

Warm-Up, Post-Warm-Up, and Re-Warm-Up Strategies to Enhance Explosive Performance in Team Sports

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Dedication

To my beloved mother, whose absence is deeply felt, yet whose presence remains in all that I do. This work is for you, and always will be!

Mar Português

*Ó mar salgado, quanto do teu sal
São lágrimas de Portugal!
Por te cruzarmos, quantas mães choraram,
Quantos filhos em vão rezaram!
Quantas noivas ficaram por casar
Para que fosses nosso, ó mar!
Valeu a pena? Tudo vale a pena
Se a alma não é pequena.
Quem quer passar além do Bojador
Tem que passar além da dor.
Deus ao mar o perigo e o abismo deu,
Mas nele é que espelhou o céu.*

Fernando Pessoa (1934), Mensagem

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It is only with the heart that one can see rightly; what is essential is invisible to the eye. - Antoine de Saint-Exupéry

List of Publications

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Study 1:

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Resumo

O aquecimento é uma componente fundamental nos desportos de competição, na medida em que contribui para a otimização do desempenho através de adaptações fisiológicas e neuromusculares. Apesar da sua utilização generalizada, a sua estrutura ideal permanece pouco definida. Nos desportos coletivos, como o basquetebol e o futsal, que envolvem esforços explosivos frequentes, é essencial compreender como o aquecimento, o período de pós-aquecimento e o reaquecimento influenciam o desempenho. No entanto, os períodos de inatividade antes do início do jogo, durante as substituições ou no intervalo podem comprometer a prontidão dos atletas e reduzir a sua capacidade de desempenho explosivo. O objetivo geral desta tese foi investigar os efeitos agudos de diferentes estratégias de aquecimento, pós-aquecimento e do reaquecimento no desempenho explosivo em desportos coletivos. Para esse efeito, foram realizados quatro estudos: (i) uma revisão sistemática dos efeitos das estratégias de aquecimento, pós-aquecimento e reaquecimento no desempenho explosivo em desportos coletivos; (ii) uma análise das práticas de aquecimento e reaquecimento utilizadas por treinadores de basquetebol; (iii) uma avaliação dos efeitos de um protocolo de aquecimento e de diferentes períodos de transição pós-aquecimento; e (iv) uma análise dos efeitos de um protocolo de reaquecimento após diferentes períodos de transição. Os resultados indicam que aquecimentos curtos, progressivos e de elevada intensidade podem melhorar o desempenho explosivo e que protocolos breves de reaquecimento podem ajudar a recuperar a prontidão em transições mais longas. Em suma, esta tese evidencia que o aquecimento, o pós-aquecimento e o reaquecimento constituem fases complementares de um processo preparatório integrado.

Palavras-chave

Desportos coletivos;Pré-exercício;Transição;Reativação;Desempenho.

Resumo Alargado

O aquecimento é uma rotina fundamental para melhorar o desempenho atlético e preparar os jogadores para as exigências físicas dos desportos de competição. O principal objetivo é aumentar a temperatura muscular, que favorece várias alterações internas, como o aumento do fluxo sanguíneo e respostas metabólicas otimizadas. Nos primeiros 3 a 5 minutos de exercício, verifica-se um aumento inicial da temperatura, que tende a estabilizar após 10 a 20 minutos de exercício contínuo. No entanto, a eficácia da rotina de aquecimento parece depender de vários fatores, nomeadamente o tipo de desporto, a condição física e a experiência de treino dos atletas, as tarefas a realizar e as condições ambientais. Nos desportos coletivos intermitentes, os jogadores têm de realizar ações explosivas de forma repetida e eficiente, mantendo a execução técnica e a consciência tática. Neste contexto, um aquecimento adequado é crucial para otimizar o desempenho explosivo e a prontidão. No entanto, os protocolos pré-jogo incluem frequentemente períodos de espera ou de descanso passivo e o aquecimento pode ser concluído muito antes do início da competição. Além disso, os atletas suplentes podem permanecer inativos por algum tempo antes de entrarem em jogo. Estes períodos de espera podem comprometer a preparação dos atletas e afetar o seu rendimento. Nos jogadores de basquetebol, os períodos de descanso passivo estão associados a reduções rápidas da temperatura e do desempenho, com diminuições de 5% e 13% na velocidade e no salto, respetivamente. Por esse motivo, estudos recentes têm-se centrado cada vez mais no papel do reaquecimento como estratégia para atenuar as quebras de desempenho durante as transições passivas prolongadas. Algumas estratégias têm demonstrado a sua capacidade de manter ou aumentar a temperatura muscular e preservar o desempenho explosivo. No entanto, muitos treinadores ainda não dispõem de conhecimentos precisos sobre a duração, a intensidade e a estrutura ideais destes protocolos. Neste enquadramento, esta tese tem como objetivo analisar os efeitos agudos de diferentes estratégias de aquecimento, pós-aquecimento e reaquecimento no desempenho de esforços explosivos em desportos coletivos. Para tal, esta tese integra uma síntese da evidência científica existente, a caracterização das práticas utilizadas pelos treinadores e é feita uma validação experimental de protocolos aplicados em contextos próximos da realidade competitiva.

Descrição dos Estudos

Estudo 1

Realizámos uma revisão sistemática com o objetivo de sintetizar e analisar os potenciais efeitos das estratégias utilizadas durante o aquecimento (antes do jogo), o pós-aquecimento (período entre o final do aquecimento e o início do jogo) e o reaquecimento (no intervalo do jogo) no desempenho explosivo em desportos coletivos. Adicionalmente, procurámos identificar as estratégias de aquecimento mais eficazes com base nos estudos incluídos. A pesquisa foi realizada em quatro bases de dados (Web of Science, Scopus, PubMed e ScienceDirect) e incluiu artigos de investigação originais publicados entre janeiro de 1981 e agosto de 2017. No total, 30 artigos cumpriram os critérios de inclusão. A ferramenta de avaliação do risco de viés da Cochrane foi utilizada para avaliar a qualidade metodológica dos estudos, e os resultados foram recalculados para determinar os tamanhos do efeito através do d de Cohen. Os resultados indicaram que diferentes estratégias de aquecimento podem melhorar o desempenho explosivo. Um protocolo composto por 8 séries de sprints de 60 metros melhorou o desempenho no sprint (-2.19%, $d = 1.20$). Da mesma forma, a realização de 7 min de exercícios dinâmicos após 5 min de corrida promoveu melhorias no sprint (-7.69%, $d = 1.72$), no salto (8.61%, $d = 0.61$) e na agilidade (-6.65%, $d = 1.40$). A utilização de jogos de pequena dimensão também demonstrou ser uma estratégia válida, especialmente no que se refere ao desempenho do salto (6%, $d = 0.8$). Estes benefícios parecem resultar da combinação de estratégias de aquecimento com algum descanso passivo (entre 2 e 10 min) antes da realização do desempenho principal. Durante o período de pós-aquecimento, o uso de roupa aquecida revelou melhores resultados do que o descanso simples (-0.89%, $d = 0.39$). No entanto, quando a transição é superior a 15 min antes da entrada em jogo, a realização de um reaquecimento com tarefas explosivas de curta duração parece ser a abordagem mais eficaz para reativar os atletas (-1.97%, $d = -0.86$). No intervalo, o vestuário aquecido contribui para manter um melhor desempenho no sprint (-1.45%, $d = 2.21$) e no salto (3.13%, $d = 1.62$). De um modo geral, os estudos analisados sugerem que a aplicação de estratégias estruturadas no aquecimento, associada à redução de períodos prolongados de inatividade no pós-aquecimento, contribui para a melhoria do desempenho explosivo. Assim, a evidência disponível sugere um aquecimento ativo curto (10–15 min), com intensidade progressiva (~50-90% da frequência cardíaca máxima). Recomenda-se também o uso de roupa aquecida após o aquecimento, a fim de preservar a temperatura muscular durante os períodos de espera. Para transições superiores a 15 minutos, a realização de 2 minutos de reaquecimento ativo, com sprints e saltos de curta duração, parece ser benéfica. Por fim, durante o intervalo, a

combinação de vestuário aquecido com uma estratégia ativa, composta por tarefas explosivas ou jogos reduzidos com a duração de 5 minutos antes do regresso ao jogo, resultou num melhor desempenho explosivo do que os 15 minutos de descanso passivo.

Estudo 2

Este estudo teve como objetivo avaliar as práticas de aquecimento dos treinadores de basquetebol portugueses e a sua conformidade com as recomendações baseadas na evidência científica. Para esse efeito, foi realizado um estudo transversal com 158 treinadores, no qual se procurou analisar a relação entre as estratégias de aquecimento e de reaquecimento utilizadas e o nível competitivo em que atuavam. Foram encontradas associações significativas nas práticas de aquecimento entre os treinadores das competições juvenis e de rendimento, particularmente em termos de volume de aquecimento. No entanto, não se verificaram associações significativas relativamente às estratégias de reaquecimento utilizadas durante o jogo ou no intervalo. Os resultados sugerem que os treinadores inseridos em contextos de rendimento tendem a utilizar estratégias de aquecimento mais abrangentes. Ainda assim, é evidente a necessidade de implementar rotinas de reaquecimento, tanto em competições juvenis como de rendimento, de modo a otimizar a prontidão e o desempenho dos jogadores.

Estudo 3

Para colmatar as lacunas identificadas na revisão sistemática e a formular recomendações práticas para os treinadores, foram desenvolvidos os estudos 3 e 4. Especificamente, este estudo teve como objetivo comparar o efeito de três períodos de transição pós-aquecimento (3, 10 e 17 minutos) no desempenho explosivo de atletas de desportos coletivos. Foi utilizado um desenho de investigação cruzado e randomizado. Catorze jogadores universitários masculinos de basquetebol realizaram o mesmo protocolo de aquecimento, com a duração de 10 minutos, seguido de um período de transição de 3, 10 ou 17 minutos até à avaliação do desempenho. Na condição de controlo, não foi realizado qualquer aquecimento. O desempenho foi avaliado através de um teste de sprints repetidos combinado com saltos repetidos. Foram analisadas variáveis de desempenho (tempo, altura de salto e potência) e variáveis fisiológicas (lactato sanguíneo e temperatura timpânica). Foram observados efeitos moderados entre as condições para o melhor tempo no primeiro sprint de 12,5 m ($F = 1.91$, $p = 0.17$, $\eta^2_p = 0.13$), com tempos mais rápidos após a transição de 3 minutos em comparação com a condição de controlo (controlo: 2.51 ± 0.12 vs. 3 minutos: 2.41 ± 0.15 , $p = 0.02$, tamanho do efeito [ES] = 0.74). As alturas dos saltos também foram mais elevadas após transições de 3 minutos (38.55 ± 5.07 cm, $p < 0.01$, ES = 0.58), 10 minutos (37.69 ± 4.92 cm, $p < 0.01$, ES = 0.40), bem como após uma transição de 17

minutos (37.87 ± 5.33 cm, $p < 0.01$, $ES = 0.42$), em comparação com a condição de controlo (35.84 ± 4.18 cm). No entanto, não foram encontradas diferenças significativas entre os diferentes tempos de transição pós-aquecimento. O aquecimento provocou também um aumento moderado dos níveis de lactato e da temperatura timpânica em comparação com a ausência de atividade ($F = 11.90$, $p < 0.01$, $\eta^2_p = 0.48$; $F = 2.56$, $p = 0.07$, $\eta^2_p = 0.16$, respetivamente). No entanto, não se verificaram diferenças significativas nas alterações entre a avaliação pré-desempenho e a avaliação pós-desempenho nas diferentes condições experimentais. De um modo geral, os resultados indicam que a realização de um aquecimento prévio favoreceu o desempenho em esforços explosivos repetidos, sobretudo em comparação com a ausência de aquecimento. Embora não tenham sido observadas diferenças significativas nos tempos de transição, a condição de 3 minutos apresentou resultados tendencialmente mais favoráveis em algumas variáveis de desempenho. Estes resultados sugerem que transições pós-aquecimento mais curtas podem ser vantajosas para preservar a prontidão e otimizar o desempenho explosivo em atletas de desportos coletivos. Os treinadores devem considerar a duração do período entre o final do aquecimento e o início da atividade competitiva, procurando minimizar os tempos de espera prolongados sempre que possível.

Estudo 4

Considerando que períodos prolongados de transição pós-aquecimento podem comprometer o desempenho explosivo, este estudo investigou os efeitos agudos de um protocolo pliométrico de reaquecimento, com a duração de 2 minutos, no desempenho explosivo de jogadores de basquetebol após duas durações distintas de transição pós-aquecimento (10 e 17 minutos). Treze jogadores de basquetebol do sexo masculino, treinados, participaram num estudo com um desenho cruzado e randomizado, envolvendo quatro condições experimentais: repouso passivo ou reaquecimento após um período de transição de 10 ou 17 minutos. O desempenho foi avaliado através de um teste de sprints e saltos repetidos, juntamente com a recolha de medidas fisiológicas (lactato sanguíneo e temperatura timpânica) e uma medida psicológica (prontidão percebida). A significância estatística foi estabelecida em $p \leq 0.05$. O reaquecimento melhorou significativamente o desempenho no sprint após uma transição de 17 minutos (FS_{best} : $p = 0.015$; $ES = 0.84$; RS_{best} : $p = 0.018$; $ES = 0.52$; RS_{mean} : $p = 0.008$; $ES = 0.57$), bem como o desempenho no salto (RJ_{best} : $p < 0.001$; $ES = -0.62$; RJ_{mean} : $p < 0.001$; $ES = -0.47$; PP : $p < 0.001$; $ES = -0.42$). Após esta transição mais prolongada de 17 minutos, o desempenho regressou a níveis comparáveis aos observados após períodos de descanso mais curtos. Por outro lado, não foram observadas diferenças

significativas no desempenho após a transição de 10 minutos. A prontidão percebida aumentou também com o reaquecimento, tanto após a transição de 10 minutos ($p = 0.005$; ES = -1.10) como após a transição de 17 minutos ($p = 0.002$; ES = 1.42). Além disso, o reaquecimento realizado após 10 minutos aumentou significativamente os níveis de lactato antes ($p < 0.001$, ES: -1.91) e após o desempenho ($p < 0.001$, ES: -1.32), sugerindo uma maior ativação metabólica. Em suma, os resultados indicam que um breve protocolo pliométrico de reaquecimento, com a duração de 2 minutos, pode atenuar a diminuição do desempenho após longos períodos de repouso passivo, sobretudo quando a transição pós-aquecimento atinge os 17 minutos. Este efeito parece ser especialmente relevante em tarefas neuromecanicamente exigentes. Assim, estes resultados sugerem que os treinadores de desportos coletivos devem considerar a incorporação de protocolos curtos de reaquecimento durante pausas prolongadas, de modo a preservar a prontidão física e psicológica dos atletas antes da sua reentrada na competição.

Conclusões gerais

A presente tese evidencia que o aquecimento, o pós-aquecimento e o reaquecimento constituem fases complementares e sequenciais de um processo preparatório integrado, orientado para a otimização do desempenho explosivo nos desportos coletivos. O aquecimento deve ter uma estrutura multifásica, dinâmica, progressiva e específica da modalidade, terminando com estímulos de alta intensidade, mas evitando excessos de duração ou carga que possam causar fadiga. Durante o período de pós-aquecimento, é fundamental preservar a prontidão fisiológica dos atletas, mantendo alguma atividade física ou recorrendo a métodos passivos de conservação da temperatura. Por sua vez, o reaquecimento deve ser utilizado para restaurar ou reforçar a prontidão em períodos de inatividade inevitáveis, como intervalos, substituições ou transições prolongadas, através da realização de exercícios curtos, intensos e específicos, como a pliometria, antes de regressar à competição. Os resultados desta tese reforçam que a otimização das ações motoras explosivas não depende apenas da qualidade do aquecimento inicial, mas também da gestão eficiente dos períodos de transição e da aplicação adequada de estratégias de reaquecimento. A aplicação de protocolos curtos, ativos e específicos, combinada com um controlo adequado do tempo entre fases, revela-se uma abordagem eficaz, prática e exequível em contextos competitivos reais. Deste modo, este trabalho contribui para o avanço do conhecimento científico e para a aplicação de práticas baseadas na evidência no treino e na competição, oferecendo orientações úteis aos treinadores e preparadores físicos sobre

como estruturar rotinas de aquecimento e de reaquecimento mais eficientes, ajustadas às exigências do jogo e às necessidades dos atletas.

Abstract

Warm-up is a fundamental component of competitive sports, contributing to performance optimization through physiological and neuromuscular adaptations. Despite its extensive use, the ideal structure of a warm-up remains poorly defined. In team sports, such as basketball and futsal, which involve frequent explosive efforts, it is important to understand the influence of warm-up, the post-warm-up period, and re-warm-up on performance. However, periods of inactivity before the start of the game, during substitutions, or at half-time may reduce athletes' readiness and compromise explosive performance. The general objective of this thesis was to investigate the acute effects of different warm-up, post-warm-up, and re-warm-up strategies on explosive performance in team sports. To this end, four studies were conducted: (i) a systematic review of the effects of warm-up, post-warm-up, and re-warm-up strategies on explosive performance in team sports; (ii) an analysis of warm-up and re-warm-up practices of basketball coaches; (iii) an assessment of the effects of a warm-up protocol and different post-warm-up transition times; and (iv) an analysis of the effects of a re-warm-up protocol following different transition periods. The results indicated that short, progressive, high-intensity warm-ups may enhance explosive performance, and that brief re-warm-up protocols may help restore readiness during longer transitions. Overall, this thesis demonstrates that the warm-up, post-warm-up, and re-warm-up phases are complementary stages in an integrated preparatory process.

Keywords

Collective sports;Pre-exercise;Transition;Reactivation;Plyometric

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List of Acronyms

ANOVA	Analysis of Variance
ATP	Adenosine Triphosphate
BSG	Blizzard Survival Garment
CC	Control Condition
CI	Confidence Interval
CMJ	Countermovement Jump
COD	Change of Direction
ES	Effect Size
HR_{max}	Maximum Heart Rate
HR_{peak}	Peak Heart Rate
HT	Half-Time
IAP	Intermittent Activity Protocol
P	Post-Warm-up
PAP	Post-Activation Potentiation
PAPE	Post-Activation Performance Enhancement
PME	Perceived Maximal Effort
PP	Peak Power
PR	Perceived Readiness
PICO	Population, Intervention, Comparison, and Outcome
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
RAMP	Raise, Activate and Mobilize, Potentiation
RM	Repetition Maximum
RSA	Repeated Sprint Ability
RSJAT	Repeated Sprint and Jump Ability Test
RWU	Re-Warm-up
SAQ	Speed, Agility and Quickness
SD	Standard Deviation
SPSS	Statistical Package for the Social Sciences
SSG	Small-Sided Game
VO₂	Oxygen Uptake
WBV	Whole-Body Vibration
WU	Warm-Up

Chapter 1. General Introduction

The warm-up is widely recognized as a fundamental component of preparation for all competitive sports and is generally understood by both athletes and coaches as essential for maximizing performance and reducing the risk of injury (Woods et al., 2007; Fradkin et al., 2010; Neiva et al., 2014; McGowan et al., 2015; Räisänen et al., 2021; Mason et al., 2022; Kapnia et al., 2023). In practical settings, however, warm-up strategy implementation is largely guided by personal experience, coaching tradition, and competition context rather than scientific evidence (Kilduff et al., 2013; Räisänen et al., 2021; Silva et al., 2025a). The main objective of a warm-up is to induce physiological and neuromuscular adaptations that enhance readiness for physical activity (McGowan et al., 2015). These adaptations include increased muscle temperature, reduced muscle and joint stiffness, enhanced oxygen delivery to working muscles, accelerated oxidative and anaerobic metabolic reactions, improved nerve conduction velocity, and better thermoregulatory efficiency (Bishop, 2003a). These effects collectively contribute to improved muscle function, coordination, and force production capacity during high-intensity efforts. Although many coaches still lack precise knowledge regarding its optimal duration, intensity, and structure (Räisänen et al., 2021).

In practice, warm-up strategies can be divided into two categories: active and passive. Active warm-up involves the performance of physical exercises that raise body and muscle temperature through metabolic heat generation, while passive warm-up depends on external factors, such as thermal attire or hot baths, to elevate temperature without physical activity (Bishop, 2003b; McGowan et al., 2015). Active warm-up is the most adopted method before competition because it elevates baseline oxygen uptake, increases range of motion, enhances motor neuron excitability, and promotes post-activation potentiation (Bishop, 2003b; Saez de Villarreal et al., 2007; Wilson et al., 2013; McGowan et al., 2015; Silva et al., 2018). Despite its extensive use, the optimal structure of a warm-up, including the ideal sequence of exercises, duration, and intensity, is still unclear. Properly designing and modulating these methodological components can establish an effective, sustainable warm-up routine that optimizes performance (Bishop, 2003b; Jeffreys, 2006; Woods et al., 2007; Racinais et al., 2017; Silva et al., 2022).

