same re-warm-up stimulus. Future studies should examine individual response patterns, considering variables such as playing position, baseline neuromuscular performance, fatigue state, training status, match load, injury history, perceived readiness, and tactical role. This could support the development of individualized re-warm-up prescriptions, in which the content and intensity of the halftime intervention are adjusted according to the player's needs and expected second-half demands. Repeated observations within the same players will be important to distinguish meaningful individual patterns from normal measurement variability.

Sixth, research addressing sex- and age-related factors should be expanded. The findings of this thesis suggest that senior female players, U19 female players, and senior male professional players may display different response patternsto similar re-warm-up protocols. However, because the studies differed in design, context, and outcome measures, these findings should not be interpreted as direct evidence of sex- or age-based differences in responsiveness. Future studies should include larger samples of female players across different competitive levels, youth age categories, and professional environments. Particular attention should be given to maturation, menstrual cycle phase, hormonal contraceptive use, and thermoregulatory responses. This is especially important

given the underrepresentation of female athletes in sport science research and the rapid development of women's soccer.

Seventh, future work should examine the dose-response characteristics of ultra-short re-warm-up protocols. Although the present thesis focused on a 3-minute window, it remains unclear whether different durations, intensities, sequencing patterns, or exercise combinations would produce greater benefits. Studies comparing 1, 3, 5, and 7 minute re-warm-up protocols could help identify the minimum effective dose required to regulate readiness without increasing fatigue or interfering with tactical priorities. Similarly, future research should explore whether the order of exercises matters, for example, whether neuromuscular priming should precede soccer-specific actions or vice versa.

Eighth, future studies should examine the temporal organization of the halftime interval itself. One applied question emerging from this thesis is whether the current use of a brief re-warm-up during the final minutes of the official interval should be compared with a broader conceptual structure comprising the full 15-minute formal halftime period followed by an additional standardized 3-minute on-field reactivation window. This comparison is relevant because the effectiveness of re-warm-up may depend not only on the content of the reactivation stimulus, but also on the duration of the preceding passive or semi-passive period. A 15 + 3 structure may allow teams to preserve the usual tactical, nutritional, and medical routines while adding a standardized reactivation window immediately before the second half. Conversely, a 12 + 3 structure may reduce the duration of passive deactivation before re-entry without extending the formal interval. Future research should therefore directly compare these organizational models to determine which structure better supports physiological, neuromuscular performance, perceptual, and match-related readiness. Importantly, the additional 3-minute on-field window represents a conceptual proposal derived from this thesis and was not directly tested in the included studies.

Ninth, future studies should evaluate the entire second-half response. The potential benefit of re-warm-up may be strongest during the first minutes after re-entry, but it is still unclear whether early improvements are sustained, disappear, or contribute to greater fatigue later in the match. Therefore, researchers should monitor physical, technical, tactical, and perceptual responses across the full second half. This would help

determine whether re-warm-up strategies merely shift physical output earlier in the half or genuinely support sustained performance regulation.

Tenth, the practical implementation of a Half-Time Reactivation Period should be tested in applied settings. Future studies should examine whether teams can consistently integrate a short reactivation window into real halftime routines without disrupting tactical communication, medical care, hydration, or player recovery. Research should also assess the feasibility of the proposed additional standardized 3-minute on-field window, including its potential implications for match flow and competition regulations. This line of research should include coaches, performance staff, medical staff, and players, as stakeholder acceptance will be essential for successful implementation. Mixed-methods studies combining quantitative performance data with qualitative feedback may be particularly useful.

Finally, future research should further develop and test conceptual models of halftime readiness regulation. The present thesis provides the basis for a dynamic and ecological interpretation of re-warm-up, but the proposed model requires further refinement and empirical validation. Future studies should examine how first-half load, passive deactivation, re-warm-up content, individual responsiveness, perceptual readiness, and second half match demands interact over time. This would allow researchers to move beyond simple comparisons of protocols and toward a more integrated understanding of how halftime interventions regulate performance readiness in soccer.

In summary, future research should progress from protocol comparison toward individualized, multidimensional, and ecologically valid models of halftime readiness regulation. Such work will be essential to determine how short-duration re-warm-up strategies can be optimized for different players, teams, population characteristics, and competitive contexts while maintaining compatibility with the practical constraints of soccer match play.