Researchers have consistently reported the benefits of warm-up routines on performance over time (Sargeant & Dolan, 1987; Stewart & Sleivert, 1998; Gregson et al., 2005; Girard et al., 2009; Sotiropoulos et al., 2010; Zois & Bishop, 2011; Yaicharoen et al., 2012; van den Tillaar et al., 2019; Silva et al., 2022). Empirical evidence indicated that warm-up routines can enhance performance in various individual sports, such as sprinting (Marinho et al., 2017; Gil, 2021), swimming (Neiva et al., 2015), cycling (Burnley et al., 2005), and explosive actions, like jumping (Burkett et al., 2005). In team sports, research demonstrate that warm-up routines were efficient in improving athletes' explosive performance on sports such as soccer (van den Tillaar et al., 2019) or Basketball (Cerrillo-Sanchis et al., 2024). Therefore, research has compared the

different types (Zois et al., 2015), volumes (van den Tillaar et al., 2019), intensities, (Zois et al., 2011; Anderson et al., 2014) recovery intervals (Silva et al., 2022), and levels of task specificity of warm-up protocols (Zois et al., 2011; Neiva et al., 2014; van den Tillaar & von Heimburg, 2016). However, the findings of these studies are inconsistent, and several methodological and contextual factors remain unclear (van den Tillaar & von Heimburg, 2016; Silva et al., 2018). For example, recent studies have shown that task specificity is important for improving performance (van den Tillaar et al., 2019; Cerrillo-Sanchis et al., 2024) and have emphasized the importance of tailoring the volume and intensity of warm-up activities based on the athlete's characteristics and sport-specific requirements (Golaś et al., 2016). Furthermore, the benefits of a warm-up are transient, and the duration of these effects remains uncertain (Kapnia et al., 2023). To address this gap, the first study of the present thesis (Study 1) conducted a systematic review that synthesized and critically analyzed the available evidence regarding the effects of warm-up, post-warm-up, and re-warm-up strategies on explosive performance in team sports.

Team sports such as basketball and futsal are complex and dynamic, requiring players to integrate decision-making with intermittent, maximal, or near-maximal explosive efforts (Pociūnas et al., 2018; Silva et al., 2020). They are characterized by frequent high-intensity movements, such as sprints, jumps, accelerations, decelerations, and rapid changes of direction, interspersed with brief periods of active or passive recovery (Bishop et al., 2013). The rate of anaerobic energy turnover is particularly high during match play (Bangsbo et al., 2006), reflecting the substantial metabolic demands of repeated explosive efforts. Success largely depends on players' ability to perform these high-intensity actions efficiently while maintaining technical execution and tactical awareness despite physical and cognitive fatigue (Ramos-Campo et al., 2017; Stojanovic et al., 2018; Petway et al., 2020). Indeed, athletes may perform over 150 brief, intense actions during a single match, reaching muscle lactate concentrations of around 15 mmol/kg (Krustrup et al., 2006).

An effective warm-up is crucial for optimizing explosive performance and readiness in team sports. Warm-up enhances neuromuscular activation, elevates muscle and core temperature, improves metabolic efficiency, and accelerates oxygen delivery. These factors are all fundamental to executing explosive movements (Bishop, 2003a; Girard et al., 2009; Neiva et al., 2014; McGowan et al., 2015). Higher-intensity warm-ups can elicit greater improvements in repeated-sprint performance, especially in the initial stages of competition (Meckel et al., 2009). Additionally, warm-up activities stimulate neural pathways and promote motor coordination, enhancing movement efficiency and reducing reaction time, both of which are critical determinants of sprint performance (Bishop et al., 2013). These neuromuscular and cognitive benefits are essential for success in the fast-paced, decision-driven environments characteristic of team sports (Jeffreys, 2006; Silva et al., 2022). Despite these known benefits, the second study of this thesis (Study 2) explored how such knowledge translates into real-world coaching practices. This study analyzed the warm-up and re-warm-up routines adopted by Portuguese

basketball coaches across different competitive levels, highlighting the discrepancies between scientific recommendations and field application.

Nevertheless, athletes in many team sports may experience periods of inactivity lasting between 10 and 20 minutes at the beginning of a game, during the transition from warm-up to competition (post-warm-up) or between halves (half-time). For instance, in basketball, such passive intervals can occur among substitutes, who often remain inactive for 9 to 23 minutes before entering the game (Kapnia et al., 2023). These transition periods lead to a progressive decline in muscle temperature and metabolic activation, which can negatively affect key performance components, such as sprinting, jumping, and rapid changes of direction, essential for success in intermittent team sports (Bishop, 2003a; Mohr et al., 2004; Kilduff et al., 2013; Bishop et al., 2013). Research shows that muscle temperature can drop by about 0.1°C per minute during a 20-minute post-warm-up period of inactivity (Kapnia et al., 2023). Strategies such as wearing heated garments can mitigate this decline in substitute athletes, reducing muscle temperature loss by around 1.1°C, and in cold environments up to 2°C (Cowper et al., 2024). In this sense, the third study (Study 3) of this thesis tried to further understand the acute effects of varying post-warm-up transition durations on explosive performance, following a standardized active warm-up protocol.

Re-warm-up strategies have been proposed as effective interventions in team sports to counteract explosive performance decline (Silva et al., 2024). Re-warm-up involves short periods of activity (González Fernández et al., 2023; Koutsouridis et al., 2024) or alternative thermal strategies (Russell et al., 2015) performed during the transition period to maintain or regain the physiological and neuromuscular advantages gained during the initial warm-up (Faulkner et al., 2010; McGowan et al., 2015). Various active re-warm-up approaches have been investigated (Koutsouridis et al., 2023), such as plyometric drills (Flórez-Gil et al., 2025), cycling (Yanaoka et al., 2021; Koutsouridis et al., 2024), and passive re-warm-up methods like heated garments and thermal blankets (West et al., 2016). Also, research on re-warm-up at half-time identified that 7 minutes of running and other exercises performed at an average heart rate ~135 bpm, ~70% HR_{peak}, resulted in improved short-term intermittent-sprint running performance compared to resting (Mohr et al., 2004). These strategies aim to elevate muscle temperature, enhance post-activation potentiation, and optimize subsequent explosive performance indicators such as sprinting, jumping, and power output (Russell et al., 2015; Raccuglia et al., 2016; Silva et al., 2024). However, team-sports coaches often tend to undervalue or overlook the implementation of re-warm-up strategies, despite growing evidence supporting their effectiveness and practical relevance (Silva et al., 2025a). Accordingly, the fourth study (Study 4) of this thesis assessed the effectiveness of a brief 2-minute plyometric re-warm-up protocol after different passive transition durations.

Given the aforementioned background, the general objective of this doctoral thesis is to investigate the acute effects of different warm-up, post-warm-up transition, and re-warm-up

strategies on explosive performance in team sports by evaluating biomechanical, physiological, and psychological parameters.

To achieve the general purpose, a sequence of studies was defined, which makes up the following thesis structure:

- **Chapter 2** presents a systematic review (Silva et al., 2018) that synthesizes and critically analyzes existing literature on warm-up, post-warm-up, and re-warm-up strategies designed to improve explosive efforts in team sports (Study 1);
- **Chapter 3** comprises the experimental component of the thesis and consists of three empirical studies that address the main research objectives:
 - Study 2 (Silva et al., 2025a) analyzed the warm-up and re-warm-up practices and perceptions of Portuguese basketball coaches across competitive levels;
 - Study 3 (Silva et al., 2022) developed a brief active warm-up protocol based on prior recommendations. This study examined the acute effects of the protocol and the impact of various post-warm-up transition durations on explosive performance;
 - Study 4 (Silva et al., 2025b) investigated the effects of a short re-warm-up protocol involving plyometric exercises on explosive performance following different passive post-warm-up transition periods in athletes from team sports.
- **Chapter 4** provides a general discussion that integrates the results obtained across the three experimental studies and highlights their theoretical and practical implications;
- **Chapter 5** summarizes the main conclusions and limitations of the research;
- **Chapter 6** presents suggestions for future research directions;
- **Chapter 7** presents the bibliographic references that support this thesis.

Chapter 2. Literature Review

Study 1. Effects of warm-up, post-warm-up, and re-warm-up strategies on explosive efforts in team sports: a systematic review

Abstract

In team sports, it is imperative that the warm-up improves acute explosive performance. However, the exact strategies, methods, and consequences of different warm-up practices remain unclear. A time delay between the warm-up and match and during half-time could negate the positive metabolic effects of the warm-up. We conducted a systematic review to synthesize and analyze the potential effects of strategies during a warm-up (before match), post-warm-up (time between the end of warm-up and the start of a match), and re-warm-up (half-time break within a match) on explosive performance in team sports. Furthermore, we examined optimal warm-up strategies based on the included studies. We performed a search of four databases (Web of Science, Scopus, PubMed, and ScienceDirect) for original research articles published between January 1981 and August 2017. A total of 30 articles met the inclusion criteria, and the Cochrane risk of bias tool was used to assess the risk of bias. The results of the included studies were recalculated to determine effect sizes using Cohen's d . A warm-up comprising 8 sets of 60-m sprints (-2.19%, $d = 1.20$) improved sprint performance. Additionally, 7 min of dynamic exercises after 5 min of jogging improved sprint (-7.69%, $d = 1.72$), jumping (8.61%, $d = 0.61$), and agility performance (-6.65%, $d = 1.40$). The use of small-sided games also seems to be a valid strategy, especially for jumping performance (6%, $d = 0.8$). These benefits resulted from the warm-up strategies combined with some passive rest (between 2 and 10 min) before the main performance. In this post-warm-up period, the use of heated garments could result in better outcomes than simple rest (-0.89%, $d = 0.39$). However, if the transition was longer than 15 min, before entering the match, performing a re-warm-up with short-term explosive tasks to reactivate was the most effective approach (-1.97%, $d = -0.86$). At half-time, heated garments maintained better sprint (-1.45%, $d = 2.21$) and jumping performance (3.13%, $d = 1.62$). Applying properly structured strategies in the warm-up and avoiding a long rest in the post-warm-up improves explosive performance. Studies tend to recommend a short active warm-up strategy (10-15 min), gradually increasing intensity (~50-90% of maximum heart rate), and the use of heated garments soon after the warm-up to maintain muscle temperature. However, 2 min of active re-warm-up with short-term sprints and jumps should be needed for transitions longer than 15 min (~90% of maximum heart rate). Last, at the half-time re-warm-up, combining heated garments to maintain muscle temperature

and performing an active strategy, with explosive tasks or small-sided games for 5 min before re-entering the game, resulted in better explosive performance than 15 min of resting.

Introduction

In training and competition, a warm-up routine has been suggested to be critical in increasing the preparedness for subsequent effort and thus maximizing performance (McCrary et al., 2016). Several preparation strategies have been investigated over the years, and recent studies have indicated that warm-up routines are generally considered to be beneficial to performance (Bishop, 2003a; Fradkin et al., 2010; McGowan et al., 2015). Data have been collected on the mechanisms related to warm-up procedures (Bishop, 2003a; Fradkin et al., 2010; Neiva et al., 2014a; McGowan et al., 2015), pre-competition strategies (Kilduff et al., 2013a; Neiva et al., 2014a; McGowan et al., 2015), and re-warm-up strategies (Yiannis, 2014; Russell et al., 2015a). Despite this information, the real-world application of warm-up strategies is still primarily based on individual experiences rather than scientific evidence (Fradkin et al., 2010; Kilduff et al., 2013a; McGowan et al., 2015).

The warm-up is usually intended to generate a muscle temperature increase that allows several internal changes to occur, such as increased blood flow and optimized metabolic responses (Bishop, 2003a; McGowan et al., 2015). Thus, the ideal warm-up should allow the athlete to attain an optimal muscle temperature range that limits fatigue as much as possible while maximizing performance (Bishop, 2003a; Racinais & Oksa, 2010). Within the first 3–5 min of exercise, there is an increase in temperature that plateaus after 10–20 min of continuous exercise (Faulkner et al., 2013; Raccuglia et al., 2016). In commonly observed ambient conditions (10–30 °C), body temperature declines rapidly after the warm-up, returning to baseline values after 15–20 min of passive rest (Kilduff et al., 2013a; Faulkner et al., 2013). With lowered body and muscle temperatures, performance tends to decline (Racinais & Oksa, 2010). In extremely hot/cold conditions, body and muscle temperatures change differently, and it was reported that more than 1 °C of muscle temperature variation could result in impaired performance (for details on temperature and neuromuscular function, see Racinais & Oksa, 2010).

In addition to the increased body temperature, studies have also reported other effects such as increased resting oxygen uptake, a post-activation potentiation (PAP) effect influenced by the previous activity of the same muscle group, enhancing muscle contractile response and thus the ability to produce power, less muscle resistance, and psychological effects (Bishop, 2003a; McGowan et al., 2015; Russell et al., 2015a). A warm-up can be characterized as active when the participant uses physical activity, or passive when it depends on the use of external means without performance of any type of physical activity by the participant (Bishop, 2003a; Fradkin et al., 2010; Bishop, 2003b). An active warm-up has been the most used strategy throughout the years, but passive warm-up strategies have gained relevance and have been investigated as a complement to preserve or maintain the effects during the transition time between the end of the warm-up and the start of a match, or half-time break within a match (Bishop, 2003a; McGowan et al., 2015).

Research on the use of warm-up techniques has shown benefits for performance, supporting the relevance of an active warm-up for a wide range of individual sports (Neiva et al., 2012; Neiva et al., 2014b; Ayala et al., 2016) and team sports (Zois et al., 2015). However, the effectiveness of the warm-up routine appears to be dependent on many factors, such as the type of sport, athlete fitness and experience, tasks to be performed, environmental conditions, and constraints imposed by the organizers of the event (Bishop, 2003b; McMillian et al., 2006).

The effect of environmental temperature on performance is related to exercise duration. In both cold (10 °C) and hot (40 °C) environments, power decrements during repeated sprints exercise have been observed (Racinais & Oksa, 2010). However, this effect can be reduced, particularly in the morning when body temperature is at its lowest, by a passive warm-up (Bishop, 2003a; Racinais & Oksa, 2010). Studies in this scenario verified that, in a hot environment, short-term exercises of 1 and 30 s enhance performance, exercises of 5 min duration resulted in no change in physical performance, and exercises lasting 10 min or more were detrimental to performance (Racinais & Oksa, 2010).

Therefore, the warm-up must be designed for the specific needs of both the athlete and the sport (Jeffreys, 2007). While we found a wide range of studies examining the effect of different warm-ups on individual sports, few studies have focused on team sports, including review papers (McGowan et al., 2015).

Despite the difficulties in analyzing games in a real-world context, or even simulated games, researchers should focus on team sports athletes performing relevant tasks for improving performance during game play. In team sports games, such as basketball or football, athletes must repeat short sequences of explosive efforts such as sprints, jumps, and changes of direction and speed (Edge et al., 2005; Marques & Izquierdo, 2014). Short-term sprints combined with short recoveries (< 60 s) are common in sports where athletes are required to perform repeated maximal or submaximal efforts, called repeated sprint ability. This is defined as the ability to produce the best average performance in a series of sprints, with brief recoveries (Bishop et al., 2011; Girard et al., 2011). Considering the vital role of repeated sprint ability, enhancing sprint performance should be a priority for athletes and sport scientists (Girard et al., 2011). Indeed, warm-ups are essential for enhancing and attaining optimal performance in these explosive tasks (Neiva et al., 2014b), and can influence the results of sporting contests.

Scientific research has demonstrated the efficacy of warm up strategies for individual sports, but there is little information for those who are interested in team sports. As a result, athletes and coaches continue to design their routines based on experience and not scientific evidence. The difficulty of analyzing the effects of a warm-up in a game situation might be one of the factors impeding the focus on specific sports (for example, football). However, we suggest analyzing specific motor skills and tasks that are relevant to team sports efforts. To the best of our knowledge, no detailed systematic review has comprehensively examined the literature regarding the effects of warm-ups on team sports performance. Analyzing studies that have

evaluated the effect of warm-up and re-warm-up strategies on explosive efforts would provide coaches and sports scientists with valuable knowledge and strategies to optimize programs for athletes in training or competition. Therefore, the purpose of this systematic review is to synthesize and analyze research findings on the effects of warm-up, post-warm-up (time between the end of a warm-up and the start of a match), and re-warm-up (half time break within a match) strategies on explosive efforts in team sports. Furthermore, we recommend optimized warm up strategies for team sports performance.

Methods

Search Strategy

A systematic review was conducted according to PRISMA (Preferred Reporting Items for Systematic reviews and Meta Analyses) guidelines (Moher et al., 2015). Relevant publications published between January 1981 and August 2017 in four databases (Web of Science, Scopus, PubMed, and ScienceDirect) were identified (search results can be found in: <https://doi.org/10.17504/protocols.io.pqkdmuw>). The search was performed using the Boolean search method, which limited the search results with operators including AND/OR to only those documents containing relevant key terms (Table 1) in the scope of this review

Eligibility Criteria

Research articles were included or excluded using criteria defined with the PICO (Population, Intervention, Comparison and Outcome) criteria (Methley et al., 2014), and the literature searches were limited to studies involving experienced team sports athletes. Theses, dissertations, and conference abstracts and proceedings were also excluded. There were no restrictions on written language, but studies were required to have an English abstract and to be published in a peer-reviewed journal. The search strategy and eligibility criteria are shown in Table 1.

Study Selection

The initial search identified 330 articles with potential relevance. After removing duplicates and studies that were not specific to a sports warm-up, a manual screening according to the abstract was performed, and those that were not relevant were excluded. From these studies, 90 original research articles were full text assessed for eligibility, and those that did not meet the inclusion criteria were excluded. For the qualitative analysis, 30 articles were included. The articles were grouped according to whether the intervention was a warm-up (n = 19), post-warm-up (n = 5), or re-warm-up (n = 6) strategy. A detailed flow chart describing the selection of relevant studies is shown in Fig. 1.

Table 1: Search strategy and inclusion/exclusion criteria based on PICO (Population, Intervention, Comparison and Outcome).

Databases	Search terms	PICO	Inclusion criteria	Exclusion criteria
Web of Science	Team sports	Population	Team sports athletes	Non-team sports athletes
Scopus	Warm-up	Intervention	Warm-up (active or passive) strategies in team sports	No activity in control group of warm-up studies
PubMed	Re-warm-up		Post-warm-up (active or passive) strategies in team sports	Not considered by the researchers a practical method to apply to team sports
ScienceDirect	Performance		Re-warm-up (active or passive) strategies in team sports	Only included stretching routines
	Prior exercise		Comparison	Warm-up strategies
	Explosive effort		Post-warm-up strategies/conditions	
	Repeated sprint		Re-warm-up strategies/conditions	
	Vertical jump	Outcome	Performance of explosive tasks (sprint, jump or agility tasks)	Outcome measures not considered in review Criterion test recovery in repeated tasks > 60 s

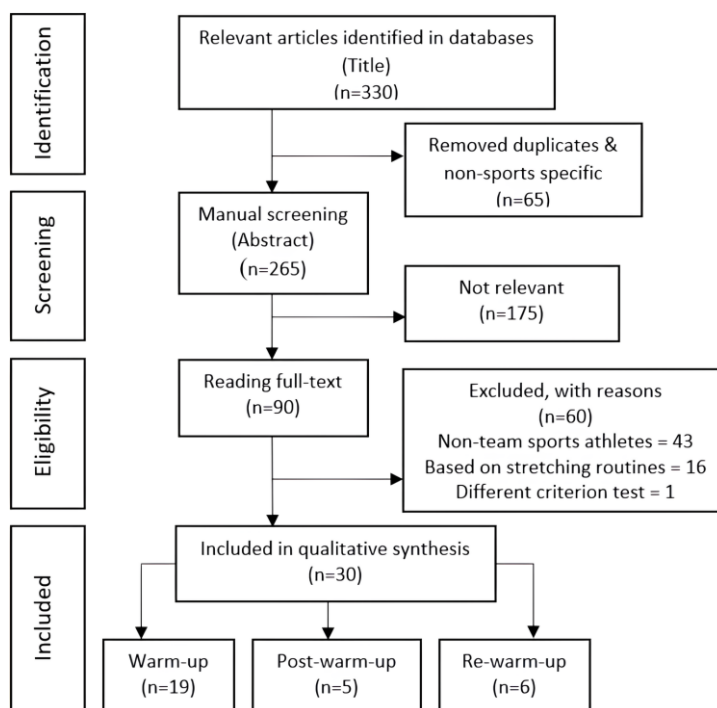


Figure 1: PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) study flow diagram

Data Extraction

From the included articles, we extracted sample size and sexes, strategies that were compared, transition times between the end of the warm-up and the criterion test, and the main results (mean and standard deviation) of sprint, jump and/or agility tasks performed. All outcome data regarding explosive tasks were grouped and analyzed individually using a Microsoft Excel 2016 spreadsheet (Microsoft, Redmond, WA, USA).

Assessment of Risk of Bias

A bias is a systematic error, or deviation from the actual effect, in results or inferences. Two authors (LS; HN) independently assessed the risk of bias of each study against key criteria: random sequence generation, allocation concealment, blinding of participants, personnel and outcomes, incomplete outcome data, selective outcome reporting, and other sources of bias, in accordance with methods recommended by The Cochrane Collaboration (Higgins & Green, 2017). The following classifications were used: low risk, high risk, or unclear risk (either lack of information or uncertainty regarding the potential for bias). The authors resolved disagreements by consensus, and a third author was consulted to resolve disagreements if necessary. Review Manager software (RevMan, The Nordic Cochrane Centre, Copenhagen, Denmark) Version 5.3.5 was used to create risk-of-bias graphs

Statistical Analysis

The results of the included studies were recalculated to determine effect sizes as a measure of the difference between averages in terms of standard deviation units, which provides information about the magnitude of the observed relationship between factors (Conboy, 2003). Thus, this analysis was calculated using Cohen's d (Cohen, 1988), where the mean experimental value was subtracted from the mean control value and divided by the combined standard deviation. This method allowed us to determine the magnitude of differences between groups or experimental conditions for the studies that provided means and standard deviations. The magnitude of the effect was classified as small ($d = 0.2$), intermediate ($d = 0.5$), or large ($d = 0.8$) (Cohen, 1988). For velocity and agility outcomes, the more negative the magnitude of the result, the better the intervention compared with the control condition. For jump outcomes, the more positive the magnitude, the better the intervention. To identify the most efficient strategy, two symbols were used to match the two best strategies: ">" (better than), for the best result against the control group; and "<" (worse than), for interventions that were no better than the control group.

Results

A chronological analysis of the articles that comprised this review showed a recent interest in this area of research, with almost half (47%) of the included studies published in the last 3 years (2015–2017). Nineteen articles reported strategies for warm-up, with 60 combinations of warm-ups. Some of these studies compared the typical routines applied in team sports with different

strategies. We defined this typical routine as a standard warm-up (a warm-up composed of a general aerobic warm-up, stretching routine, and specific sport exercises). In the included studies, we identified that strategies such as 8 sets of 50-m sprints (-0.46% , $d = -0.02$), a 5-min jog with 5 repetition maximum (RM) leg press, or completing back squats (4.75% , $d = 0.75$) at the end of a typical warm-up improve explosive task performance. Among the investigations that showed a large effect size (Table 2) on sprints, performing 8 sets of 60-m sprints (60-s intervals) in the warm-up improved sprint performance (-2.19% , $d = 1.20$), possibly as a result of a PAP effect. This effect was observed with 5RM leg presses (5.7% , $d = -0.7$). Beneficial effects were also observed on jumps after 5 min of sprinting sets at the end of the warm-up (3.21% , $d = 1.01$). This shows that a short specific warm-up is as effective as a long specific warm-up for sprints in football. However, 7 min of seven dynamic exercises after 5 min of jogging was associated with a general improvement in explosive tasks such as sprinting (-7.69% , $d = 1.72$), jumping (8.61% , $d = 0.61$), and agility performance (-6.65% , $d = 1.40$). Other strategies such as carrying an extra load (10%) during all warm-up activities (3.38% , $d = 2.79$), participating in 12 min of small-sided games (6% , $d = 0.8$), or whole-body vibration at 50 Hz with a 30% extra load (-5.12% , $d = 1.52$) may improve performance in explosive tasks. It should be highlighted that most warm-ups were followed by some rest before the main performance (between 2 and 10 min), allowing a reduction in fatigue and the participant to benefit from the potential effects of the warm-up.

Table 2: Effects of warm-up (W) strategies in explosive tasks

Reference	Subjects	Sport	W strategy	Transition (min)	Main outcome and d		
					Sprint	Jump	Agility
van den Tillaar et al. (2016)	12 M	Football	W_1 : 10' jog + 7 DE + 20' jog W_2 : w_1 + 3x60-m sprints + 20' jog W_3 : 10' 8x60-m sprints, 60"	3	$W_2 > W_1$ $d = -1.20$ -2.19%		
van den Tillaar & von Heimburg (2016)	10 M	Football	W_1 : 19' standard W W_2 : 8x50-m sprints, 60" rest	3	$W_2 > W_1$ $d = -0.02$ -0.46%		
Sue et al. (2016)	9 M	Volleyball	W_1 : standard W W_2 : w_1 + 8' bs + 5rm bs	2		$W_2 > W_1$ $d = 0.75$ 4.75%	
Barry et al. (2016)	14 M	Rugby	W_1 : 3' jog + ds + 7x10-m sprint W_2 : w_1 + 5r low-load ge W_3 : w_1 + 10r low-load ge W_4 : w_1 + 15r low-load ge	8	$W_4 > W_1$ $d = -0.21$ -1.13%		
Jamshidi et al. (2016)	30 F	Volleyball	W_1 : 5' jog + ss + de W_2 : 4' 26 hz vibration + squat W_3 : w_1 + w_2	n/a	$W_3 < W_1$ $d = 0.01$ 9.52%		$W_3 > W_1$ $d = 0.00$ -6.05%
Pojskić et al. (2015a)	21 M	Football	W_1 : 5' jog + 7' ds + static squat W_2 : w_1 + 30% bw W_3 : 5' jog + 7' ds + wbv 50 Hz W_4 : w_3 + 30% bw	2	$W_4 > W_1$ $d = -1.04$ -3.56%	$W_4 > W_1$ $d = 0.35$ 5.36%	$W_4 > W_1$ $d = -1.52$ -5.12%
Pojskić et al. (2015b)	21 M	Football	W_1 : 5' jog + 7' rest W_2 : 5' jog + ds W_3 : 5' jog + static half squat W_4 : w_3 + 30% bw	2	$W_2 > W_1$ $d = -1.72$ -7.69%	$W_2 > W_1$ $d = 0.61$ 8.61%	$W_2 > W_1$ $d = -1.40$ -6.65%
Guinoubi	20 M	Football	W_1 : 4' jog + 8' ds + 5' sprint	10	$W_2 > W_1$	$W_2 > W_1$	

et al. (2015)			exercises + 8' specific exercises		$d = -0.78$ -3.47%	$d = 1.01$ 3.21%	
Zois et al. (2015)	10 M	Football	W_2 : 4' jog + 8' ds + 8' specific exercises + 5' sprint exercises	4	iap: $W_2 > W_1 > W_3$		
Cilli et al. (2014)	35 M	Basketball Volleyball	W_1 : dynamic w + 2% bw W_2 : dynamic w + 4% bw W_3 : dynamic w + 6% bw W_4 : dynamic w + 8% bw W_5 : dynamic w + 10% bw	n/a		$W_5 > W_1$ $d = 2.79$ 3.38%	
Sander et al. (2013)	121 M	Football	W_1 : 16' standard W W_2 : w_1 + 4 functional exercises	n/a			$W_2 < W_1$ $d = 0.32$ 1.80%
Gabbett et al. (2008)	14 M	Basketball	W_1 : 7' general movements + ds and ss (gwi) + 15' open skills W_2 : gw ₁ + 15' closed skill	n/a	$W_2 < W_1$ $d = 0.03$ 1.03%	$W_2 < W_1$ $d = -0.01$ -0.20%	$W_2 > W_1$ $d = -$ 0.09 -0.45%
Taylor et al. (2013)	11 M	Football	W_1 : 5' jog + specific sprints W_2 : 5' jog + ss + specific sprints W_3 : 5' jog + ds + specific sprints	n/a	$W_3 > W_1$ $d = -0.03$ -0.13%		
Okuno et al. (2013)	12 M	Handball	W_1 : 5' jog W_2 : 5' jog + 1x5 50% 1rm + 1x3 70% 1rm + 5x1 90% 1rm	n/a	$W_2 > W_1$ $d = -0.38$ -1.16%		
Turki et al. (2012)	16 M	Football Handball	W_1 : 5' jog + ads + specific w W_2 : 5' jog + 2x ads + specific w W_3 : 5' jog + 3x ads + specific w	n/a	W_1 $d = 1.17$		
Zois et al. (2011)	10 M	Football	W_1 : 5' jog + 12' ssg 3 vs. 3 W_2 : 5' jog + 5rm leg press W_3 : 23' standard W	4	$W_2 > W_3$ $d = -0.7$ 5.7%	$W_1 > W_3$ $d = 0.8$ 6%	$W_2 > W_3$ $d = -1.1$ 4.7%
Turki et al. (2011)	20 M	Handball Football Basketball	W_1 : 5' jog (control) W_2 : 5' jog + 3rm deadlift W_3 : 5' jog + 3x3 s isometric squat W_4 : 5' jog + 3x3 tuck jumps W_5 : 5' jog + 3x drop jumps W_6 : 5' jog + ds	n/a		$W_5 > W_1$ $d = 0.67$	
Rønnestad & Ellefsen (2011)	9 M	Football	W_1 : 7' jog + 3' sprints + 15 squats W_2 : w_1 + wbv 30 Hz W_3 : w_1 + wbv 50 Hz	1	$W_3 > W_1$ $d = -0.20$ -0.72%		
Beckett et al. (2009)	12 M	Football Rugby Hockey	W_1 : 5' jog + de + 3 x rsa W_2 : 5' jog + de + 3 x rsa + ss W_3 : 5' jog + de + 3 x cod W_4 : 5' jog + de + 3 x cod + ss	4	$W_2 < W_1$ $d = 0.03$ 0.10%		$W_4 > W_3$ $d = -$ 0.09 -0.49%

ads active dynamic stretch, *bs* back squat, *bw* body weight, *cod* change of direction, *de/s* dynamic exercises/stretch, *f* female, *ge* gluteal exercises, *iap* intermittent activity protocol, *M* male; *r* repetition, *rm* repetition maximum, *rsa* repeated sprint ability, *ss* static stretch, *ssg* small sided game, *wbv* whole body vibration

Globally, applying dynamic exercises, 5RM leg presses or small-sided games seemed to favor most of the explosive efforts analyzed. In addition, the studies indicated that static stretching (0.10%, $d = 0.03$) was the least effective at improving sprint performance and agility.

For post-warm-up strategies, five articles verified the effectiveness of 14 conditions on the transition time after warm-up (Table 3). A progressive decrease in performance was observed in resting situations. Decreases of between 4% and 6% in sprint performance and between 12 and 20% in jump performance were observed. The use of heated garments had a moderate effect on

sprint performance (-0.89% , $d = -0.39$). However, when this intervention was combined with three sets of five countermovement jumps with 20% body weight, a large effect was observed on sprint performance (1.97% , $d = 0.86$). No strategy was found to be effective in improving jump performance.

Table 3: Effects of post-warm-up (*P*) strategies in explosive tasks

Reference	Subjects	Sport	Warm-up (min)	Transition (min)	<i>P</i> strategy	Main outcome and <i>d</i>	
						Sprint	Jump
Crowther et al. (2017)	2 M	Basketball	20	20	<i>P</i> ₁ : rest		Player 1: ↓15.4% Player 2: ↓11.9%
West et al. (2016)	15 M	Rugby	25	20	<i>P</i> ₁ : nta <i>P</i> ₂ : bsg <i>P</i> ₃ : nta + 3x5 cmj+20% bw <i>P</i> ₄ : bsg + 3x5 cmj+20% bw	<i>P</i> ₄ > <i>P</i> ₁ $d = -0.86$ -1.97%	<i>P</i> ₄ < <i>P</i> ₁ $d = 0.00$ -0.02%
Alberti et al. (2014)	81 M	Basketball	15	20	<i>P</i> ₁ : control <i>P</i> ₂ : sitting <i>P</i> ₃ : standing <i>P</i> ₄ : tapping <i>P</i> ₅ : lbm		<i>P</i> ₃ < <i>P</i> ₁ $d = -0.07$ -0.79%
Kilduff et al. (2013b)	20 M	Rugby	25	15	<i>P</i> ₁ : nta <i>P</i> ₂ : bsg	<i>P</i> ₂ > <i>P</i> ₁ $d = -0.39$ -0.89%	<i>P</i> ₂ < <i>P</i> ₁ $d = -0.02$ -0.13%
Galazoulas et al. (2012)	8 M 8 F	Basketball	25	40	<i>P</i> ₁ : 10' rest <i>P</i> ₂ : 20' rest <i>P</i> ₃ : 30' rest <i>P</i> ₄ : 40' rest	↓ 4% - 6%	↓ 13% - 20%

bsg blizzard survival garment, *bw* body weight, *cmj* countermovement jump, *F* female, *lbm* low back mobilization, *M* male, *nta* normal training attire, ↓ decline in performance

Seven studies assessed the effect of 13 re-warm-up strategies (half-time break within a match) (Table 4). A decrease in performance was identified when passive resting situations were implemented. The utilization of heated garments had the best effect size compared with resting in sprint (-1.45% , $d = 2.21$) and jump performance (3.13% , $d = 1.62$). Among all the strategies, only the use of eccentric exercise was detrimental to performance, showing the worst effect on sprint (0.1% ; ± 1.3) and jump performance (-1.8% ; ± 2.7) (Abade et al., 2017).

Table 4: Effects of re-warm-up (*Rw*) strategies in explosive tasks

Reference	Subjects	Sport	Half-time (min)	<i>Rw</i> strategy	Main outcome and <i>d</i>	
					Sprint	Jump
Abade et al. (2017)	22 M	Football	15	<i>Rw</i> ₁ : 12' rest (control) <i>Rw</i> ₂ : 6' rest + eccentric exercise <i>Rw</i> ₃ : 6' rest + 4x5 jumps <i>Rw</i> ₄ : 6' rest + rcod	<i>Rw</i> ₃ > <i>Rw</i> ₁ -2.9%	<i>Rw</i> ₃ > <i>Rw</i> ₁ 3.8%
Russel et al. (2015)	18 M	Rugby	15	<i>Rw</i> ₁ : nta <i>Rw</i> ₂ : bsg	<i>Rw</i> ₂ > <i>Rw</i> ₁ $d = -2.21$ -1.45%	<i>Rw</i> ₂ > <i>Rw</i> ₁ $d = 1.62$ 3.13%
Edholm et al. (2014)	22 M	Football	15	<i>Rw</i> ₁ : traditional half-time break <i>Rw</i> ₂ : 7' rest + 7': jog and calisthenics	<i>Rw</i> ₂ > <i>Rw</i> ₁ $d = -0.72$ -2.02%	<i>Rw</i> ₂ > <i>Rw</i> ₁ $d = 0.29$ 3.02%
Lovell et al. (2013)	10 M	Football	15	<i>Rw</i> ₁ : rest (control) <i>Rw</i> ₂ : 9' rest + 5' iae <i>Rw</i> ₃ : 9' rest + 5' wbv 40 Hz	<i>Rw</i> ₂ > <i>Rw</i> ₁	<i>Rw</i> ₂ > <i>Rw</i> ₁

Zois et al. (2013)	8 M	Football	15	Rw ₁ : 15' rest (control)	Rw ₂ > Rw ₁ <i>d</i> = -0.6 -4.6%	Rw ₂ > Rw ₁ <i>d</i> = 0.4 3%
				Rw ₂ : 10' rest + 5m leg press		
				Rw ₃ : 8' rest + 7' ssg		
Mohr et al. (2004)	9 M	Football	15	Rw ₁ : 15' rest (control)	Rw ₂ > Rw ₁ <i>d</i> = -0.66 -0.67%	
				Rw ₂ : 7' rest + 7' jog + exercises at 135 beat/min		

bsg blizzard survival garment, *iae* intermittent agility exercise, *M* male, *nta* normal training attire, *rcod* repeated change of direction, *rm* repetition maximum, *ssg* small-sided game, *wbv* whole body vibration

Risk of Bias in the Included Articles

Most investigations were randomized and used a crossover design (80%). For practical reasons, most studies did not adopt a blinding design, but all made a between-group comparison. Morton (2009) identified that blinding is the item that is least adhered to, as it is difficult to achieve for practical reasons (Figs. 2, 3).

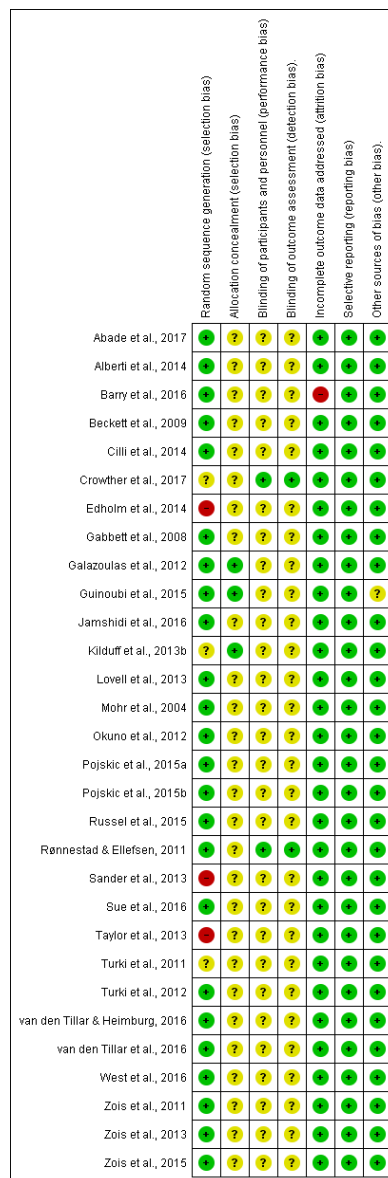


Figure 2: Judgments about each risk-of-bias item for each included study. + indicates low risk, ? indicates unclear risk, - indicates high risk

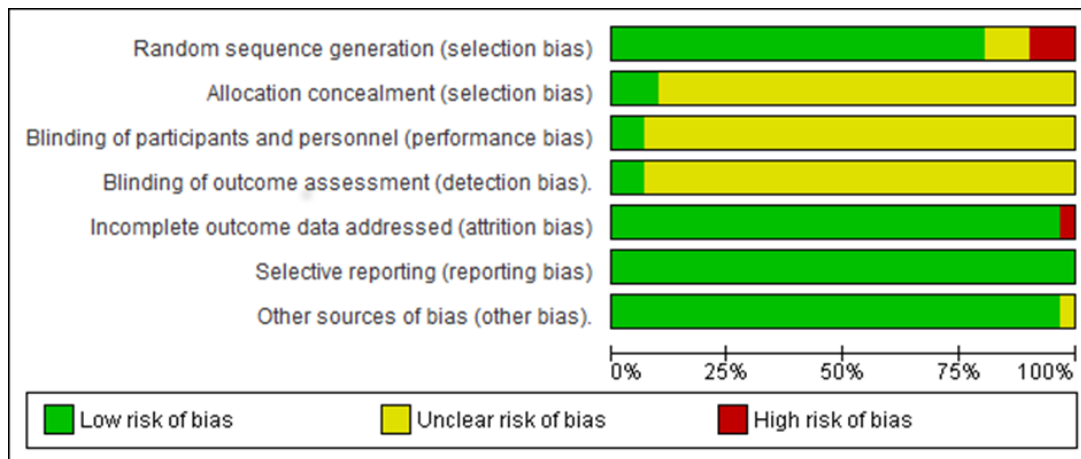


Figure 3: Risk-of-bias item presented as percentages across all included studies

Discussion

The present review aimed to analyze, from a qualitative and quantitative point of view, the findings provided in the literature regarding warm-up, post-warm-up, and re warm-up strategies for team sports athletes. The included studies identified substantial improvements in explosive activities (i.e., sprinting, jumping, agility) using different warm-up strategies. Although numerous studies have been conducted, to date, no consensus has been reached regarding an optimal strategy or protocol to apply in team sports. Of the 19 included articles that assessed warm-up strategies, 69% showed an improvement in sprint performance, 87.5% showed an improvement in jump performance, and 83% showed an improvement in agility performance. These improvements indicated that a properly structured strategy can substantially increase athlete performance in many different sports. However, some gaps were found between studies that make comparing the results difficult. Different control groups (jogging, standard routines, or structured strategy) and different warm-up volumes and tasks were used, making it difficult to directly compare the magnitude of the effect between strategies. Additionally, the lack of blinding and allocation concealment of the athletes might represent a potential risk of bias in the results, as the efforts may not have been natural.

Therefore, to define a properly structured warm-up strategy, it is important to know which variables are critical (type, composition, intensity, volume, and transition period) for optimizing subsequent explosive performance tasks. Nevertheless, studies tend to recommend a short active warm-up strategy that progresses in intensity until maximal effort is attained close to the end of the warm-up. Shortly afterwards, a passive strategy should be used in the transition time before the game, and a re-warm-up should be performed before entering the game, with short-term sprints and jumps for longer transition times. Finally, resting should be avoided at half-time, and a passive strategy or an active strategy should be incorporated as a re-warm-up before re-entering the game.

Warm-Up Structure (Volume, Intensity, Tasks)

The typical pre-match warm-up protocol used in team sports consists of a general warm-up phase of sub-maximal aerobic exercises, followed by a specific phase with stretching routines and sports-specific skill exercises (Fradkin et al., 2010; Ayala et al., 2012; Andrade et al., 2015). These warm-up programs are traditionally designed to focus on energy systems and physiological processes, while the neurological aspects of the warm-up are often overlooked (Jeffreys, 2007). Moreover, the warm-up period usually lasts a long period (>20 min), which could introduce a risk of cumulative fatigue, compromising subsequent performance, as suggested in sports such as cycling and rowing (Tomaras & MacIntosh, 2011; Mujika et al., 2012). In three studies, athletes exhibited poorer sprint, jump, and agility performance after a standard warm-up than they did using other strategies such as 12-min small-sided games, 5RM leg press, or 8-min back squats (Zois et al., 2011, 2015; Sue et al., 2016). In addition, two of the studies reported that a short warm-up might have the same benefits on performance as a long warm-up and may be more practical (Taylor et al., 2013; van den Tillaar & Heimborg, 2016). Likewise, the 23-min professional warm-up applied in the study by Zois et al. (2011) resulted in a 4–6% poorer performance in explosive tasks compared with other shorter strategies (for example, 12 min of small-sided games or 5RM leg press).

These data agreed with results obtained in cycling, for example, the work of Tomaras and MacIntosh (2011). These authors reported that a warm-up performed at an intensity too high for longer than needed could result in fatigue and impair subsequent short-term all-out performance in track cyclists. This might be caused by a reduction in energy stores and a decline in heat storage capacity. However, some athletes seemed to feel psychologically more prepared after a 25-min warm-up than with a shorter warm-up, an effect that was independent of the decrease in physical performance (Pardeiro & Yanci, 2017). Still, we may conclude that performing a shorter warm-up routine for between 10 and 15 min provides the same or more benefits than a longer routine, avoiding increased fatigue and leaving more free time for other tactical interventions.

Research suggests that an optimum preparation strategy should provide sufficient intensity (~40–60% maximum rate oxygen uptake) and duration (5–10 min), followed by a proper recovery (5 min) (Bishop, 2003b; Jeffreys, 2007; Yaicharoen et al., 2012). Explosive tasks such as sprints and jumps seemed to require a more strenuous warm-up intensity [~90% of maximum heart rate (HR_{max}) plus level 16 of rating of perceived exertion] and recovery to achieve high levels of explosive force production at the initial stages of a match (Meckel et al., 2009; Anderson et al., 2014). However, this differs from the usual tasks performed in real-world contexts. Three studies showed that completing some sprint tasks at the end of the warm-up led to a 2–3% improvement in sprint performance (Taylor et al., 2013; Guinoubi et al., 2015; van den Tillaar et al., 2016). Similarly, for jump performance, the application of sprint tasks seems to boost performance by 3% (Guinoubi et al., 2015) and post-activation potentiation can be induced by three sets of three tuck jumps (Turki et al., 2011).