Chapter 4. Final Considerations, References, and Appendices

5. Final Considerations

The present doctoral thesis explored the effects of short-duration halftime re-warm-up strategies on neuromuscular performance, perceptual, selected perceptual responses, and match-related outcomes in soccer. Across four experimental studies involving female and male players from different competitive levels, the thesis examined the feasibility and potential effects of 3-minute re-warm-up protocols performed within the practical constraints of the halftime interval. Overall, the findings suggest that a 3-minute re-warm-up is feasible and compatible with applied soccer contexts. However, its effects should not be interpreted as universal or independent of context. The responses observed across the studies varied according to the population assessed, the protocol applied, the comparison condition, and the outcome measured. Therefore, the evidence supports a cautious and exploratory interpretation: short-duration re-warm-up strategies may contribute to the regulation of second-half readiness, but their effectiveness may be influenced by age, sex, competitive level, accumulated fatigue, protocol content, and match-related demands.

In senior female players, the findings suggest that active re-warm-up may be more beneficial than passive rest, particularly for improving sprint performance after halftime. However, when different active protocols were compared, no clear superiority was observed between power-based and soccer-specific strategies. This indicates that, within a restricted 3-minute window, maintaining some form of active stimulation may be relevant, but the specific content of the intervention may need to be adjusted according to the players' characteristics and fatigue state. In U19 female players, the IRW-Soccer protocol did not clearly outperform passive rest in sprint, CMJ, or perceived readiness responses. This suggests that younger athletes may respond differently to halftime re-warm-up, possibly due to differences in fatigue accumulation, recovery capacity, maturation, competitive demands, or test familiarity. These potential explanations remain speculative and should be examined directly in future studies. The findings reinforce the need for age- and context-informed approaches rather than the direct transfer of protocols between senior and youth populations.

In professional male players, the comparison between SPBP and SSP showed no clear immediate differences in sprint or CMJ performance. However, the SPBP protocol was associated with greater match-related external-load outputs during the first 25 minutes of the second half, including total distance, sprint distance, and high-speed running distance. This finding suggests that the potential effects of re-warm-up may not always be captured by isolated neuromuscular performance tests and may emerge more clearly during dynamic match play. Nevertheless, external-load variables should be interpreted as indicators of physical output rather than direct measures of performance quality. Taken together, the studies support the conceptual value of SPBP, SSP, and IRW-Soccer as complementary re-warm-up strategies. SPBP may be particularly relevant when the aim is to stimulate neuromuscular priming and high-intensity locomotor readiness. SSP may be more relevant when the aim is to promote soccer-specific re-engagement, perceptual involvement, decision-making, and technical-tactical continuity. IRW-Soccer may represent an exploratory hybrid approach that attempts to integrate neuromuscular activation and soccer-specific stimulation within a short and ecologically feasible time window. In this sense, halftime re-warm-up should be viewed not as a single intervention, but as a family of strategies whose success depends on the intended performance target, the competitive environment, and the characteristics of the athletes.

A central contribution of this thesis is the interpretation of halftime re-warm-up as a strategy for dynamic readiness regulation rather than as a simple performance-enhancement intervention. The halftime interval should not be viewed only as a passive pause, but as a transitional period in which physiological, neuromuscular, perceptual, and contextual factors interact before players re-enter the second half. In this sense, short-duration re-warm-up may help reduce the mismatch between halftime deactivation and the high-intensity demands typically required after match re-entry.

The findings of this doctoral research also contribute to the growing literature on halftime re-warm-up by suggesting that short, structured protocols can be implemented within the practical constraints of elite soccer. The studies collectively indicate that a 3-minute halftime window is sufficient to apply structured active interventions, but not necessarily enough to guarantee improvements across all physical, perceptual, and match-related outcomes. This highlights the tension between ecological feasibility and physiological effectiveness, a central issue in applied match-day preparation.

Another important contribution is the sex and age-informed perspective. The female studies suggest that the benefits of halftime re-warm-up are present but modest and variable, reinforcing the need for protocols tailored to female athletes rather than simply transferring male-derived evidence. The different patterns observed in U19 female players and senior male professionals further suggests that competitive level, maturation, sex, and match context may influence the response to re-warm-up, especially in early second-half high-intensity actions. However, because the studies differed in design, context, and outcome measures, the findings should not be interpreted as direct evidence of sex- or age-based differences in responsiveness. This strengthens the argument that IRW-Soccer should be treated as an adaptable framework rather than as a fixed protocol, and that future work should refine the dose, content, timing, and sequencing of each component according to the population and performance goal.

The thesis also supports the conceptual proposal of a Halftime Reactivation Period. *Under current match conditions, this period could be integrated into the final minutes of the official halftime interval when logistical conditions permit. At a broader organizational level, the thesis also raises the possibility of preserving the full official 15-minute interval and introducing an additional standardized 3-minute on-field reactivation window immediately before the second half.* This proposal does not imply reducing or replacing tactical, nutritional, recovery, or medical priorities. Rather, it suggests that the transition between recovery and match re-entry may be strategically organized to facilitate progressive reactivation. Such a proposal may also create practical opportunities for substitute integration and team reorganization. Nevertheless, the additional standardized 3-minute on-field window was not directly tested in the present thesis and remains a conceptual proposal requiring empirical validation and stakeholder discussion.

Based on the present investigation, future applications may consider the integration of neuromuscular activation and soccer-specific stimuli within the IRW-Soccer framework as a plausible synergistic approach to support neuromuscular readiness, soccer-specific re-engagement, and intermittent high-intensity actions, thereby contributing to functional readiness for second-half re-entry. In conclusion, this doctoral thesis provides exploratory evidence that short-duration, structured, and ecologically valid re-warm-up strategies may contribute to the regulation of second-half readiness in

soccer. Rather than identifying a single optimal protocol, the findings indicate that re-warm-up should be adapted to the player, team, competitive context, and expected second-half demands. The IRW-Soccer framework and the broader Half-Time Reactivation Period proposal should therefore be understood as flexible and context-sensitive approaches that may inform future research and applied practice in soccer performance preparation.

5.1. Conceptual model of IRW-Soccer and second-half readiness in soccer.

The findings of the present thesis support the conceptualization of halftime re-warm-up as a strategy for the dynamic regulation of second-half readiness rather than as a universally effective performance-enhancement intervention. Across the studies conducted with female and male players from different age groups and competitive levels, short-duration re-warm-up protocols were shown to be feasible within the practical constraints of the halftime interval. However, the magnitude and direction of the observed responses varied according to the population assessed, the protocol applied, the comparison condition, and the outcome measured. These findings reinforce the need to understand half-time re-warm-up as a family of strategies that should be adapted to the context, the characteristics of the players, and the anticipated demands of second-half re-entry.

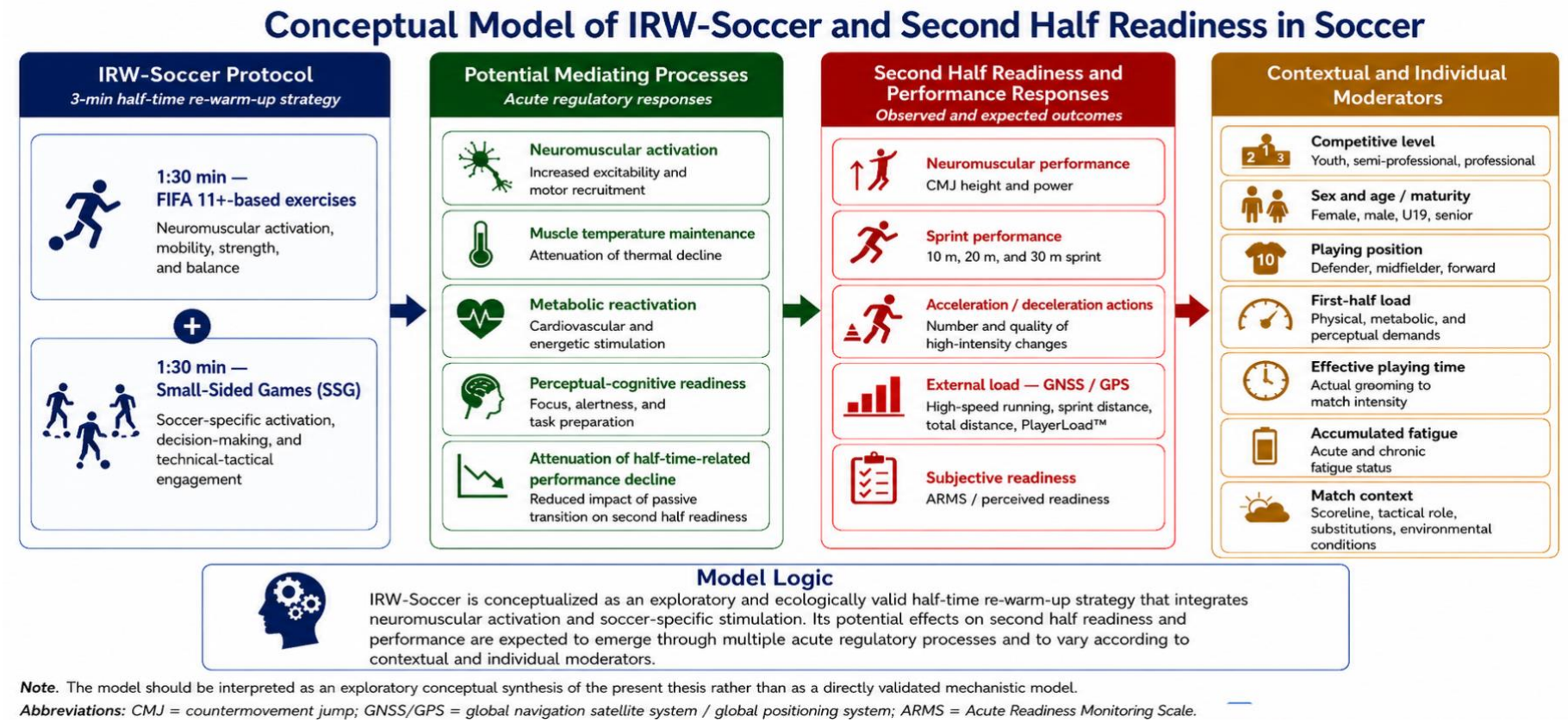
Building on the findings of Article 2 and the broader implications of this thesis, an organizational and regulatory adjustment may be considered to create more favorable conditions for the implementation of brief reactivation strategies on the pitch. The IRW-Soccer model may be applied in two ways. The first and preferred option consists of the formal implementation of a standardized, 3-minute on-field re-warm-up period immediately following the official 15-minute halftime interval. This solution would preserve the time allocated to passive recovery, hydration, nutritional intake, tactical reorganization, and medical procedures, while adding a specific transitional phase before the start of the second half. The second option, should the formal extension of the half-time period not be feasible, consists of allowing players to access the pitch to perform a brief reactivation strategy before match resumption within the existing time framework. In both cases, the aim is to facilitate a more progressive and soccer-specific transition from recovery to competitive readiness. Importantly, the additional standardized 3-