To the best of our knowledge, no studies have specifically evaluated warm-up intensity in team sports. The only studies that focused on intensity applied different post activation potentiation strategies by using muscle stimulation. Strategies such as a 5RM leg press (Zois et al., 2011, 2015), dynamic exercise with an additional load of 10% body weight (Cilli et al., 2014), or whole-body vibration 50 Hz plus a 30% body weight load (Pojskić et al., 2015a) seem to improve performance. However, these studies were conditioned by the use of specific muscle strength measuring and evaluation apparatus. Therefore, based on these findings, we may conclude that structuring a shorter warm-up (10–15 min), progressive in intensity (~50–90% HR_{max}), with open or closed skills exercises (Gabbett et al., 2013) and ending the warm-up with sprint tasks (~90% HR_{max}) may be an optimal strategy. Moreover, during a team sport competition, fatigue will cause the players' performance to decrease at a certain point in time. Reducing the duration and/or intensity of the warm-up will probably delay fatigue and lead to higher overall performance during the match.

Currently, coaches worldwide typically implement stretching routines (static, dynamic, ballistic, or proprioceptive neuromuscular facilitation stretching) as an important part of their warm-up preparations, believing that they improve performance and range of motion and reduce injury risk (Ayala et al., 2012). However, there is little scientific evidence that supports the benefits of these practices. A recent study verified that a warm-up complemented with stretching exercises positively influences repeated sprint ability, especially after the first sprint (Marinho et al., 2017). Among the investigations with the best results, we found that dynamic stretching at the end of the warm-up improved explosive tasks by up to 9% (Pojskić et al., 2015b; Jamshidi et al., 2016). One study reported that completing one set of active dynamic stretching, and no more, may result in better sprint performance (Turki et al., 2012). Additionally, Pojskić et al. (2015a) observed 6–8% better performance in explosive tasks following dynamic stretching at the end of the warm-up, which can be a feasible option before sprint tasks (Taylor et al., 2013). Conversely, a considerable number of studies indicated that static stretching and proprioceptive neuromuscular facilitation stretching performed prior to strength, power-dominant, speed, and agility activities result in performance deficits and should normally be avoided (Beckett et al., 2009; McHugh & Cosgrave, 2010; Behm & Chaouachi, 2011; Carvalho et al., 2012; Peck et al., 2014; Sampaio-Jorge et al., 2014). However, recent findings suggested that performing dynamic movements after static stretching could have a positive effect on performance (Gabbett et al., 2013; Little & Williams, 2006). Still, dynamic stretching generally can be recommended in the period immediately prior to activity, while static and proprioceptive neuromuscular facilitation stretching are probably best after activity (Peck et al., 2014). It seems clear that an acute bout of stretching will decrease the acute ability to generate a maximal force (McHugh & Cosgrave, 2010), but it may be valid to apply a dynamic stretching routine in the middle of the warm-up or just before a maximum intensity exercise to potentiate performance.

Post-Warm-Up Transition Time Effects

Another important factor that might impair subsequent performance is the time spent by athletes in resting situations, such as between the warm-up and the match and during half-time. Usually, team sports games take approximately 12 min of transition time between the warm-up and the start of the game (Kilduff et al., 2013a; McGowan et al., 2015), and this interval could eventually negate the positive metabolic effects of the warm-up. In addition, not all athletes begin to play shortly after the warm-up, as they may be substitutes. Accordingly, research indicated that substitutes might be physiologically underprepared when they are called upon, as just 6 min after warm-up, the core temperature significantly decreased, and heart rate and muscle temperature returned to baseline values (Crowther et al., 2017). Similarly, Galazoulas et al. (2012) reported that resting resulted in rapid and highly associated decreases in temperature and performance, with the greatest impact on tasks demanding explosive and high-velocity efforts.

All the included articles identified a progressive decrease in performance with the traditional passive rest period. The reduction in jumping, sprint, and agility performance increased with resting time. After 20 min of rest, athletes showed a decrease of approximately 15% in jumping performance (Crowther et al., 2017). Extending the rest to 40 min, jumping performance decreased 20% and sprint performance about 6% (Galazoulas et al., 2012). Additionally, one of the studies found that standing up 20 mins after the warm-up reduced the decrease in performance compared with sitting on the bench, which is more common and is significantly unfavorable to explosive tasks (Alberti et al., 2014). However, owing to restrictions imposed by the rules of some team sports games, the athlete is not allowed to stand during the game and must remain seated. Because of these constraints, the use of passive warm-up strategies for transitions could help maintain optimal performance, diminishing the decline in force production and sprint performance (West et al., 2016). Moreover, two studies identified some strategies to mitigate possible losses in performance (Kilduff et al., 2013b; West et al., 2016). These authors showed that the application of heated garments after the warm-up can significantly maintain the benefits gained by the warm-up or at least reduce their decline. However, it seems even more beneficial to combine this passive strategy with an active strategy (three sets of five countermovement jumps with 20% body weight) (West et al., 2016). This finding is relevant to athletes who spend more time on the bench and suggests that these athletes should combine a post-warm-up strategy with a re-warm-up before entering the game.

Half-Time Re-Warm-Up

Team sports are usually played with a half-time break of 10–20 min in the middle of the game, which is used to rest, rehydrate, address injuries, and receive tactical instructions (Racinais & Oksa, 2010). However, studies have identified a decrease in physical and cognitive performance associated with the traditional rest time. All the included articles found that a passive rest period decreased performance in commonly observed ambient conditions (10–30 °C). It should be noted that different results were found under specific conditions, such as hot environments,

resulting in different muscle temperature responses (Mohr & Mujika, 2010). Despite these conditions not being usual during matches, we should be aware that football matches performed in the heat caused muscle temperatures above optimal after the end of the first half, and perhaps influenced values during rest time and performance in the second half (Mohr & Mujika, 2010).

Knowing that temperature rapidly decreases, researchers have recently been interested in investigating strategies to prevent this decline. This could be particularly relevant in cold ambient conditions. However, studies on this topic are scarce and have mostly focused on football. Four studies on the effects of a re-warm-up found that active strategies, for example, 7–8 min of running with an intensity of $\sim 70\%$ HR_{max} (Mohr et al., 2004; Zois et al., 2013; Edholm et al., 2014), as well as a post-activation strategy of four sets of five jumps (Abade et al., 2017), were better for subsequent performance than the traditional interval rest. However, these results should be interpreted carefully, as one study reported that eccentric exercise could increase the decline in performance and that it should be avoided (Abade et al., 2017).

In accordance with the evidence observed during post-warm-up transitions, passive strategies appear safe to use and may prevent physiological losses that cause performance impairment. However, only one study focused on this matter and reported that using heated garments during the entire half-time period had a major positive impact compared with resting alone (Russell et al., 2015b). Passive strategies and active strategies seem to be adequate to maintain or improve performance; however, none of the included studies investigated the benefits of a combination of both strategies during half-time. In a theoretical model for re-warm-up, a combination of heat maintenance strategies (active and/or passive), hormonal priming (verbal persuasion, feedback, and video clips prior to exercise), and caffeine and carbohydrate consumption was found to provide positive results in avoiding and/or reducing decreases in performance and physiological responses in the second half (Racinais & Oksa, 2010). However, so far, no studies have tested this combination. With the available findings, we may conclude that for an effective re-warm-up strategy, athletes should at least use some sort of external heat-retaining garments or perform an active routine 5–8 min before subsequent activity.

Developed Warm-Up Programs

As a result of the importance of a warm-up, some researchers have attempted to develop guidelines for warm-up protocols. First, Jeffreys (2007) developed general recommendations with the “RAMP” method, which focused on three phases that should be of great importance for a good warm-up in all types of activities: (1) raise, which aims to elevate body temperature, heart rate, respiration rate, blood flow, and joint fluid viscosity via low-intensity activities; (2) activate and mobilize, which involves a series of specific dynamic key movement patterns involved in sports, together with a focus on key muscles that need to be activated to produce these movements; and (3) potentiation, which aims to increase activity to maximal intensity and potentiate PAP (Jeffreys, 2007). Specifically, in team sports, the FIFA Medical and Research

Centre developed the FIFA 11+ warm-up program for football players and a recently injury prevention program for children called FIFA 11+ Kids (Rössler et al., 2018). The FIFA 11+ consists of running, strength, plyometric, and balance exercises (Soligard et al., 2008) combining cardiovascular activation and neuromuscular exercise to reduce and prevent injury incidences in football players (for details, please see Soligard et al., 2008). Conversely, the FIFA 11+ Kids focuses on injury prevention and the development of special orientation, body stability, movement coordination, and fall techniques (Rössler et al., 2016). This study observed that application of this prevention warm-up program improved performance in dynamic balance, agility, jumping, and slalom dribbling (for details, see Rössler et al., 2016). Another program (Harmoknee) has been developed to prevent injuries in football players (Kiani et al., 2010). This program was developed to provide a warm-up that improved motion patterns and caused less strain to the knee joint (Bizzini et al., 2013). It is recommended as a multi-faceted football-specific prevention program that combines education, proper motion patterns, strength, and balance, without using special equipment. Research indicates that this protocol resulted in a 77% decrease in the incidence of knee injury (for details, see Kiani et al., 2010).

Studies on these programs reported that FIFA 11+ can be potentially effective for reducing the risk of injury and can enhance subsequent performance (Bizzini et al., 2013). This program improved jump height, agility, and football skills while Harmoknee only improved football skills (Daneshjoo et al., 2013). Although these programs have been proposed, only a few studies have evaluated their effects on athlete performance. Additionally, they are mainly directed towards football players and there is limited research on use of these programs in other sports (Longo et al., 2012). Further research is needed to indicate possible adaptations that can be replicated for other team sports.

Future Research

Many warm-up protocols have been tested, with several identifying positive performance results. However, comparing these positive results to identify the best strategy is difficult owing to differences in the control groups. Future studies should have a common control group, with a structured strategy for comparison with other studies, aiming to identify the best methodology that results in the best player performance. Furthermore, there are many opportunities for bias that should be eliminated, as in the case of blinding and allocation concealment, to reduce the potential for bias to affect the results. Warm-up effects are usually assessed by sprints and jumps, but agility tests are valid and should be used also for analysis. In addition, new technology may allow further ecological analysis than what has been possible to date. The use of tracking systems such as a global positioning system in a real-world context could contribute to increased knowledge about warm-ups in team sports. This would facilitate the conduct of blinded studies, perhaps in the context of ‘friendly’ games and other settings, with the aim of gathering more data in ecological contexts for establishing external validity.

Given that in these types of competitions not all the athletes take the field at the same time, and that each player performs different functions, it seems important to know what specific warm-up components are best for the players' actions on the field. The possibility of applying specific warm-up strategies that differ between athletes should be investigated. It must be remembered that recommendations provided were based on a mean change and a small minority of individuals can respond differently. In addition, more research should be conducted on transition times, perhaps on combinations of active and passive strategies, as well as different interval times. Such studies would be of great importance for developing re-warm-up strategies and optimizing performance, especially in team sports. Additionally, most of the studies included focused on male athletes, and future investigations should also consider differences between sexes, ages, and training experiences and levels. The effect of time of the season should be analyzed, and warm-up data should be provided according to each phase of the annual training plan. It would also be interesting to understand the psychological aspects of a warm-up (for example, the belief of being ready after a warm-up), rarely investigated in team sports.

Future studies should aim to improve our knowledge of warm-up effects, by assessing and establishing different relationships between physical performance and physiological and biomechanical variables, which will increase the accuracy of feedback provided to optimize physical performance. By understanding the relationships between these variables, it could be possible to establish a comfortable range of the responses of physiological variables that are desirable immediately before the main physical task performance. Integrating this knowledge with recent technological innovations, for example, wearables, could provide a great opportunity to individualize each warm-up, leading to specific individual actions and increased efficiency of a warm-up and/or re-warm-up.

Limitations

Most of the results reported in the current review were based on the findings of single studies, limiting their applicability to alternative team sports and different populations. We found some limitations in the comparison of the results presented by different investigations, and specific recommendations concerning 'optimal' warm-up, post-warm-up, and re-warm-up strategies and exercise content were formulated based on the present set of data. Within the included studies, many strategies were investigated; however, they differed widely in the applied control group. Thus, it proved unfeasible to perform a meta-analysis, extrapolate conclusions, and compare strategies in various sports and populations. Furthermore, there were several methodological variations related to warm-up intensity, duration, recovery time, and type. These might partly account for the fact that warm-up protocols often vary significantly among players and sports.

Conclusion

The results of the critical analysis of the scientific literature performed in this review could translate into positive effects on short-term explosive performance. In team sports such as

football, basketball, or rugby, which require athletes to sprint intermittently throughout the match (Edge et al., 2005), it is imperative that the warm-up improves acute explosive performance. To this end, it seems clear that the structure currently used for warm-ups should change. Implementing other strategies appears to be more effective in increasing explosive performance. The vast majority of studies on warm-ups obtained better results with a shorter and intensive warm-up. In general, the warm-up should be between 10 and 15 min, progressive in intensity (~50–90% HR_{max}), aim to increase body temperature and prepare for specific tasks of the sport, and end with tasks of maximum intensity such as sprints (~90% HR_{max}) to induce the PAP effect. Additionally, the warm-up benefits could be lost during transition phases between the warm-up and the start of a match if an effective post-warm-up strategy is lacking. This should be considered a critical component of the warm-up strategy. Although research indicates that the athlete should avoid sitting on the bench and would be better off standing, unfortunately this option is not possible owing to the rules of team sports. Studies suggest that it is essential, in light of these restrictions, to put on heated garments soon after a warm-up, to maintain muscle temperature. However, for transitions longer than 15 min, a 2-min active re-warm-up with explosive tasks (~90% HR_{max}), just before entering the game, appears essential.

Regarding the half-time re-warm-up, it has been shown that rest should be avoided or minimized, as it causes a marked decrease in performance. In the current review, it was found that it was important to wear heated garments, to maintain muscle temperature, and to perform an active re-warm-up of 5 min with explosive tasks or small-sided games. Implementation of these strategies gives us an idea of whether an athlete is conditioned to perform well in sporting activities, but it remains unknown whether these isolated activities result in better sport performance on the field. Finally, we should emphasize that our findings were based on the results of studies conducted in commonly observed ambient conditions (10–30 °C), and that studies conducted in extremely hot or cold conditions might have produced different results.

Chapter 3. Experimental Studies

Study 2. Analysis of competition warm-up and re-warm-up practices of Portuguese basketball coaches

Abstract

Basketball is a dynamic team sport characterized by intense, strategic play that requires high-intensity activities such as sprinting, jumping, and changing direction. Proper warm-up routines are crucial for improving athletic performance and adapting to the game's physical demands. This study evaluates the warm-up practices of Portuguese basketball coaches and their adherence to evidence-based guidelines. A cross-sectional survey of 158 Portuguese basketball coaches was conducted to analyze the relationships between their warm-up and re-warm-up strategies and the coached competition. Significant associations in warm-up were found among coaches of youth competitions and performance competitions, especially in warm-up volume, but no significant associations were found regarding in-game or half-time re-warm-up strategies. This study shows that coaches in performance contexts tend to use more comprehensive warm-up strategies. However, there is a need for increased practice of re-warm-up routines by the coaches of youth and performance competitions to optimize player performance.

Keywords: Sports performance; Competition; Basketball; Warm-up; Reactivation

Introduction

Basketball is an intense, fast-paced team sport emphasizing strategic territorial progress on the court. Players must master diverse movement patterns and continuously execute technical and tactical skills to achieve high performance levels (Petway et al., 2020). The intermittent nature of the gameplay requires players to switch dynamically between offence and defense, with or without the ball, maintaining performance against one or more opponents (Altavilla & Raiola, 2014). Frequent bursts of high-intensity activities, such as sprints, jumps, and quick directional changes, are interspersed with short active or passive recovery periods, all performed from various positions on the court (Ferioli et al., 2020). Success in basketball relies on the players' ability to rapidly accelerate, decelerate, jump, and shuffle, adapting these skills under continuous defensive pressure (Stojanović et al., 2018).

Pre-competition warm-up is a critical routine that enhances athletic performance and prepares players for the physical demands of the game. Evidence suggests that WU routines enhance explosive performance (e.g., sprints, jumps, and agility) by increasing muscle readiness (Silva et al., 2018) and reducing injury risks (Ding et al., 2022). These routines typically include a general phase with low-intensity aerobic exercises, dynamic stretching, and sport-specific drills, lasting 15–20 minutes at 50–90% of maximal heart rate (Silva et al., 2018). The physiological benefits of WU include increased muscle temperature, increased fiber performance and conduction velocity, optimized oxygen uptake and psychological preparation (McGowan et al., 2015). However, these benefits are transient (Neiva et al., 2017) and can dissipate quickly if the athlete remains inactive for extended periods (Silva et al., 2022).

In basketball, where game substitutions often occur 9–23 minutes after play begins (Kapnia et al., 2023), maintaining physical readiness through WU strategies becomes critical. Declines of up to 15% in jump performance have been observed after only six minutes of inactivity (Crowther et al., 2017). Passive WU techniques during prolonged transitions to gameplay, including external methods to maintain core temperature, have shown promise in mitigating performance losses (Cowper et al., 2024). Also, re-warm-up (RWU) strategies during in-game (Koutsouridis et al., 2024) or in pauses, such as half-time (HT) have been proposed to counteract performance drops (González-Devesa et al., 2021).

Although WU is widely recognised as crucial for performance optimisation and injury prevention, many coaches lack precise knowledge about its optimal duration, intensity and structure (Räisänen et al., 2021). This gap highlights the need for studies that align current WU practices with advancements in sports science. This study aims to analyze the WU and RWU practices of Portuguese basketball coaches in youth and senior competitions, assessing their adherence to scientific recommendations regarding duration, intensity, and structure.

It was hypothesized that Portuguese basketball coaches implement WU and RWU routines that adhere to recommended practices for duration, intensity, and structure.

Methods

Participants

This study included 158 Portuguese basketball coaches who met specific eligibility criteria: i) possession of a valid Portuguese coaching license, divided into Portuguese coaching grade 1 (n = 41), grade 2 (n = 59), and grade 3 (n = 58); ii) at least one year of coaching experience, divided into 1-5 years (n = 34), 5-10 years (n = 37), 10–15 years (n = 15), and over 15 years (n = 72); and iii) participation in a formal national basketball competition, with coaches of youth teams (n = 100) and senior teams (n = 58). All participants were provided with detailed study information, gave written consent to participate, and were informed of their right to withdraw at any time. Ethical approval was granted by the Human Research Ethics Committee of the University of Beira Interior, and the study was conducted in accordance with the Declaration of Helsinki.

Measures and Procedures

With an observational and descriptive study design, data were collected through a cross-sectional, self-administered questionnaire. The questionnaire was developed by the research team based on prior research (McGowan et al., 2016). Afterwards, to establish face validity and suitability, a prior pilot test was conducted with three basketball coaches. Feedback was used to refine questions, and these data were not included. The first section of the questionnaire gathered demographic information about the coaches' competitive basketball background, coaching experience, formal basketball coaching qualifications, and the competition at which they regularly coached. In subsequent sections, detailed information was collected on the coaches' WU and RWU practices in competition. For further comparison, coaches were divided into youth coaches (youth competitions) and performance coaches (senior competitions).

The questionnaire was distributed to coaches during the 2023/24 basketball season. Coaches were contacted in person or via email sent to clubs registered with the Portuguese Basketball Federation, including a link to a Google Form. They received descriptions of the study, consent form and the questionnaire to complete independently.

Statistical Analysis

All question data collected from the questionnaire were analyzed using relative frequencies to determine the percentage response of coaches. Responses that were not conclusive were removed from consideration. The Chi-square test was used to verify the relationship between the answers of coaches (McHugh, 2013). Significance was set at $p = 0.05$. To quantify the degree of association between the variables, Cramer's association coefficient V was calculated, where values below 0.1 indicate a very weak association, and values above 0.5 represent a strong association (Cohen, 2013). The statistical software IBM Statistical Package for Social Sciences (SPSS, version 27.0) for Microsoft Windows (Armonk, NY, EU: IBM Corp.) was used for the analyses.

Results

Analysis of the WU volumes revealed significant associations based on the competition. Specifically, coaches managing youth competition programs WU with an average duration of 20 minutes. In contrast, coaches at performance competitions program longer WU, averaging 30 minutes or more. A moderate association between the type of competition and the volume of WU was found ($p = 0.001$; $V = 0.408$) (Figure 4).

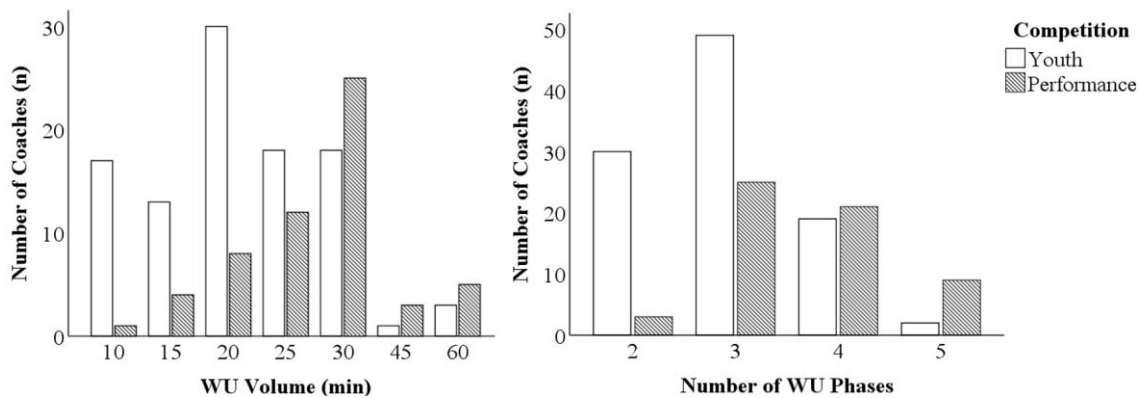


Figure 4: Overview of WU volume and phases structured by the coach's competition.