minute on-field window represents a conceptual proposal and was not directly tested in the present thesis.

This flexibility of implementation is particularly relevant to IRW-Soccer because the model integrates two complementary dimensions of re-warm-up. The Strength-Power-Based Protocol (SPBP) is based on exercises derived from the FIFA 11+ programme and is designed to promote neuromuscular activation and readiness for explosive actions. The Soccer-Specific Protocol (SSP) is operationalized through small-sided games (SSGs), which aim to provide a form of reactivation that is more closely aligned with the functional demands of match play, including perceptual-cognitive engagement, decision-making, and technical-tactical continuity. IRW-Soccer integrates neuromuscular activation exercises and soccer-specific SSG stimuli within a brief, hybrid, and ecologically valid framework. It should not be interpreted as the complete combination of the SPBP and SSP protocols tested separately in other studies.

Based on these premises, the findings obtained across the thesis, and the literature reviewed in the preceding chapters, Figure 3 presents an exploratory conceptual model of IRW-Soccer. The model proposes that a 3-minute hybrid strategy combining FIFA 11+-based exercises and SSGs may contribute to second-half readiness through multiple potential acute regulatory processes, including neuromuscular activation, attenuation of thermal decline, metabolic reactivation, perceptual-cognitive preparation, and reduction of halftime-related deactivation. These responses may, in turn, influence neuromuscular performance, sprint capacity, acceleration and deceleration actions, match-related external load, and perceived readiness. Some of these outcomes were assessed across the studies included in this thesis, whereas others remain hypothesized components of the conceptual model. The model assumes that the effectiveness of IRW-Soccer is context-sensitive and may be moderated by individual and match-related factors, including age, sex, maturation, competitive level, playing position, first-half load, effective playing time, accumulated fatigue, and match context. Accordingly, the proposed model should be interpreted as an exploratory conceptual synthesis derived from the present thesis rather than as a directly validated mechanistic model or a rigid prescriptive protocol.

Figure 3 – Conceptual model of IRW-Soccer and second half readiness in soccer.



Legend. IRW-Soccer = Integrated Re-Warm-Up Soccer; SSG = small-sided games; CMJ = countermovement jump; GNSS = global navigation satellite system; GPS = global positioning system; ARMS = Acute Readiness Monitoring Scale. **Note:** *The image was developed using generative artificial intelligence, based on instructions, iterative feedback, and conceptual assumptions provided by the author. The creative idea, conceptual organization, and definition of the scientific elements represented are the responsibility of the author, while the visual design was produced with AI support.*

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Appendix I - Acute Readiness Monitoring Scale

Section 1 - About your readiness

Please answer the following questions in relation to how ready you feel for any upcoming task or challenge.

Total	**Item**	Question wording – OVERALL READINESS	**Response right now**
1	OV1	I feel physically ready for any challenge	Does not apply at all — Fully applies 0-------1--------2-------3-------4-------5------6
2	OV2	I feel mentally ready for any challenge	Does not apply at all — Fully applies 0-------1--------2-------3-------4-------5------6
3	OV3	I feel ready to deal with serious threats	Does not apply at all — Fully applies 0-------1--------2-------3-------4-------5------6
4	OV4	My team is ready to work together	Does not apply at all — Fully applies 0-------1--------2-------3-------4-------5------6
5	OV5	My equipment is fit-for-purpose	Does not apply at all — Fully applies 0-------1--------2-------3-------4-------5------6
6	OV6	My skills and experience make me capable of meeting any challenge	Does not apply at all — Fully applies

			0-------1--------2-------3-------4-------5------6
7	OV7	I feel ready to deal with uncertainty	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
8	OV8	I feel confident in taking control of situations	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
9	OV9	I feel confident that my actions contribute to our overall objectives	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
10	OV10	I feel ready for any physically demanding task	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
11	V11	I feel ready for any mentally demanding task	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
12	V12	I feel ready to deal with stressful situations	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
13	H1	I am physically strong	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
14	H2	I am physically fit	Does not apply at all Fully applies

			0-------1--------2-------3-------4-------5------6
15	H3	I am physically prepared	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
16	H4	I am physically fresh	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
17	H5	I am physically tired	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
18	H6	My muscles are sore	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
19	H7	I feel energetic	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
20	H8	I am ready to exert physical effort	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
21	H9	I am fatigued	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
22	H10	I am physically spent	Does not apply at all Fully applies

			0-------1--------2-------3-------4-------5------6
23	H11	I am sick today	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
24	H12	I am injured today	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
25	O1	I am mentally fit	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
26	O2	I can focus well	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
27	O3	I am mentally prepared	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
28	O4	I am thinking clearly	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
29	O5	I am mentally fresh	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
30	O6	I am mentally tired	Does not apply at all Fully applies

			0-------1--------2-------3-------4-------5------6
31	O7	My mind is fuzzy today	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
32	O8	I cannot focus today	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
33	O9	I am ready to problem solve today	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
34	O10	I feel alert	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
35	O11	I am easily distracted today	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
36	O12	I have no willpower today	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
37	C1	I am in a good mood	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
38	C2	I feel in a good place today	Does not apply at all Fully applies

			0-------1--------2-------3-------4-------5------6
39	C3	I feel threatened	Does not Fully apply at all applies 0-------1--------2-------3-------4-------5------6
40	C4	I feel anxious	Does not Fully apply at all applies 0-------1--------2-------3-------4-------5------6
41	C5	I can manage my emotions today	Does not Fully apply at all applies 0-------1--------2-------3-------4-------5------6
42	C6	I feel annoyed	Does not Fully apply at all applies 0-------1--------2-------3-------4-------5------6
43	C7	Nothing can upset me today	Does not Fully apply at all applies 0-------1--------2-------3-------4-------5------6
44	C8	I feel down today	Does not Fully apply at all applies 0-------1--------2-------3-------4-------5------6
45	C9	I feel exhausted	Does not Fully apply at all applies 0-------1--------2-------3-------4-------5------6
46	C10	I could handle anything today	Does not Fully apply at all applies

			0-------1--------2-------3-------4-------5------6
47	C11	I am ready to process significant problems	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
48	C12	No matter the challenge, I am ready for it	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
49	C13	I have things under control today	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
50	C14	I can handle unpleasant feelings	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
51	P1	I can talk to my team about problems/challenges	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
52	P2	I feel supported by people around me	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
53	P3	My team is functioning well	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
54	P4	My team is ready	Does not apply at all Fully applies