Moreover, there was a moderate association between WU phases and the competition context among coaches ($p = 0.001$; $V = 0.398$) (Figure 4). Coaches in performance competitions predominantly structured their WU into three to five phases (94.8%), whereas those in youth competitions typically used fewer phases, with 79% implementing only two to three.

Despite the observed associations in the number of WU phases, a similarity was found in the tasks performed by coaches. In the general phase, coaches mostly included aerobic and stretching exercises, while during the specific phase, coaches mostly tended to use technical exercises (Table 5).

Table 5: The three most represented WU tasks in each phase structured by the coach's competition.

WU Tasks		Youth	%	Performance	%	Total
General	Aerobic	62	67.40	33	62.30	95
	Stretching	51	55.40	31	58.50	82
	Strength exercises	25	27.20	15	28.30	40
Specific	Technical exercises	52	64.20	39	78.00	91
	Free throws	31	38.30	17	34.00	48
	SSG	19	23.50	9	18.00	28

Regarding the WU intensity, no significant associations were found in the general phase between competitions ($p = 0.155$; $V = 0.160$), with coaches typically using moderate intensities (Table 6). Also, no significant associations were found on the WU intensity at the specific phase

between competitions ($p = 0.636$; $V = 0.114$), with coaches mostly using moderate to vigorous intensities on their tasks (Table 6).

Table 6: WU Intensity in general and specific phases structured

	WU intensity	Youth	%	Performance	%	Total	%
General	55-70%	59	64.10	35	66.00	94	64.80
	70-90%	12	13.00	2	3.80	14	9.70
	Self-controlled	21	22.80	16	30.20	37	25.50
Specific	55-70%	29	35.80	19	38.00	48	36.60
	70-90%	39	48.10	23	46.00	62	47.30
	+90%	5	6.20	1	2.00	6	4.60
	Self-controlled	8	9.90	7	14.00	15	11.50

Regarding RWU strategies after prolonged rest periods, 41.77% of coaches do not implement RWU protocols for substitutes. No significant associations were found between coaches ($p = 0.796$; $V = 0.021$). Also, no associations were observed between coaches at youth or performance competitions that use RWU strategies ($p = 0.768$; $V = 0.131$). The majority of the coaches that use RWU (66.70%) reported 2 to 3 minutes of RWU before player substitutions (Figure 5). In contrast, only 25.90% of coaches reported not programming RWU activities at HT, but no significant association was observed between coaches of youth and performance competitions in HT RWU strategies ($p = 0.057$; $V = 0.151$). When HT RWU was applied, the duration was mostly 5 minutes (Figure 5), with no significant associations between coaches of youth and performance competitions ($p = 0.332$; $V = 0.197$).

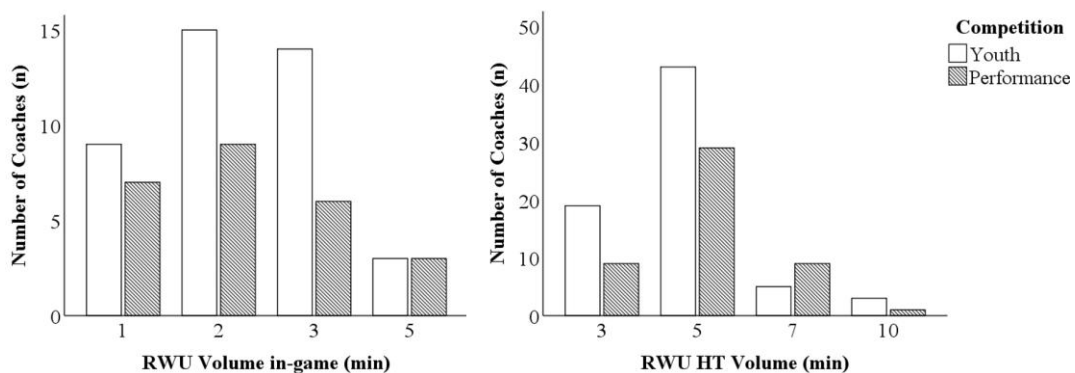


Figure 5: Overview of RWU volume structured by the coach's competition.

Concerning the tasks for RWU in-game, our results indicated that coaches of youth and performance competitions use mostly explosive tasks, while for the HT break, coaches in both competitions use mostly technical exercises.

Table 7: The three most represented RWU tasks structured

RWU Tasks		Youth	%	Performance	%	Total
In-game	SAQ exercises	9	34.60	8	32.00	17
	Sprints	8	30.80	6	24.00	14
	Jump exercises	6	23.10	5	20.00	11
HT	Technical drills	18	69.20	29	60.40	47
	Jogging	9	34.60	13	27.10	22
	SSG	2	7.70	9	18.80	11

Furthermore, there were no significant associations in the intensity of the RWU tasks of youth or performance coaches during the game ($p = 0.349$; $V = 0.223$), with the majority of coaches opting for moderate or vigorous intensity (Table 7), neither in HT RWU tasks ($p = 0.416$; $V = 0.155$), with mostly using moderate intensities (Table 8).

Table 8: RWU Intensity structured by the coach's competition.

RWU Intensity		Youth	%	Performance	%	Total	%
In-game	55-70%	15	36.60	8	32.00	23	34.80
	70-90%	14	34.10	12	48.00	26	39.40
	+90%	4	9.80	0	0.00	4	6.10
	Self-Controlled	8	19.50	5	20.00	13	19.70
HT	55-70%	42	59.20	24	50.00	66	55.50
	70-90%	13	18.30	15	31.30	28	23.50
	+90%	1	1.40	1	2.10	2	1.70
	Self-Controlled	15	21.10	8	16.70	23	19.30

Discussion

This study analyzed the WU and RWU strategies of basketball coaches in youth and performance competitions. Specifically, coaches in performance competitions used more complex WU routines, including higher volumes and additional phases, compared to coaches in youth competitions. Despite its importance, the RWU is often neglected, especially during in-game. Our results showed no associations in RWU practices between youth or performance competitions, with durations ranging from 1 to 3 minutes during the game and 5 minutes at HT, primarily at moderate to vigorous intensities.

The multiphase WU, which includes general and specific phases, is predominantly used by coaches of performance teams. This structured approach, characterized by greater WU volume, reflects a strategic emphasis on comprehensive player preparation to improve performance and reduce injury risk. This is consistent with previous research indicating that experienced coaches

prioritize a holistic preparation strategy that addresses physical, mental, strategic, and neuromuscular aspects to optimize pre-competition readiness (Räisänen et al., 2021). Multiphase WU are tailored to the specific needs of the sport and the athlete (Silva et al., 2018). They enhance game readiness, muscle memory, and technical precision, which are crucial for executing complex in-game movements (Ferioli et al., 2020).

However, there are disadvantages to prolonged WU, such as potential depletion of energy stores and reduced heat storage capacity, which could impair explosive performance (Silva et al., 2018). In contrast, our findings suggest that youth team coaches generally implement shorter WU with fewer phases and moderate intensities. While this approach effectively increases body temperature and prepares athletes for sport-specific movements, it may not adequately prepare players for the higher demands of competitive basketball, potentially reflecting a gap between current evidence-based practices and WU routines used in youth settings (Räisänen et al., 2021).

Following WU, physiological measures such as core temperature, heart rate, and muscle temperature begin to decline and return to baseline within approximately 6 minutes, and performance levels are nearly back to baseline within 17 minutes (Crowther et al., 2017; Silva et al., 2022). To counteract these declines, a well-designed transition period using passive WU strategies can mitigate potential performance losses and improve player readiness for the game (Cowper et al., 2024). Our study found that only 39% of coaches implement an in-game RWU protocol, typically lasting 1–3 minutes at moderate to vigorous intensity. Research supports that 2 minutes of active RWU, including explosive tasks at maximum intensity, immediately prior to re-entering the game is critical to maintaining performance levels (Silva et al., 2018). Conversely, RWU is more routinely practiced during the HT break, with 70% of coaches performing approximately 5 minutes of moderate-intensity RWU. Integrating passive strategies during this break has been shown to offset the negative effects of inactivity, thereby improving explosive performance and reducing the likelihood of early fatigue in the second half (González-Devesa et al., 2021).

A notable limitation of this study is the uneven distribution of coaches surveyed, with fewer coaches from performance competitions. This may limit the generalization of the findings, particularly for high-performance coaching contexts. A more balanced sample could reveal greater associations in practices between coaches.

Further research should also analyze additional factors, such as the sporting level of the coaches, specific routines employed, and adaptability to different environmental conditions throughout the season. This may provide deeper insights into the WU and RWU routines employed by the coaches.

Conclusions

This study identifies key differences in WU practices between youth and performance-level coaches, highlighting the need for more structured RWU strategies, especially during games. Coaches in the performance context generally implement more comprehensive WU strategies characterized by increased volume and multiple phases, while coaches of youth competitions implement less WU volume and phases. Nevertheless, it is notable that RWU is often overlooked by coaches of youth and performance competitions, especially during games, and is primarily addressed during HT. Effective WU and RWU are critical to improving player performance and should be carefully planned to meet the specific needs of different competitions.

Study 3. Short post-warm-up transition times are required for optimized explosive performance in team sports

Abstract

This study aimed to compare the effect of 3 different post-warm-up transition times (3, 10, and 17 minutes) on team sports performance. A randomized crossover research design was used. Fourteen university male basketball players completed the same 10-minute warm-up followed by a transition time of 3, 10, or 17 minutes until the performance assessment. In the control condition, no warm-up was performed. The performance was measured using the repeated sprint and jump ability test. Performance variables (time, jump height, and peak power) and physiological variables (lactate and tympanic temperature) were analyzed. Moderate effects were found between conditions for the best first 12.5-m sprint ($F = 1.91$, $p = 0.17$, $\eta^2_p = 0.13$), with faster times after 3-minute transition (control: 2.51 ± 0.12 vs. 3 minutes: 2.41 ± 0.15 , $p = 0.02$, effect size [ES] = 0.74). Jump heights were higher after transitions of 3 minutes (38.55 ± 5.07 cm, $p < 0.01$, ES = 0.58), 10 minutes (37.69 ± 4.92 cm, $p < 0.01$, ES = 0.40), and 17 minutes (37.87 ± 5.33 cm, $p < 0.01$, ES = 0.42) compared with the control condition (35.84 ± 4.18 cm). However, no significant differences were found between resting conditions. The warm-up caused a moderate increase in lactate and temperature compared with no activity ($F = 11.90$, $p < 0.01$, $\eta^2_p = 0.48$; $F = 2.56$, $p = 0.07$, $\eta^2_p = 0.16$, respectively), but changes from preperformance to postperformance evaluation showed no differences between experimental conditions. The results showed that the warm-up maximized the performance of explosive efforts. However, no significant differences were found between transition times. Despite a trend toward optimized explosive performances after a short post-warm-up transition time (3 minutes), further research is needed.

Keywords: basketball, priming exercise, short-term effort, rest frame, warm-up exercise

Introduction

During competitions, athletes perform different warm-up routines aiming to achieve maximal performance, benefiting from several neuromuscular, metabolic, and psychological changes (Bishop, 2003a; Kilduff et al., 2013; Neiva et al., 2014; McGowan et al., 2015; Silva et al., 2018). The effectiveness of the warm-up routine seems to be dependent on many factors, such as the type of sport (McGowan et al., 2015), the athlete's fitness and training experience (Seitz et al., 2014), the tasks to be performed (Bishop, 2003b; Silva et al., 2018), and the environmental conditions (Silva et al., 2018). Moreover, there are other constraints imposed by the organizers of the events, such as long transition periods between the end of the warm-up and the start of the competition (Silva et al., 2018). Therefore, the warm-up must be designed for the specific needs of both the athlete and the sport (Jeffreys, 2007).

Most studies examining the effect of different warm-ups focus on several specific aspects of the warm-up (duration, rest, tasks, and intensity) implemented in individual modalities (e.g., Tomaras & MacIntosh, 2011; Neiva et al., 2015, 2017; Marinho et al., 2017; Gil et al., 2021). For instance, performances were optimized in cycling (Tomaras & MacIntosh, 2011) and swimming (Neiva et al., 2015) with a short warm-up duration or reducing post-warm-up passive rest from 20 to 10 minutes (Neiva et al., 2017). In specific explosive activities, such as sprinting or jumping, warm-up specific tasks influenced sprint running (Gil et al., 2021) and jumping (Andrade et al., 2015) with remarkable positive results. Researchers have recently found that in general, for explosive efforts, the warm-up should last 10-15 minutes, be progressive in intensity (~50–90% maximal heart rate [HR_{max}]), prepare for sport-specific tasks, and finish with tasks of maximum intensity (~90% HR_{max}) (Silva et al., 2018). Moreover, acute positive effects on jumping performance after warm-up can be maintained after long recovery periods (e.g., 6 hours after warm-up), particularly when previous high-intensity dynamic actions were performed (Saez Saez de Villarreal et al., 2007). However, sports usually have a transition phase that follows the end of the warm-up and precedes the start of the competition (Kilduff et al., 2013). After the cessation of the warm-up, the body temperature declines to near baseline after 15–20 minutes of recovery (Faulkner et al., 2013; Neiva et al., 2017). Thus, the warm-up benefits could be lost during transition phases, and they should be considered a critical component in the warm-up strategy (Silva et al., 2018).

In the past decade, some studies have tried to better understand the effect of transition times between warm-up and subsequent individual sports performance, mostly in swimming and specific anaerobic assessments (Poprzęcki et al., 2007; West et al., 2013; Neiva et al., 2017). Reducing the post-warm-up transition time from 20 to 10 minutes resulted in a 1.1% improvement in 100-m freestyle (Neiva et al., 2017). As well, 1.5% improvement was found in 200-m freestyle when the transition time was reduced from 45 to 20 minutes (West et al., 2013). Nevertheless, the 30-second Wingate test performance was similar when preceded by a 15-minute or a 5-minute rest after the warm-up (Poprzęcki et al., 2007). However, only a few studies have focused on the transition times and their effect on performance, and some

contradictory results have been reported (Poprzęcki et al., 2007; Alikhajeh et al., 2011). Research found that a 5- or 15-minute interval did not affect either anaerobic power or acid-base variables (Poprzęcki et al., 2007). On the contrary, it was reported that 5-minute rest was better than a 15-minute rest for sprint performance in young soccer players (Alikhajeh et al., 2011).

Previous findings indicated that a recovery period between 5 and 20 minutes allows an optimal balance between phosphocreatine restoration and muscle potentiation (Dawson et al., 1997; Silva et al., 2018; Blazevich & Babault, 2019). Moreover, it seems that this time interval helps to prevent a decrease in muscle temperature and thus maintain the positive effects of the warm-up (Burnley et al., 2005; Neiva et al., 2017). Muscle temperature could drop about 2° C during the 15-minute half-time break in a soccer match and result in decreased sprint performance (Mohr et al., 2004). The authors suggested that the decrease in body temperature probably affected the neural transmission rate and speed of muscle contraction rate because of adenosine triphosphate (ATP) availability in the nervous system and muscles (Mohr et al., 2004). In addition, it seems that resting time negatively affects muscle stiffness (Alberti et al., 2014), and other physiological responses to warm-up, such as heart rate and oxygen uptake (Neiva et al., 2017). Thus, it seems that the physiological responses to warm-up that could optimize performance could be compromised with transition time after warm-up.

The role of the transition time could be even more highlighted in team field sports, where the warm-up can be completed long before the game. For instance, in soccer, the transition period between the end of the warm-up and the kick-off averages to 12.4 ± 3.8 minutes (Towlson et al., 2013). In other sports, such as basketball, the game starts almost immediately after the warm-up period. However, substitute athletes must wait some time before entering the game. The first substitution usually happens between 6 and 12 minutes after the start of the game (Alberti et al., 2014). This waiting time could be harmful to the preparedness of the athletes and could compromise their performance. It has been reported that a resting time among basketball players resulted in rapid decreases in temperature and performance, and sprinting and jumping declined by 5 and 13%, respectively (Kilduff et al., 2013). However, to the best of our knowledge, no previous research has attempted to further understand the practical consequences of the different times that an athlete may be subjected to after warming up and before entering the game in team sports. Therefore, the current study aimed to compare the effect of 3 different post-warm-up transition times (3, 10, and 17 minutes) on team sports performance. The primary outcomes were performance-related variables (sprint time, repeated sprint times, jumping performance, and peak power), and the secondary outcomes were physiological variables (blood lactate: [La-] and tympanic temperature). It was hypothesized that a shorter transition rest time (3 minutes) would result in a better explosive performance.

Methods

Experimental Approach to the Problem

A randomized crossover research design was used to compare the effect of different post-warm-up transition times before the main performance. The independent variable was the transition time. The performance-related dependent variables were first sprint best (FS_{best}), repeated sprint best (RS_{best}) and mean (RS_{mean}), repeated jump best (RJ_{best}), repeated jump mean (RJ_{mean}), percent of decrement in sprint (RS_{dec}), jump (RJ_{dec}), and peak power (PP). The metabolic dependent variables ([La-] and tympanic temperature) were used to better understand the potential effects of transition time in performance-related variables. The tympanic temperature could be used as an indicator of brain temperature, which controls body temperature (Nimah et al., 2006). Moreover, [La-] is commonly used as a practical method of estimating acid-base status and metabolic contributions during high-intensity exercise (Theofilidis et al., 2018). Both variables are usually monitored in warm-up-related studies as secondary outcomes (Tomaras & MacIntosh, 2011; Neiva et al., 2015; Marinho et al., 2017).

Each subject completed a standard warm-up that was designed based on previous recommendations (Silva et al., 2018). In the control condition, no warm-up was performed before the assessment. After the warm-up, each subject remained seated, resting for 3, 10, or 17 minutes before the maximal performance assessment. Each post-warm-up transition time and control condition were evaluated in a randomized order, separated by 48 hours. The post-warm-up transition time was set according to research reporting that the recovery interval after warm-up should not last more than 15–20 minutes to provide the greatest ergogenic effect on short-term performance (Bishop, 2003b; Blazevich & Babault, 2019). Furthermore, literature identified a post activation potentiation enhancement between 3 and 12 minutes, depending on the level of subjects (Seitz et al., 2014). This effect takes some time to appear (6–10 minutes), and it might last for more than 15 minutes (Blazevich & Babault, 2019). Considering these facts and knowing that the game does not start immediately after warm-up, 3-minute (short), 10-minute (intermediate), and 17-minute (long) transition times were defined for comparison. This design was able to test the effect of warming up followed by different transition times on intermittent explosive performance. The investigation protocol consisted of 4 testing sessions scheduled on different days (with 4 conditions assessed for each subject).

Subjects

Fourteen university male basketball players aged 18–25 years volunteered to participate in this study (age 21.36 ± 4.42 years; height 1.80 ± 0.08 m; body mass 75.82 ± 8.43 kg; and basketball training experience 10 ± 2.18 years; $\pm SD$). All subjects were asked to report any previous illness, injury, or other physical issues that would hinder their performance. The eligibility criteria were being healthy and injury-free, aged between 18 and 30 years, and having more than 2 years of experience competing at the university level. Subjects were excluded if there was evidence of an orthopedic or medical problem or another self-reported issue that could endanger their own

health. The subjects were informed about the study procedures, and they signed a written informed consent form. The investigation was conducted at the end of the season and in accordance with the Declaration of Helsinki and was approved by the University of Beira Interior Research Ethics Committee.

Procedures

The experiments were performed for 4 weeks, and all the procedures took place at the same time of the day (8:00 PM) for each subject under the same environmental conditions ($\sim 22^{\circ}$ C air temperature and $\sim 60\%$ humidity) in an indoor sports hall. The subjects were familiarized with the warm-up procedures 1 week before the experiments. They were reminded to maintain the same training, recovery and diet routines, avoid strenuous exercise, and abstain from smoking and consuming caffeine during the assessment days. After arriving at the sports hall, each subject remained seated for 5 minutes, and their baseline measurements of tympanic temperature (Braun ThermoScan IRT 4520, Kronberg, Germany) and blood lactate concentration ([La⁻]; Lactate Pro LT 1710; Arkray Inc., Kyoto, Japan) were taken (Marinho et al., 2017; Gil et al., 2020). Each volunteer was then randomly assigned to a warm-up protocol.

Warm-up Protocols. The subjects performed a standardized 10-minute warm-up followed by different transition times until the performance trial: (a) control condition (CC) (no activity during the 10-minute warm-up), (b) warm-up followed by 3 minutes of transition time (T3), (c) warm-up followed by 10 minutes of transition time (T10), and (d) warm-up followed by 17 minutes of transition time (T17). In each session, the subjects were randomly allocated to 1 of the 4 conditions, and each subject performed all the conditions.