			0-------1--------2-------3-------4-------5------6
55	P5	My team is united	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
56	P6	My team has clear goals	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
57	P7	My team has strong systems and processes	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
58	P8	My team works well together	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
59	P9	My team can do more together than as individuals	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
60	P10	I have confidence in my team	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
61	P11	I have confidence in my team's leadership	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
62	P12	Our team is sufficiently trained and equipped to achieve operational effectiveness	Does not apply at all Fully applies

			0-------1--------2-------3-------4-------5------6
63	K1	I have the skills and competencies required for my role	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
64	K2	I can adapt when things don't go well	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
65	K3	I can adapt to new problems	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
66	K4	I know my role	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
67	K5	I offer significant value to my role/Unit	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
68	K6	I question my abilities	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
69	K7	I feel under-prepared	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
70	K8	I am capable of delivering my role	Does not apply at all Fully applies

			0-------1--------2-------3-------4-------5------6
71	K9	I feel able to meet the challenge of performing my role	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
72	K10	My training and experience have been the ideal preparation	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
73	K11	I am good at adapting to unfamiliar challenges	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6
74	K12	I feel confident in my abilities to perform my role	Does not apply at all Fully applies 0-------1--------2-------3-------4-------5------6

Effect of a half-time re-warm-up protocol on high-intensity demands of male soccer players in the first 15 minutes of the second half: an exploratory study

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The initial minutes of the second half are critical, as players exhibit their highest frequency of high-intensity actions, irrespective of position (Oliva-Lozano et al., 2023). However, passive recovery during the half-time interval reduces core and muscle temperature by 1.1 - 2.0 °C (Mohr et al., 2004), negatively impacting physical performance such as high-intensity running (HSR), sprints, and jump, during the first 15 minutes of the second half (Russell et al., 2015). Re-warm-up strategies can counteract the effects of passive recovery, facilitating the transition to activity, but are constrained by the brief interval (Towlson et al., 2013). The present study investigated the effect of a 3-minute re-warm-up protocol on high-intensity actions of soccer players during the first 15 minutes of the match's second half. Ten players from a club in the 2024/2025 Portuguese National Football Championship season were randomized and allocated into Control Group (G1) and Experimental Group (G2). The re-warm-up protocol consisted of continuously performing (i) a strength, plyometrics, and balance protocol (11+

Protocol Part 2: (i) squats with toe raise jumping, (ii) walking lunges squats, (iii) one-leg squats jumping, (iv) vertical jumps, (v) lateral jumps squats and (vi) box jumps) for 1.5-minutes, and (ii) a soccer-specific protocol a (small-sided game: 5 vs. 5 + Floater) for 1.5-minutes. After completing the re-warm-up protocol, the players immediately positioned themselves to start the match's second half. To analyze the protocol's effect on high-intensity physical demands, the t-test for independent samples and the Mann-Whitney test were conducted to compare G1 with G2. Effect size for independent t-tests was assessed using Cohen's d (small = 0.2, medium = 0.5, large > 0.8). The significance level adopted was 5% ($p < 0.05$). The G1 covered greater distances during accelerations in comparison to the group that underwent the re-warm-up protocol ($p < 0.05$), with a large effect size ($d = 1.54$) (Table 1).

Table 1. High-intensity demands of control and experimental groups.

Variable	**G1** (n=5) Md [IQR] / M±SD	**G2** (n=5) Md [IQR] / M±SD	*p*-value	Effect Size
$Speed_{max}$ (Km/h)	25.5[3.9]	26.0[4.9]	0.624	0.16
HSR (m)	87.9[77]	101.9[39]	0.624	0.16
Number of sprints	2.0±2.7	1.8±1.4	0.891	0.18
Accelerations (>3.0 $m \cdot s^{-2}$)	138±45.7	78.6±29.9	0.049*	1.58

Abbreviation: G1: control group; G2: experimental group; M±SD: Mean ± standard deviation; Md [IQR]: Median and Interquartile Range; $Speed_{max}$: maximum speed; HSR: high-intensity running.

We observed that the re-warm-up protocol impaired the players' acceleration capacity (>3.0 m s^2) during the first 15 minutes of the second half, without influencing other performance metrics compared to G1. This suggests that our protocol may not be optimal. However, these findings are limited by the small sample size and the potential variability in individual response to re-warm-up, influenced by factors such as fitness level, position, contextual match factors, and possibly demands made by the opponent during the third of the second half evaluated. Future research, including studies with passive control groups are warranted to elucidate further the effects of different re-warm-up protocols on performance in competitive matches, considering variables such as duration, intensity, and specificity of the interventions.

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