The same warm-up was performed in all the assessed conditions, which lasted for 10 minutes. Based on the previous recommendations (Silva et al., 2018), a two-phase warm-up was structured (Table 9), comprising 5 minutes of neuromuscular activation and 5 minutes of task-specific activities related to intermittent team sports. The initial 5 minutes of the warm-up was divided into a 2-minute dynamic stretch and 3 minutes of speed, agility, and quickness (SAQ) drills aiming for improvements in neuromuscular control, efficiency, range of motion, and decreased injury risk (Marinho et al., 2017; Herman et al., 2012; Yap et al., 2000). Then, the players were divided into 2 teams, playing 3 minutes of a passing small-sided game (SSG) between them, aiming to provide high and brief intense movements, with techniques and tactics that can replicate game-like scenarios (Hill-Haas et al., 2011). To end the warm-up, the subjects performed a 2-minute post activation potentiation (PAP) task, divided into 4 sprints of 15 m each with a 25-second recovery in between, aiming to increase the excitability of speed-contracted units (Guinoubi et al., 2015). After the warm-up, each player remained seated during the transition time (T3, T10, or T17) without knowing how long they would rest.

Table 9: Active warm-up protocol.*

	Neuromuscular activation		Task-specific activities	
	Dynamic stretch	SAQ	Specific sport task	PAP
Volume	2 min	3 min	3 min	2 min
Intensity (PME)	65-75%		75%-85%	86-95%
Task	30-s each: Spiderman w/rot. Frankenstein Side lunge w/reach Air squat	20-s 3 count drill 10-s Arm drill 2x Lean Fall Run 2 rounds: LEFT drill: 15s Line Scissors 15s Pogo jumps	4 vs. 4 game: Teams must complete 30 passes. Each player is permitted one dribble per possession. Changes of possession occur for every violation or unassertive play.	4 x 15-m sprint, 25s recovery

*SAQ = speed, agility, and quickness; PAP = postactivation potentiation; PME = perceived maximal effort; w/ = with; rot = rotation; m = meters

Performance Variables. The performance was measured using the repeated sprint and jump ability test (Buchheit et al., 2010). The test protocol is reliable and valid to measure the repeated explosive efforts commonly performed in team sports (Buchheit et al., 2010). The test consisted of 3 maximal shuttle sprints comprising 2 x 12.5 m (~5 seconds) departing every 25 seconds. During the recovery between sprints (~20 seconds), the athletes decelerate, and after stopping, they performed a countermovement jump (CMJ) with hands on the hip and then an active recovery (covering 36 m ~ running at 2.1 m·s⁻¹). Sprint performances were recorded by photocell timing gates (Brower photocells, Wireless Sprint System, Draper, UT) and the jumping performance with OptoJump Next System (Microgate, Bolzano, Italy).

The test circuit (Figure 6) was performed 3 consecutive times. The data used for further analysis comprised FS_{best}, RS_{best}, RS_{mean}, and RS_{dec} for sprint performance and RJ_{best}, RJ_{mean}, RJ_{dec}, and PP for jump performances. The FS_{best} was considered the best first initial sprint time out of the 3 times that it was performed. The RS_{mean} was the mean value from the 3 times that the repeated sprint (sprint to the cone and return to the starting point) was performed during the test. The RS_{dec} was calculated as $([\text{mean sprint time}/\text{best sprint time} \times 100] - 100)$. Regarding the jumping assessments, the best repeated jump height (RJ_{best}) was obtained from the best value during the jump. In each RSA trial, 1 jump was performed, and the mean repeated jump height (RJ_{mean}) was considered from the mean value of the 3 jumps performed during the test. Then, the PP of the jump was calculated as being $(\text{jump [W]} = (60.7 \times \text{height [cm]}) + (45.3 \times \text{body mass [kg]}) - 2055)$, and jump height percent of decrement (RJ_{dec}) was calculated as $(100 - [\text{mean jump}/\text{best jump} \times 100])$ (Buchheit et al., 2010).

Physiological Variables. Capillary blood samples for [La-] assessment and tympanic temperature measures were collected before the warm-up, immediately before the performance test (1 minute before), and after the performance evaluation (1 and 3 minutes). The higher

values obtained after the performance evaluation were considered for further analysis. Each tympanic temperature was taken 3 times, and the maximal value was recorded. The thermometers had a measuring accuracy of 0.2° C for temperatures between 32.0 and 42.0° C.

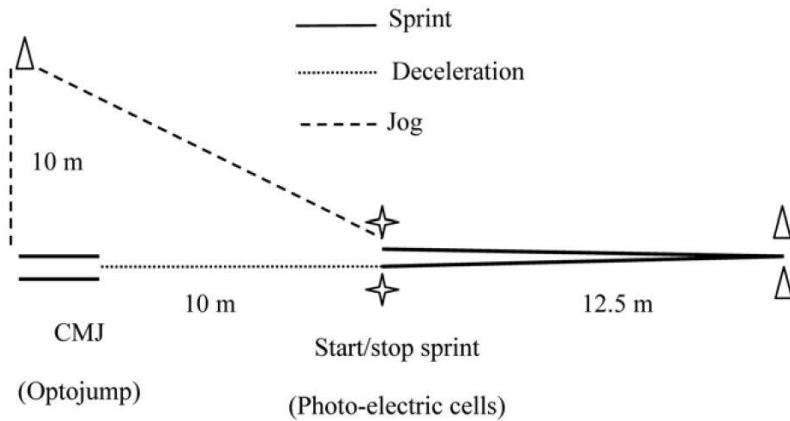


Figure 6: Diagram of the sprint and jump repeated sprint and jump ability test. CMJ = countermovement jump.

Statistical Analyses

Standard statistical methods were used for the calculation of mean \pm *SD* and 95% confidence intervals for all variables. The normality of all distributions was verified using Shapiro-Wilk tests. Data for all the analyzed variables were homogeneous and normally distributed. The effect of the warm-up procedure was analyzed by an analysis of variance for repeated measures, with sphericity checked using Mauchly's test. When the assumption of sphericity was not met, the significance of F-ratios was adjusted according to the Greenhouse-Geisser procedure. The effect size was calculated to estimate variance between conditions (partial eta-squared: η^2_p) and the Hedges' *g* (effect size [ES]) for within subject comparisons. The interpretation of the ES was deemed as small when 0.2, medium when 0.5, and large when 0.8, and for the η^2_p , cutoff values were interpreted as 0.01 for small, 0.09 for moderate, and 0.25 for large (Cohen, 1988). The level of statistical significance was set at alpha $p < 0.05$. All statistical data treatment was performed using the Statistical Package for Social Sciences (IBM SPSS Statistics for Windows, Version 27.0. Armonk, NY: IBM Corp).

Results

Table 10 presents the values recorded after each warm-up condition. Although the sprint and jump performances were optimized in all the warm-up experimental conditions, it was the 3-minute transition time that showed the best overall mean results (Table 11).

Table 10: RSJAT performance after warm-up transition time presented in mean \pm SD.*

Variable	Control	3 min	10 min	17 min
FS _{best} (s)	2.51 \pm 0.12	2.41 \pm 0.15	2.48 \pm 0.11	2.49 \pm 0.18
RS _{best} (s)	5.28 \pm 0.19	5.24 \pm 0.24	5.23 \pm 0.19	5.24 \pm 0.21
RS _{mean} (s)	5.39 \pm 0.22	5.33 \pm 0.23	5.31 \pm 0.19	5.30 \pm 0.20
RS _{dec} (%)	2.08 \pm 1.3	1.73 \pm 1.13	1.64 \pm 1.09	1.16 \pm 0.99
RJ _{best} (cm)	35.84 \pm 4.18	38.55 \pm 5.07	37.69 \pm 5.1	37.87 \pm 5.33
RJ _{mean} (cm)	35.02 \pm 4.29	37.91 \pm 5.04	37 \pm 4.92	37.04 \pm 5.36
RJ _{dec} (%)	2.34 \pm 1.2	1.68 \pm 0.48	1.8 \pm 0.64	2.24 \pm 1.05
PP (w)	3529.77 \pm 310.72	3717.11 \pm 314.92	3665.08 \pm 362.8	3675.92 \pm 306.83

*RSJAT = repeated sprint and jump ability test; FS_{best} = first sprint best; s = seconds; cm = centimeters; RS_{best} = repeated sprint best; RS_{mean} = repeated sprint mean; RS_{dec} (%) = repeated sprint decrement (%); RJ_{best} = repeated jump best; RJ_{mean} = repeated jump mean; RJ_{dec} (%) = repeated jump decrement (%); PP = peak power.

Moderate variations between conditions were found in the FS_{best} ($F = 1.91$, $p = 0.17$, $\eta^2_p = 0.13$), RS_{mean} ($F = 1.61$, $p = 0.20$, $\eta^2_p = 0.11$), and RS_{dec} ($F = 1.71$, $p = 0.18$, $\eta^2_p = 0.12$), and only small variations were found in the RS_{best} ($F = 0.90$, $p = 0.45$, $\eta^2_p = 0.06$). Regarding the jumping performances, large variations were observed in RJ_{best} ($F = 7.39$, $p < 0.001$, $\eta^2_p = 0.36$), RJ_{mean} ($F = 7.68$, $p < 0.001$, $\eta^2_p = 0.37$), and PP ($F = 9.79$, $p < 0.001$, $\eta^2_p = 0.43$) and moderate variations in RJ_{dec} ($F = 2.13$, $p = 0.11$, $\eta^2_p = 0.14$). The warm-up showed effectiveness in all experimental conditions, particularly in FS_{best}, RJ_{best}, RJ_{mean}, and PP.

Table 11: Comparison between control (no WU) and warm-up with time transition (differences, p values, and effect sizes).*

Variable	Control vs. 3 min			Control vs. 10 min			Control vs. 17 min		
	Mean change; $\pm 95\%$ CI	p	ES	Mean change; $\pm 95\%$ CI	p	ES	Mean change; $\pm 95\%$ CI	p	ES
FS _{best} (s)	0.10 \pm 0.08	0.02	0.74	0.03 \pm 0.04	0.10	0.26	0.02 \pm 0.12	0.65	0.13
RS _{best} (s)	0.04 \pm 0.09	0.32	0.18	0.06 \pm 0.08	0.14	0.26	0.04 \pm 0.08	0.25	0.20
RS _{mean} (s)	0.06 \pm 0.12	0.27	0.27	0.08 \pm 0.11	0.14	0.39	0.09 \pm 0.09	0.05	0.43
RS _{dec} (%)	0.35 \pm 1.08	0.49	0.29	0.44 \pm 0.94	0.34	0.37	0.92 \pm 0.95	0.05	0.80
RJ _{best} (cm)	-2.71 \pm 1.50	<0.01	0.58	-1.86 \pm 1.16	<0.01	0.40	-2.04 \pm 1.27	<0.01	0.42
RJ _{mean} (cm)	-2.89 \pm 1.61	<0.01	0.62	-1.98 \pm 1.14	<0.01	0.43	-2.02 \pm -1.36	0.01	0.42
RJ _{dec} (%)	0.66 \pm 0.74	0.08	0.72	0.53 \pm 0.79	0.17	0.56	0.09 \pm 0.72	0.78	0.09
PP (w)	-187.33 \pm 91.32	<0.01	0.60	-135.31 \pm 70.81	<0.01	0.40	-146.14 \pm 77.82	<0.01	0.47

*CI = confidence interval; p = p value; ES = effect size; FS_{best} = first sprint best; s = seconds; RS_{best} = repeated sprint best; cm = centimeters; RS_{mean} = repeated sprint mean; RS_{dec} (%) = repeated sprint decrement (%); RJ_{best} = repeated jump best; RJ_{mean} = repeated jump mean; RJ_{dec} (%) = repeated jump decrement (%); PP = peak power.

Despite no significant differences being found between the transition times (Table 12), greater values of ES were found when comparing T3 with the T17, specifically in FS_{best} , RJ_{mean} , RJ_{dec} , and RJ_{mean} , with better performances being accomplished with a shorter transition time.

Table 12: Comparison between warm-up transition times (differences, p values, and effect sizes).*

Variable	3 vs. 10 min			3 vs. 17 min			10 vs. 17 min		
	Mean change; ±95% CI	p	ES	Mean change; ±95% CI	p	ES	Mean change; ±95% CI	p	ES
FS_{best} (s)	-0.07 ± 0.08	0.09	0.53	-0.07 ± 0.10	0.15	0.48	0.00 ± 0.11	0.94	0.07
RS_{best} (s)	0.02 ± 0.04	0.48	0.05	0.00 ± 0.10	0.99	0.00	-0.02 ± 0.08	0.69	0.05
RS_{mean} (s)	0.02 ± 0.06	0.53	0.09	0.03 ± 0.10	0.56	0.14	0.01 ± 0.10	0.83	0.05
RS_{dec} (%)	0.08 ± 0.56	0.75	0.08	0.57 ± 0.75	0.13	0.54	0.49 ± 0.94	0.29	0.46
RJ_{best} (cm)	0.86 ± 1.50	0.24	0.17	0.68 ± 0.99	0.16	0.13	-0.18 ± 1.33	0.78	0.03
RJ_{mean} (cm)	0.91 ± 1.48	0.21	0.18	0.87 ± 1.00	0.08	0.17	-0.04 ± 1.41	0.95	0.01
RJ_{dec} (%)	-0.12 ± 0.36	0.47	0.21	-0.56 ± 0.62	0.07	0.69	-0.44 ± 0.72	0.21	0.51
PP (w)	52.03 ± 91.03	0.24	0.15	41.19 ± 60.25	0.16	0.13	-10.84 ± 80.49	0.78	0.03

*CI = confidence interval; s = seconds; p = p value; ES = effect size; FS_{best} = first sprint best; RS_{best} = repeated sprint best; RS_{mean} = repeated sprint mean; RS_{dec} (%) = repeated sprint decrement (%); RJ_{best} = repeated jump best; cm = centimeters; RJ_{mean} = repeated jump mean; RJ_{dec} (%) = repeated jump decrement (%); PP = peak power.

The warm-up immediately caused an elevation of [La-] values compared with no activity ($F = 11.90$, $p < 0.01$, $\eta^2_p = 0.48$). As expected, higher [La-] values were observed after T3 (Figure 7). The acute [La-] response to the evaluation test was higher in the control group (3.68 ± 1.69 mmol·L⁻¹) than in T3 (2.15 ± 1.53 mmol·L⁻¹; $p = 0.04$, ES = 0.69). Despite no differences being found between the experimental conditions (3, 10, and 17 minutes), lower increases in [La-] values from before to after performance were observed in the T3 (Figure 7).

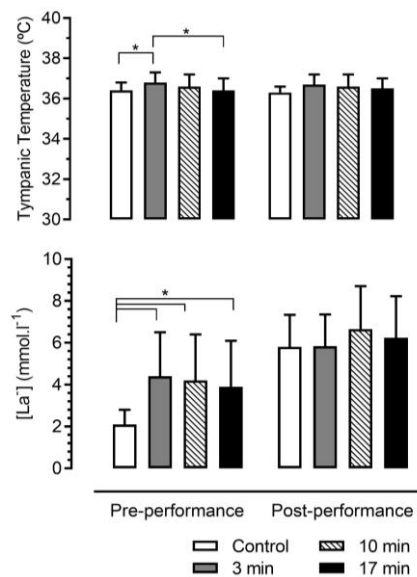


Figure 7: Blood lactate concentration [La-] and tympanic temperature recorded after transition time (before performance) and after trial evaluation (after performance), in the conditions evaluated. *p < 0.05.

There was a moderate effect regarding transition times on the measured temperature before the performance assessments ($F = 2.56$, $p = 0.07$, $\eta^2_p = 0.16$). These findings were the result of the lower values observed in the CC compared with the T3 and the lower values of 17 minutes vs. 3 minutes. Changes from the preperformance to postperformance evaluation showed no differences between groups. Nevertheless, the shorter transition (3 minutes) showed a trend toward a decrease in temperature ($0.15 \pm 0.40^\circ \text{C}$) compared with the increased values ($0.09 \pm 0.44^\circ \text{C}$) obtained in longer transition time (17 minutes, $p = 0.08$, $ES = 0.52$).

Discussion

We sought to compare the effect of 3 different post-warm-up transition times (i.e., 3, 10, and 17 minutes) on repeated explosive efforts. The warm-up promoted a significant improvement in explosive performance after a 3-, 10-, or 17-minute transition time, compared with no warm-up. Despite no significant differences being found between resting conditions (T3 vs. T10 vs. T17), there was a tendency for a drop in performance with the increase in transition time. Overall, a 3-minute rest between the warm-up and the performance presented the best results. Under this condition, the sprint was approximately 4% faster, and the jumping was approximately 8% higher than without warm-up. A 10- and 17-minute transition times were sufficient to mitigate the difference found for CC in sprint performance. Still, the positive effects of warm-up in jumping performance were found after 10 minutes or 17 minutes of transition time.

It has been suggested that the benefits of active warm-ups are mainly attributed to increases in muscle and core temperature caused by priming exercises, which are the main factors that influence performance (Bishop, 2003b). After warming up, the temperature was higher in the T3, which could have influenced the performance. An increase in the athlete's temperature results in a lower time required to achieve peak tension and relaxation, reduced viscous resistance of the muscles and joints, increased muscle blood flow, improved efficiency of muscle glycolysis and high-energy phosphate degradation, and an increased nerve conduction rate (Febbraio et al., 1996; Bishop, 2003b; Pearson et al., 2011). In a simulated game, it was verified that the performance improvement was related to the increase in body temperature, for which the sprinting and jumping performances seemed to be associated with body temperature changes (Pliauga et al., 2015).

Although temperature could be an important variable to better understand our findings, temperature alone cannot fully explain the acute improvement. The effect may also be explained by the PAP stimulation effect. High-intensity actions activate temperature and metabolic mechanisms that enhance subsequent performance (Blazevich & Babault, 2019). Maximal efforts such as sprints rely on a fast and constant turnover of ATP powered by the phosphocreatine system and anaerobic glycolysis (Turner & Stewart, 2013) and require a warm-up with higher stimulation (i.e., 90% of HR_{max} and a rating of perceived effort at least of 16) (Anderson et al., 2014; Meckel et al., 2019). The warm-up can change the metabolic profile of subsequent exercise by accelerating oxygen uptake (VO_2) kinetics and diminishing the blood

lactate response (Burnley et al., 2005). A warm-up that includes higher intensity exercises promotes an increase in the elevation of baseline VO_2 , an increase in pulmonary perfusion, an increase in oxygen consumption at the muscle level (Nejad et al., 2018), and stimulation of glycolysis, contributing to enhanced performance in anaerobic tasks (Anderson et al., 2014). Thus, a change in VO_2 kinetics under the experimental conditions could have allowed a faster response, enabling a subsequently increased glycolytic contribution and explaining the better performance and lower [La-] peak after the 3-minute transition. In addition, acceleration of overall VO_2 kinetics can occur because of enhanced oxygen delivery associated with increased blood flow to the muscles, which could in turn be associated with an increase in temperature (Pearce et al., 2009).

In the current study, the temperature and performance began to decline with increasing time spent in the transition. A 10-minute rest was sufficient to cause a decline in the sprint and jump performances. In this context, previous research on basketball players found that there was a highly significant decline in tasks that required explosive strength performance just 6 minutes after warm-up (Galazoulas et al., 2012; Alberti et al., 2014; Crowther et al., 2017). These findings were mainly associated with an interruption of activity, a drop in body temperature, and a decrease in plasma glucose concentration. In addition, Alberti et al. (2014) previously reported that sitting on the bench for 20 minutes after the warm-up resulted in significant decreases in the vertical jump (8.5%) and muscle stiffness (10.5%). These authors addressed an interesting finding, which is that the seating position could have a considerably negative effect on the player's performance level compared with standing. This can probably explain the results in our study with the players seated for the T17, which reduced the sprint performance to almost control values. Some events or competition rules require players to be in a seated position for longer transition times before the start of the matches, and this could compromise performance. Even understanding this tendency to drop sprinting and jumping performances with resting time after warm-up, we should not neglect that no significant differences in performance were found between T3, T10, and T17. Thus, further studies are needed to clarify different transition times for short-term performance.

Research on passive post-warm-up strategies showed that passive heat maintenance combined with neuromuscular priming activity prevents an accentuated decline in core temperature, lower-body peak power output, and repeated sprint ability during the post-warm-up recovery period (West et al., 2016). In addition, it was discovered that to maintain the post-warm-up muscle temperature, an increase in the leg temperature from 40 to 43° C is sufficient to virtually eliminate the deep thigh muscle temperature drop during a 30-minute recovery period (Raccuglia et al., 2016). However, research suggests that when transitions last for more than 15 minutes, performing a 2-minute active re-warm-up with explosive tasks is recommended (Silva et al., 2018). The effect of including the use of a second warm-up in post-warm-up transitions seems to be positive (Pearce et al., 2009; Alberti et al., 2014).

Despite the relevance of the results, this study presents some limitations that should be considered. The sample comprised amateur players, and different athletic levels could elicit different adaptations. In addition, a larger sample would achieve clearer conclusions in some of the analyzed variables. Considering our limitations, readers should interpret our results with caution. Our differences between resting conditions could be interpreted as nonmeaningful differences. Even so, practitioners should be aware of the possible decline in short-term performance after 3 minutes of rest. The current findings are relevant for coaches and researchers to increase our knowledge about warming up and its effect on performance. Further research should focus on passive or active methods of resting to maintain the benefits of warm-up (i.e., elevated temperature, heart rate, and VO_2) during the time frame between warm-up and performance, as well as other variables (e.g., VO_2 kinetics, muscle temperature, and nutritional intake), to improve our understanding of the mechanistic phenomenon. Furthermore, it should involve a larger number of subjects, including women, to clarify some of the analyzed findings.

In summary, a significant increase in explosive performance, particularly for jumping performance, was found with warm-up regardless of using 3, 10, or 17 minutes of transition time. Although there were no significant differences between resting conditions, there was a tendency for a drop in sprint performance with the increase in transition time. The longer rests (10 and 17 minutes) revealed no significant differences in sprint performance compared with no warm-up. Moreover, the shorter transition (3 minutes) tended to show the best explosive performances.

Practical Applications

This study highlights the important effect of the transition time after the warm-up on performance. The main findings of the current study indicate that a short transition time (3 minutes) is possible to be the best option to maximize the performance of repeated explosive efforts in team sports. Nevertheless, our findings should be carefully understood by professionals because the differences found between resting conditions could be interpreted as nonmeaningful differences. Coaches and athletes should be aware that an increase in the transition time seems to cause a decline in explosive performance, and it should be considered when planning warm-ups for team sports. The current results provide new insights for sports professionals and researchers to maximize efficiency and optimize performance before the competition.

Study 4. Effects of a Short Re-Warm-Up Protocol on Explosive Performance Following Extended Transition Periods in Team Sports

Abstract

This study investigated the acute effects of a 2-minute plyometric re-warm-up protocol on explosive performance in male basketball athletes following two distinct post-warm-up transition durations (10 and 17 minutes). Thirteen trained male basketball players participated in a randomized crossover design involving four conditions: passive rest or re-warm-up following either a 10- or 17-minute transition period. Performance was assessed using the Repeated Sprint and Jump Ability Test (RSJAT), alongside physiological (blood lactate, tympanic temperature) and psychological (perceived readiness) measures. Statistical significance was set at $p \leq 0.05$. re-warm-up significantly improved sprint (FS_{best} : $p = 0.015$; ES = 0.84; RS_{best} : $p = 0.018$; ES = 0.52; RS_{mean} : $p = 0.008$; ES = 0.57) and jump performance (RJ_{best} : $p < 0.001$; ES = -0.62; RJ_{mean} : $p < 0.001$; ES = -0.47; PP: $p < 0.001$; ES = -0.42) after the 17-minute transition, with performance returning to levels comparable to shorter rest periods. No significant performance differences were observed after the 10-minute transition. Although perceived readiness increased with re-warm-up (10-min: $p = 0.005$; ES = -1.10; 17-min: $p = 0.002$; ES = 1.42). Re-warm-up after 10-minute significantly elevated pre ($p < 0.001$, ES: -1.91) and post ($p < 0.001$, ES: -1.32) performance lactate levels, suggesting enhanced metabolic activation. A brief time-efficient plyometric re-warm-up protocol on extended passive rest of 17-minute transition can mitigate performance decline, particularly in neuromechanically demanding tasks. These findings support the integration of time-efficient re-warm-up strategies during prolonged in-game stoppages to maintain physical and psychological readiness.

Keywords: Collective sports; Basketball; Post-warm-up; Readiness; Plyometric.

Introduction

Before sports competitions, coaches and researchers widely recognize warm-up as fundamental for improving performance (Mason et al., 2022). The main objectives of warm-up are to optimize physical readiness (Silva et al., 2018) and minimize injury risk (Ding et al., 2022). These benefits are primarily attributed to increases in body and muscle temperature (Silva et al., 2018) and adaptations of neurophysiological mechanisms, such as improved motor unit recruitment conduction velocity of muscle fibers and post-activation performance enhancement (PAPE) (Xu et al., 2025). Studies have shown that warm-up strategies improve explosive performance in high-intensity activities, such as sprint (Mohr et al., 2004; van Den Tillaar et al., 2019) and jump (Crowther et al., 2017). Similar improvements have been observed, in high-intensity efforts in intermittent team sports, such as soccer (Mohr et al., 2004; Zois et al., 2013; Silva et al., 2024) and basketball (Meckel et al., 2009; Galazoulas et al., 2012; Crowther et al., 2017). However, despite the immediate benefits of warm-up, a transition period typically occurs between the end of warm-up and the start of competition (Silva et al., 2018), during which athletes may experience a decline in physiological readiness.

In team sports such as soccer, official pre-game protocols often include a passive rest period of 10–15 minutes, which may be extended to 20 minutes in international competitions (D'Onofrio et al., 2024). In basketball, the game starts almost immediately after warm-up, with the first half of a basketball game during approximately 40 min of real time (Galazoulas et al., 2012). In this time frame substitute players may remain inactive for extended periods after warm-up, with substitutions in basketball typically occurring between 9 and 23 minutes after the start of the game (Kapnia et al., 2023). During these transition periods, key physiological parameters such as skin temperature and heart rate begin to decline rapidly, with noticeable reductions occurring within just six minutes after the warm-up (Crowther et al., 2017). The acute benefits of warm-up on performance appear to be highly time-sensitive, and prolonged passive rest may attenuate its positive effects, particularly in terms of explosive actions (Silva et al., 2022). Therefore, it is essential to maintain physiological readiness during these intervals to preserve optimal performance levels (D'Onofrio et al., 2024).

Previous studies have shown that a 10-minute period of inactivity after warm-up can negatively affect sprint performance (Abade et al., 2025). This may be due to reductions in plasma glucose concentration (Galazoulas et al., 2012), impaired motor coordination, and decreased muscle temperature (Abade et al., 2025). Extending the inactive period to 20 minutes has been associated with additional declines in physiological responses, such as reduced heart rate and oxygen uptake (Neiva et al., 2017), decreased muscle stiffness (Alberti et al., 2014), impaired jump performance (Crowther et al., 2017), and poorer technical execution (Kapnia et al., 2023).

Given these results, recent studies have increasingly focused on the role of re-warm-up as a way to reduce performance drops during extended passive transitions (Yanaoka et al., 2020; González-Devesa et al., 2022; Nourshahi et al., 2024; Koutsouridis et al., 2024, 2025; Flórez-Gil

et al., 2025). Most research on re-warm-up strategies have been conducted in specific contexts, particularly during half-time in team sports such as soccer (González-Devesa et al., 2021; González-Fernández et al., 2023) and basketball (Pociunas et al., 2018; González-Devesa et al., 2022). These protocols have shown effectiveness in mitigating declines in explosive performance and have also been explored more recently during short breaks in active play (D'Onofrio et al., 2024; Koutsouridis et al., 2024). While these re-warm-up strategies have shown positive results, their application remains limited in live gameplay due to practical constraints, including restricted time and space, sport-specific rules, limited equipment availability, and the unpredictable nature of competitive environments (Towilson et al., 2013). Therefore, there is a need for time-efficient, adaptable, and ecologically valid re-warm-up protocols that can be realistically implemented in competition (D'Onofrio et al., 2024).

Some re-warm-up strategies, such as short bouts of high- or low-intensity cycling, have been shown to effectively elevate muscle temperature, oxygen uptake, and neuromuscular activation (Yanaoka et al., 2020; Koutsouridis et al., 2024, 2025). Yet, these protocols often rely on stationary equipment, which may be impractical or unavailable in competitive settings. To enhance the ecological validity of re-warm-up interventions, easy-to-execute protocols adapted to the specific demands and constraints of in-game environments. Also, manipulating volume, intensity, and recovery remains critical to enhancing or impairing subsequent performance (Abade et al., 2017). These strategies should preserve key physiological and neuromuscular benefits, such as improved postural control, interlimb symmetry, muscle activation, and the ability to sustain explosive output (González-Fernández et al., 2023).

In this context, Silva et al. (2018) proposed a practical solution for prolonged transition periods: a brief, two-minute re-warm-up protocol involving explosive movements performed at maximum intensity. These exercises, plyometrics, are a practical and accessible strategy for enhancing performance, not requiring additional equipment, and can be easily implemented in competitive environments (Munshi et al., 2022). These were suggested to enhance neuromuscular performance and are effective when integrated into re-warm-up protocols (Abade et al., 2017; Nourshahi et al., 2024; Flórez-Gil et al., 2025; Xu et al., 2025). Also, it was suggested that they can induce PAPE within 30 seconds to 4 minutes after activity, offering a time-efficient way for coaches to enhance performance during transitional periods (Seitz & Haff, 2016; Xu et al., 2025). Brief, high-intensity muscle contractions can also raise muscle temperature by 0.3°C to 0.9°C, potentially leading to performance improvements of up to 10% (Blazevich et al., 2019), while enhancing cognitive function, attention, and decision-making, which are key factors in fast-paced team sports (Nourshahi et al., 2024).

Given these physiological and neuromechanical benefits, an effective re-warm-up protocol likely requires a carefully tailored approach that considers key variables such as duration, task sequencing, intensity, and individual athlete characteristics (Silva et al., 2018). The intensity must be sufficient to stimulate the neuromuscular system and sustain elevated body

temperature, while avoiding excessive fatigue (Koutsouridis et al., 2025). Although various re-warm-up modalities have been studied, there is limited evidence regarding the acute effects of short-duration re-warm-up interventions, particularly those involving plyometric exercises, on repeated explosive performance across different transition periods. To address this gap, the present study aimed to investigate the effects of a 2-minute re-warm-up protocol based on plyometric movements implemented after two distinct post-warm-up transition durations (10 and 17 minutes) on the performance of team sport athletes. Primary outcomes included performance-related measures such as sprint and jump. Secondary outcomes included physiological variables, such as blood lactate concentration ($[La^-]$) and tympanic temperature, as well as psychological indicators of perceived readiness. The hypothesis was that the re-warm-up protocol would meaningfully enhance explosive performance following a prolonged transition period.

Methods

Experimental Approach to the Problem

A randomized crossover design was used to examine the effects of a re-warm-up (RWU) protocol on performance after an extended passive transition period following an initial warm-up. Each participant completed a 10-minute warm-up tailored to improve explosive performance in team sports (Silva et al., 2022). Following the warm-up, participants remained seated for either 10- or 17-minute transition periods chosen based on prior evidence of performance declines within similar time frames (Crowther et al., 2017; Silva et al., 2022; Abade et al., 2025). These durations also reflect real game conditions, particularly in sports such as basketball, where players often remain seated for 9 to 23 minutes before entering the game (Kapnia et al., 2023). Then, participants either performed in each transition time a 2-minute RWU protocol, which included plyometric exercises at maximal perceived intensity (Silva et al., 2018), or remained inactive in the control condition. Following, a 1-minute standing rest period was provided to simulate in-game reentry conditions, during which physiological and psychological measures were collected. Performance was assessed using the Repeated Sprint and Jump Ability Test (RSJAT), a validated protocol designed to assess repeated explosive efforts characteristic of team sports (Buchheit et al., 2010).

The within-subject factors were condition (no RWU vs. RWU) and transition duration of the post-warm-up transition period (10 vs. 17 minutes). The dependent variable was the Repeated Sprint and Jump Ability Test (RSJAT), which included performance-related measures such as first sprint time, repeated sprint performance, repeated jump performance, percentage decrease in sprint and jump performance, and jump peak power. In addition, physiological and psychological outcomes were assessed. Physiological variables included tympanic temperature and blood lactate concentration ($[La^-]$). Although tympanic temperature does not directly measure core body temperature, it was chosen as a practical and non-invasive measure suitable for field-based, and enables monitoring of relative thermoregulatory changes (Nimah et al., 2006). Furthermore, it has been shown to positively correlate with core temperature estimates

obtained from ingestible devices during exercise (Fogt et al., 2017). Blood lactate concentration is widely used to assess acid-base balance and metabolic contributions during high-intensity efforts (Theofilidis et al., 2018). The inclusion of these measures is consistent with previous warm-up related studies and provides relevant insights into physiological and metabolic responses to exercise (Neiva et al., 2015; Marinho et al., 2017; Silva et al., 2022). Psychological responses were assessed using the Perceived Readiness (PR) scale (Karu et al., 2000), which have been used in recent RWU research to better understand athletes' subjective responses to readiness (Koutsouridis et al., 2025).

This design allowed for the assessment of the effects of a RWU strategy on intermittent explosive performance following prolonged transitions before subsequent performance. The study protocol included four test sessions, with four conditions assessed for each subject. Each condition was assessed in a random order.

Subjects

This study included thirteen trained male basketball players from a Portuguese second division team who volunteered to participate (mean \pm SD; age: 22.8 \pm 3.7 years; height: 1.84 \pm 0.06 m; body mass: 81 \pm 9.5 kg; basketball training experience: 9.3 \pm 5.6 years) (McKay et al., 2022). Participants had a weekly schedule of three on-court training sessions (\approx 90 minutes in duration) and one official weekend match. To be eligible, they had to be healthy and uninjured, between 18 and 30 years of age, and have at least 2 years of experience in national competition. Participants were excluded if they had any injuries, medical conditions, or self-reported problems that might affect their health or performance. Also, each player was required to participate in all four conditions. All subjects were informed of the study procedures and provided written informed consent with the assurance that they could withdraw at any time. The research was conducted in accordance with the ethical principles of the Declaration of Helsinki and was approved by the Research Ethics Committee of the University of Beira.

Procedures

The study protocol was conducted over four weeks during the competitive season. All testing sessions were conducted at the same day of the week (Thursday), same time of day (10:00 PM) and under consistent environmental conditions (\sim 20°C air temperature and \sim 60% relative humidity) in an indoor sports hall. One week prior to data collection, participants were familiarized with the RWU protocol and assessments. On each experimental day, participants were divided and randomly assigned to one of the two transition times. Furthermore, they were divided into Control or RWU condition before performance (Figure 8). They were instructed to maintain their usual training, recovery, and dietary routines and to refrain from strenuous exercise, smoking, and caffeine on the test days.

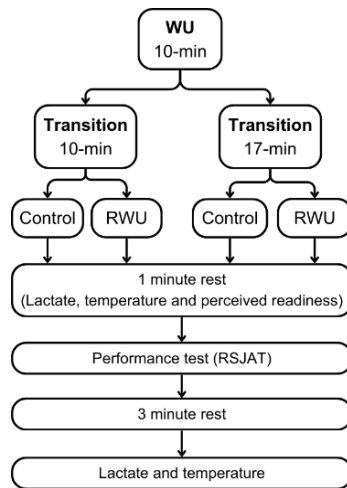


Figure 8: Study flow diagram.

RWU protocol. The protocol was identical for both transition periods and was developed based on previous recommendations (Silva et al., 2018; Staniszewski et al., 2024). As detailed in Table 13, the protocol consisted of three plyometric exercises performed in sequence. Participants performed one set of each exercise for 20 seconds at self-perceived maximal intensity, followed by 20 seconds of passive recovery. This 1:1 work-to-rest ratio was chosen to allow partial recovery between efforts, potentially enhancing adaptations to fatigue, as intermittent exercise has been shown to promote more efficient recovery and improved muscle energy metabolism compared to continuous exercise of the same volume (Staniszewski et al., 2024). Following the RWU, players were given one minute to recover and hydrate in a standing position before beginning the performance test (Blazevich & Babault, 2019).

Table 13: Active RWU Protocol

Volume	2-minutes (1x20-s, with 20-s recovery each exercise)
Intensity	Perceived maximal effort
Task	High Knee Run Plyometric Push-Ups Tuck Jumps

s seconds.

Physiological Variables. Capillary blood samples were collected to assess [La-] and tympanic temperature. For the control group, samples were collected immediately after the transition period; in the RWU groups, samples were collected immediately after the RWU; and for all groups, samples were collected three minutes after performance. This protocol was designed to capture the peak [La-] concentration (Goodwin et al., 2007), with the highest post-exercise values used for analysis. Tympanic temperature was measured twice per evaluation, with the highest recorded value used for analysis, before and after performance. The thermometers used had an accuracy of $\pm 0.2^{\circ}\text{C}$ within the range of 32.0°C to 42.0°C .

Psychological Variable. PR was assessed prior to performance in all conditions using a 5-point scale, with 1 indicating "not at all ready to begin" and 5 indicating "Completely ready to begin" (Karu et al., 2000).

Performance Variables. The RSJAT protocol (Figure 9) consisted of three maximal shuttle sprints, each consisting of 2x12.5m sprints. During the recovery phase, the athletes decelerated, stopped, and performed a countermovement jump (CMJ) with hands on hips, followed by an active recovery. Sprint performance was assessed using photocell timing gates (Brower photocells Wireless Sprint System, Draper, UT), while jumping performance was measured using the OptoJump Next system (Microgate, Bolzano, Italy). The test was performed three consecutive times. The data analyzed included sprint and jump performance variables. For the sprint performance assessment, best first sprint (FS_{best}) was defined as the fastest initial sprint time recorded over the three trials. The repeated sprint mean (RS_{mean}) represented the average sprint time of the three repeated sprints (sprint to the cone and back to the starting point) performed during the test. Repeated sprint decrement (RS_{dec}) was calculated using the following formula: $RS_{dec} = (\text{mean sprint time}/\text{best sprint time} \times 100) - 100$. For the jumping assessments, the best jump (RJ_{best}) was determined as the highest jump height recorded during the repeated jump attempts. The repeated jump mean (RJ_{mean}) was calculated as the average height of the three jumps performed in each trial. Jump peak power (PP) was calculated using the formula: $PP (W) = (60.7 \times \text{jump height (cm)}) + (45.3 \times \text{body mass (kg)}) - 2055$ (Buchheit et al., 2010).

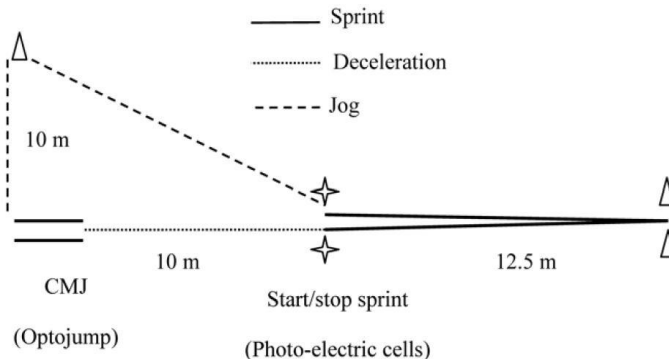


Figure 9: Diagram of the repeated sprint and jump ability test (RSJAT) (Buchheit et al., 2010).

Statistical Analyses

Descriptive statistics for all variables were calculated and are presented as means and standard deviations (SD). The Shapiro-Wilk test was used to verify data normality, and all variables satisfied the assumptions of normality and homogeneity. A two-way repeated-measures ANOVA examined the main effects of transition time (10 vs. 17 minutes) and condition (Control vs. RWU) on performance and perceived readiness, as well as the transition vs. condition interaction. For physiological variables, a three-way repeated-measures ANOVA was conducted, considering transition time, condition, and moment (pre- vs. post-performance) as the within-subject factors. Post hoc pairwise comparisons were performed using Bonferroni adjustments for multiple testing. Statistical significance was set at $\alpha = 0.05$. For the estimation of effect sizes

were calculated partial eta squared (η_p^2), interpreted as small (≥ 0.02), moderate (≥ 0.13), or large (≥ 0.26) (Levine & Hullett, 2002) and Cohen's d , classified as trivial (0.00–0.19), small (0.20–0.59), moderate (0.60–1.19), large (1.20–1.99), very large (2.00–3.99), or extremely large (> 4.00) (Hopkins et al., 2009). All statistical analyses were performed using IBM SPSS Statistics for Windows, Version 30.0 (IBM Corp., Armonk, NY, USA).

Results

Table 14 presents the mean values recorded after each experimental condition.

Table 14: Means and standard deviations of RSJAT performance and perceived readiness across all experimental conditions.

Variable	10C	10R	17C	17R
FS _{best} (s)	2.29 ± 0.11	2.24 ± 0.14	2.32 ± 0.12	2.21 ± 0.14
RS _{best} (s)	4.90 ± 0.23	4.85 ± 0.23	4.92 ± 0.24	4.80 ± 0.26
RS _{mean} (s)	5.00 ± 0.25	4.91 ± 0.24	5.06 ± 0.26	4.92 ± 0.23
RS _{dec} (%)	1.99 ± 1.69	1.23 ± 0.71	2.81 ± 1.28	2.71 ± 1.97
RJ _{best} (cm)	36.13 ± 5.50	36.62 ± 5.36	33.62 ± 5.97	37.72 ± 7.27
RJ _{mean} (cm)	35.02 ± 5.56	35.10 ± 5.63	32.99 ± 6.37	36.16 ± 7.21
RJ _{dec} (%)	3.13 ± 2.03	4.32 ± 2.96	3.48 ± 2.22	4.19 ± 2.00
PP (w)	3813.54 ± 479.51	3840.34 ± 447.95	3684.16 ± 472.50	3905.49 ± 572.69
PR	3.2 ± 0.95	4.19 ± 0.85	2.73 ± 1.33	4.31 ± 0.85
[La-] pré (mmol/L)	2.3 ± 1.03	5.83 ± 2.38	3.79 ± 1.86	7.4 ± 3.403
[La-] post (mmol/L)	6.48 ± 2.60	7.77 ± 2.56	7.51 ± 3.57	9.8 ± 3.83
Temp. pré (C°)	36.5 ± 0.44	36.58 ± 0.44	36.46 ± 0.60	36.43 ± 0.30
Temp. post (C°)	36.38 ± 0.45	36.55 ± 0.41	36.45 ± 0.50	36.54 ± 0.43

C Control; cm centimeters; R re-warm-up; s seconds; w watts; [La-] Lactate; FS_{best} First Sprint best; RS_{best} Repeated Sprint best; RS_{mean} Repeated Sprint mean; RS_{dec}% Repeated Sprint decrement %; RJ_{best} Repeated Jump best; RJ_{mean} Repeated Jump mean; RJ_{dec}% Repeated Jump decrement; PP Peak Power

A two-way repeated-measures ANOVA revealed significant main effects of condition (Control vs. RWU) on sprint and jump performance variables (Table 15). No significant differences in performance were observed between transition durations, except for RS_{dec}%, for which a significant effect was found with time ($F(1, 12) = 7.853$; $p = 0.016$; $\eta_p^2 = 0.396$). Specifically, a longer transition (10R vs. 17R) was associated with a greater sprint decrement, reflecting a substantial negative impact ($F(1, 12) = 10.050$; $p = 0.008$; $\eta_p^2 = 0.456$). In contrast, performance outcomes and athletes' subjective preparedness were significantly better when RWU was performed prior to effort, compared to passive rest. While no significant interaction effects were found between transition time and condition for sprint performance or perceived readiness, significant interaction effects were observed for jump-related performance outcomes (Table 15).

Table 15: Summary of main effects and interaction effects of transition duration (10 min vs. 17 min) and condition (Control vs. RWU) on RSJAT performance and perceived readiness (PR).

Variable	Transition (10 min vs. 17 min)			Condition (Control vs. RWU)			Transition × Condition		
	F (1,12)	p	η_p^2	F (1,12)	p	η_p^2	F (1,12)	p	η_p^2
<i>FS_{best}</i> (s)	0.000	0.990	0.000	10.163	0.008	0.459	2.183	0.165	0.154
<i>RS_{best}</i> (s)	0.193	0.668	0.016	8.195	0.014	0.406	1.845	0.199	0.133
<i>RS_{mean}</i> (s)	1.635	0.225	0.120	10.475	0.007	0.466	0.647	0.437	0.051
<i>RS_{dec}</i> (%)	7.853	0.016	0.396	0.665	0.431	0.053	1.207	0.293	0.091
<i>RJ_{best}</i> (cm)	1.832	0.201	0.132	18.601	0.001	0.608	11.531	0.005	0.490
<i>RJ_{mean}</i> (cm)	0.824	0.382	0.064	17.020	0.001	0.586	13.423	0.003	0.528
<i>RJ_{dec}</i> (%)	0.027	0.872	0.002	2.678	0.128	0.182	0.213	0.653	0.017
<i>PP</i> (w)	0.899	0.362	0.070	20.073	<.001	0.626	12.553	0.004	0.511
<i>PR</i>	0.862	0.372	0.067	15.956	0.002	0.571	3.729	0.077	0.237

C Control; cm centimeters; R re-warm-up; s seconds; w watts; p p-value; *FS_{best}* First Sprint best; *RS_{best}* Repeated Sprint best; *RS_{mean}* Repeated Sprint mean; *RS_{dec}%* Repeated Sprint decrement %; *RJ_{best}* Repeated Jump best; *RJ_{mean}* Repeated Jump mean; *RJ_{dec}%* Repeated Jump decrement; *PP* Peak Power

Table 16 shows the post hoc comparisons between the control and RWU conditions, as derived from the ANOVA analysis. No significant performance differences were observed between conditions for the 10-minute transition. During this period, only perceived readiness showed a significant difference, with the RWU condition having a moderate effect.

Table 16: Post hoc comparisons between Control and RWU conditions across transition durations (10 min and 17 min) for RSJAT performance and perceived readiness.

Variable	10C vs. 10R			17C vs. 17R		
	Difference (mean change ± 95 % CI)	p	ES	Difference (mean change ± 95 % CI)	p	ES
<i>FS_{best}</i> (s)	-0.005 ± 0.099	0.073	0.40	0.025 ± 0.187	0.015	0.84
<i>RS_{best}</i> (s)	-0.027 ± 0.13	0.178	0.22	0.025 ± 0.227	0.018	0.52
<i>RS_{mean}</i> (s)	-0.017 ± 0.195	0.092	0.37	0.043 ± 0.233	0.008	0.57
<i>RS_{dec}</i> (%)	-0.391 ± 1.898	0.177	0.58	-1.36 ± 1.562	0.883	0.06
<i>RJ_{best}</i> (cm)	-1.755 ± 0.786	0.422	-0.09	-6.026 ± -2.159	<.001	-0.62
<i>RJ_{mean}</i> (cm)	-1.227 ± 1.081	0.893	-0.01	-4.53 ± -1.818	<.001	-0.47
<i>RJ_{dec}</i> (%)	-2.948 ± 0.58	0.169	-0.47	-2.318 ± 0.908	0.360	-0.34
<i>PP</i> (w)	-101.617 ± 48.014	0.450	-0.08	-315.35 ± -127.319	<.001	-0.42
<i>PR</i>	-1.641 ± -0.359	0.005	-1.10	-2.465 ± -0.689	0.002	-1.42

C Control; CI Confidence Interval; cm centimeters; R re-warm-up; s seconds; w watts; p p-value; ES Effect Size; *FS_{best}* First Sprint best; *RS_{best}* Repeated Sprint best; *RS_{mean}* Repeated Sprint mean; *RS_{dec}%* Repeated Sprint decrement %; *RJ_{best}* Repeated Jump best; *RJ_{mean}* Repeated Jump mean; *RJ_{dec}%* Repeated Jump decrement; *PP* Peak Power

By contrast, significant improvements in both sprint and jump performance were observed under the RWU condition during the 17-minute transition of 4.7% for *FS_{best}*, 2.4% for *RS_{best}*, and 2.8% for *RS_{mean}*, with effect sizes ranging from small to moderate. Perceived readiness also

increased significantly following the performance test. For jump performance, significant transition \times condition interactions were observed for RJ_{best} ($p = 0.005$; $\eta_p^2 = 0.490$) and RJ_{mean} ($p = 0.003$; $\eta_p^2 = 0.528$). These findings suggest that RWU strategies have a greater impact on performance and perceived preparedness when longer transition periods are involved.

Table 17 presents the results of a repeated-measures ANOVA with three factors on lactate concentration and tympanic temperature. No significant main or interaction effects were found for temperature.

Table 17: Main and interaction effects of transition duration (10 min vs. 17 min), condition (Control vs. RWU), and moment (Pre- vs. Post-performance) on lactate concentration and tympanic temperature.

Factor	[La-]			Temp		
	<i>F</i>	<i>p</i>	η_p^2	<i>F</i>	<i>p</i>	η_p^2
<i>Transition</i>	4.185	0.063	0.259	0.228	0.642	0.019
<i>Condition</i>	16.386	0.002	0.577	0.750	0.403	0.059
<i>Moment</i>	39.583	<.001	0.767	0.031	0.862	0.003
<i>Transition \times Condition</i>	0.512	0.488	0.041	0.324	0.580	0.026
<i>Transition \times Moment</i>	0.000	0.996	0.000	3.848	0.073	0.243
<i>Condition \times Moment</i>	6.606	0.025	0.355	1.252	0.285	0.064
<i>Transition \times Condition \times Moment</i>	0.780	0.395	0.061	0.006	0.938	0.001

[La-] Lactate; *p* p-value

However, lactate analysis revealed significant main effects for condition (Control vs. RWU) and moment (pre- vs. post-performance), and a significant interaction between them, where the moment is significantly influenced by the RWU condition, particularly on the pré-performance (Table 18).

Table 18: Post hoc comparisons between Control and RWU conditions at each moment (Pre- vs. Post-performance) for lactate concentration.

Moment	Condition	Difference (mean change \pm 95 % CI)	<i>p</i>	ES
[La-] Pre	10C vs. 10R	-5.065 \pm -1.996	<.001	-1.91
	17C vs. 17R	-2.970 \pm 0.385	0.119	-0.50
[La-] Post	10C vs. 10R	-5.284 \pm -1.947	<.001	-1.32
	17C vs. 17R	-4.875 \pm 0.290	0.077	-0.62

C Control; *R* Re-warm-up; *CI* Confidence Interval; [La-] Lactate; *p* p-value

Discussion

This study examined the acute effects of a short RWU protocol involving plyometric exercises after two transition periods (10 and 17 minutes) on the explosive performance of team sport athletes. Findings showed that the RWU protocol effectively attenuated declines, particularly after the 17-minute transition period, allowing athletes to restore their performance levels. This

suggests that short, practical RWU strategies can help athletes maintain physical readiness during extended periods of rest. Given its practicality and time efficiency, this protocol can be easily integrated into in-game routines or extended stoppages, to help maintain optimal physical and psychological performance (Silva et al., 2018).

Following the 10-minute transition period, no significant differences were observed in sprint or jump performance between the control and RWU conditions. This suggests that shorter passive intervals may have limited impact on neuromuscular readiness. Our findings align with previous studies that reported stable performance within similar transition durations after warm-up (Silva et al., 2022). During brief transitions, it appears that athletes may retain the benefits of the initial warm-up without the immediate need for an RWU intervention. Nevertheless, applying the RWU protocol significantly increased PR, which supports its psychological value. Even when objective performance metrics remain unchanged, enhancing an athlete's subjective preparedness may optimize tactical engagement and decision-making (Nourshahi et al., 2024).

In contrast, after the 17-minute transition period, the performance during the control condition declined and RWU mitigated the observed decline, producing significant improvements in both jump (12%) and sprint performance (5%). These results align with prior findings showing performance decrements after prolonged passive rest (Crowther et al., 2017; Christaras et al., 2023; Koutsouridis et al., 2024; Flórez-Gil et al., 2025), particularly in neuromechanically demanding tasks, such as jumping and agility. Possible mechanisms for these impairments include reductions in muscle temperature, neuromuscular activation, and post-activation potentiation (PAP), all of which deteriorate with extended inactivity (Mohr et al., 2004; Tillin & Bishop, 2009). Furthermore, prolonged sitting can adversely affect muscle stiffness and jumping ability, potentially leading to greater performance losses (Alberti et al., 2014), which could partly explain the additional decrease in overall jump performance observed in the control group after 17 minutes. This is an important consideration in sports that require athletes to sit on the bench for long periods.

Previous research examining RWU strategies to mitigate performance decline has reported significant improvements in vertical jump performance (Sanchez-Sanchez et al., 2024; Koutsouridis et al., 2025; Flórez-Gil et al., 2025), sprinting ability (Abade et al., 2017; Sanchez-Sanchez et al., 2024), change-of-direction speed (Abade et al., 2017; Sanchez-Sanchez et al., 2024; Flórez-Gil et al., 2025), agility (Matsentides et al., 2023) and neurological benefits (Nourshahi et al., 2024). For instance, similarly to our results, Abade et al. (2017) demonstrated that integrating plyometric movements and repeated directional changes into a RWU routine before football competition effectively attenuated declines in sprint and vertical jump performance.

A plausible explanation for the observed performance gains following the RWU protocol is the occurrence of PAPE. It refers to performance increase following a maximal- or near-maximal-intensity activity, including plyometric and other neuromuscular exercises (Xu et al., 2025). The

effects of PAPE are linked to increased muscle temperature, changes in muscle water content, enhanced motor unit recruitment and greater motor neuron excitability (Blazevich & Babault, 2019). However, the magnitude of PAPE is not consistent across individuals or protocols and may be influenced by factors such as sex, strength level, training experience, recovery interval and condition activity (Seitz & Haff, 2016; Blazevich & Babault, 2019).

While the results provide valuable insights, some limitations must be acknowledged. The sample was limited to athletes classified as Trained/Developmental, and different levels of competition may produce different physiological responses (Blazevich & Babault, 2019; McKay et al., 2022). Additionally, only basketball players were included, so generalization to other team sports should be done cautiously, and a larger sample size may have provided more robust conclusions regarding some of the variables examined. Given these limitations, the results should be interpreted with caution. The observed differences with regard to RWU for longer transitions may not have a meaningful effect on sprint performance, but they may be significant with respect to jump, physiological, and neurological readiness. Nevertheless, evidence of a potential short-term decline in performance after 17 minutes of passive rest highlights the importance of implementing appropriate RWU strategies.

Future research should explore the effects of RWU strategies integrating active and passive elements across different age groups, competitive levels, and sports-specific settings. Although passive RWU alone does not enhance performance, it can attenuate the decline in muscle temperature during rest periods (Faulkner et al., 2013). For instance, heated garments have been shown to reduce muscle temperature loss by about 1.1°C during soccer matches and by about 2°C in colder environments (Cowper et al., 2024). Additionally, it is important to consider the variability of physiological responses among individuals and the contextual demands of each match. Standardized protocols may not benefit all athletes equally, given differences in fitness levels, fatigue profiles, and positional roles.

Practical Applications

This study provides insight into timing for RWU strategies in team sports, particularly in the basketball context, and helps develop evidence-based RWU strategies that can easily sustain performance readiness during matches. Our results highlight a negative impact of prolonged inactivity on performance after warm-up. Coaches and performance staff in team sports should consider incorporating these protocols during particularly when athletes' transition times exceed 17 minutes. This type of RWU requires minimal equipment and space, allowing it to be adapted to various competitive environments without disrupting game logistics.

Chapter 4. General Discussion

The purpose of this thesis was to investigate the effects of warm-up, post-warm-up, and re-warm-up strategies in team sports, focusing particularly on their influence on the improvement of explosive performance in team sports. This research also sought to identify measurable physiological, biomechanical, and perceptual indicators that may guide evidence-based recommendations for coaches, bridging the gap between scientific findings and field implementation. To accomplish that purpose, four studies were developed in this thesis. Specifically, the investigation aimed to evaluate the impact of warm-up, post-warm-up transition, and re-warm-up structures on key performance, biomechanical, physiological, and psychological outcomes. The lack of consensus on the optimal warm-up and re-warm-up design for enhancing explosive actions in team sports, coupled with the limited evidence on the transition post-warm-up phases, provided the basis for the experimental studies presented in this thesis. By combining a systematic review, a nationwide survey, and controlled experimental interventions, this work offers a multidimensional understanding of how preparatory routines can optimize explosive readiness in intermittent sports. As a result, coaches will be able to apply some of these findings to develop optimized warm-up, post-warm-up, and re-warm-up protocols to enhance explosive performance.

In general, the studies included in this thesis provide a comprehensive understanding of how warm-up, post-warm-up, and re-warm-up strategies affect explosive performance in team sports. Our systematic review (Silva et al., 2018) established the conceptual and empirical foundations for subsequent experimental work by summarizing the evidence on warm-up, post-warm-up, and re-warm-up protocols in team sports. The review confirmed that warm-up consistently enhances explosive performance in team sports, such as football (Zois et al., 2015; Pojskić et al., 2015; van den Tillaar & Heimbürg, 2016), Basketball (Gabbett et al., 2013), Rugby (Barry et al., 2016), Handball (Okuno et al., 2013), or Volleyball (Sue et al., 2016). However, considerable variability was found in the methods, intensities, and transition durations across studies. Based on the reviewed studies, a recommended warm-up plan was outlined, lasting between 10 and 15 minutes and increasing in intensity from around 50% to 90% of HR_{max} . The protocol should include dynamic and sport-specific exercises, concluding with short bouts of maximal or near-maximal intensity, such as sprints performed at around 90% HR_{max} (Silva et al., 2018). Performing in warm-up high-intensity shuttle running provides higher acceleration and deceleration actions (Silva et al., 2023). Accordingly, a more recent study identified that tailoring a specific warm-up program appears to be effective in improving explosive performance in team sports (Cerrillo-Sanchis et al., 2024). The review also identified research gaps related to the post-warm-up phase (i.e., the period between the end of the warm-up and the start of competition) and to re-warm-up strategies. In particular, very few studies examined the combined influence of physiological decay and readiness during prolonged transitions,

which later became a key focus of the experimental components of this thesis. Nevertheless, it was possible to verify that during the transition period between the end of the warm-up and the start of the competition, athletes should avoid sitting and wearing heated garments to maintain muscle and core temperature. For instance, in basketball, substitutions typically occur between 9 and 23 minutes after the start of the game (Kapnia et al., 2023). Therefore, after 15 minutes of rest, athletes should perform a brief, active re-warm-up consisting of explosive, high-intensity exercises ($\sim 90\%$ HR_{max}) immediately before competition to restore readiness and optimize performance (Silva et al., 2018). Furthermore, this review revealed significant methodological limitations in previous research, including small samples, a lack of physiological measures such as core temperature and lactate, and inconsistent control of rest intervals. These aspects justified the methodological rigor of the experimental designs in the subsequent studies, where transition times and reactivation protocols were carefully standardized and monitored.

In order to understand the coaches' perceptions, the second study examined the warm-up and re-warm-up practices and perspectives of Portuguese basketball coaches across competitive levels (Silva et al., 2025a). The findings revealed that, although most coaches recognize the importance of warm-up to prepare for performance, substantial heterogeneity exists in the methods they use and in their understanding of the underlying physiological mechanisms. These results are consistent with previous studies showing that many coaches adopt only some elements of evidence-based warm-up programs, often relying on personal experience, peer imitation, or tradition rather than structured scientific guidelines (Räisänen et al., 2021; Weldon et al., 2022). Nevertheless, the answers of coaches in this study were consistent with previous research (Mason et al., 2022), with most coaches agreeing that warm-up should progress from low to high intensity, with mobility, muscle activation, and structured team-based drills phases performed before the beginning of the competition (Silva et al., 2025a). Importantly, the study revealed that the concept of re-warm-up is not well integrated into coaching practices, particularly at the youth level. This is largely due to time constraints and logistical challenges on game days that limit opportunities for structured reactivation during transition periods. This finding aligns with previous studies that report re-warm-up strategies are rarely implemented in real match contexts despite their proven physiological and performance benefits (Russell et al., 2015). Research has demonstrated that passive heat-maintenance interventions, such as heated garments, can effectively preserve muscle temperature and neuromuscular readiness (Cowper et al., 2022), yet their use remains uncommon among teams and coaching staff. Furthermore, differences seemed to emerge across competitive levels. Coaches in performance contexts tended to use longer, more specific, and structured warm-ups, aligning more closely with the literature, while youth coaches relied on shorter, less organized routines. This highlights the need for targeted educational strategies to bridge the gap between scientific evidence and coaching practice. Additionally, the lack of structured re-warm-up among youth categories may limit athletes' long-term understanding of readiness and injury prevention mechanisms.

Based on the evidence summarized in the review, the first experimental study (Silva et al., 2022) was conducted to develop and test an active warm-up protocol designed to improve explosive performance in team sports. The results of this study regarding the effects of the warm-up on performance appear to be consistent with the existing literature (Silva et al., 2018). Several studies have shown that short, progressive, sport-specific warm-ups effectively improve explosive performance by increasing body temperature (Kapnia et al., 2023) and specific muscle activation according to subsequent main activity (Gil et al., 2019; Afonso et al., 2023). Additionally, the study examined how the duration of the passive post-warm-up transition period influences physiological readiness and explosive performance. The results showed that explosive performance was optimal when the transition period following the warm-up was short (Silva et al., 2022). Accordingly, evidence suggests that relatively short transition intervals of 5 to 10 minutes can lead to a slight decrease in performance (Abade et al., 2025). However, performance declined markedly as the duration of this period increased (Silva et al., 2022). These findings aligned with previous research suggesting that muscle temperature and explosive capacity decline significantly after 15–20 minutes of inactivity, negatively affecting sprint and jump performance (Mohr et al. 2004; Kilduff et al. 2013). With lowered body and muscle temperatures, performance tends to decline (Racinais, et al., 2010). Muscle temperature drops 0.1°C every minute during a 20-minute post-warm-up inactivity period (Kapnia, et al., 2023) and therefore is a crucial factor in enhancing explosive performance. Taken together, these converging findings confirm that the post-warm-up timing and structure management after the warm-up are critical determinants for explosive performance in team sports. Interestingly, the results seemed to show that sprint performance was more negatively affected by longer transitions than jump performance, possibly. This nuance adds to the literature by showing that distinct explosive skills may decay differently over time. Moreover, the physiological results supported this interpretation, demonstrating that reduced body temperature corresponded with decreased readiness and performance output.

Therefore, based on the findings from the first two studies (Silva et al., 2022; Silva et al., 2025a), the final experimental investigation was designed to enhance the understanding and applicability of re-warm-up strategies in team sports (Silva et al., 2025b). It was already identified that longer passive transitions are detrimental to performance (Silva et al., 2018; Silva et al. 2022; Abade et al. 2025), and the final study examined the acute effects of a short re-warm-up protocol involving plyometric exercises performed after two distinct transition periods (10 and 17 minutes) to address this gap. The results showed that the plyometric re-warm-up protocol effectively enhanced explosive performance, especially after the longer transition. This allowed athletes to restore performance levels similar to those immediately following the initial warm-up. This outcome is consistent with previous evidence showing that re-warm-up can counteract the negative physiological effects of passive rest by maintaining muscle temperature and neuromuscular function (Silva et al., 2018). According to research, short, high-intensity RWU protocols performed after passive rest improve power output, change of direction, and shooting velocity in well-trained soccer players, emphasizing their efficacy in restoring explosive

performance (Matsentides et al., 2023). Additionally, similarly to our study results, research reported that plyometric protocol was the most effective strategy, preserving similar performances levels (Silva et al., 2024; Flórez-Gil et al., 2025). In contrast, within 10-minute passive transition period, no significant differences in sprint or jump performance were observed between the re-warm-up and control conditions (Silva et al., 2025b). These results suggest that shorter passive intervals may not substantially compromise neuromuscular readiness. This finding aligns with previous research showing that the physiological benefits of an effective warm-up can be maintained for approximately ten minutes without significant performance decline (Mohr et al., 2004; Silva et al., 2022).

Despite the valuable contributions of the studies, this research has several limitations that should be acknowledged. First, the experimental studies were conducted under controlled conditions and involved relatively small, homogeneous samples. This may limit the generalizability of the findings to other populations, competitive levels, or sports disciplines. Another limitation concerns the ecological validity of the experimental protocols. Although efforts were made to simulate competitive conditions, real-game environments involve complex unpredictable variables. Tactical constraints, psychological stress, and environmental factors, such as temperature and humidity, can affect physiological responses and behavioral performance. Finally, the study on coaches' perceptions was limited to Portuguese basketball, which restricts the transferability of the findings to other team sports or cultural contexts. Expanding this line of research to different team sports could help to better understand how coaching practices and contextual demands shape the application of evidence-based warm-up, post-warm-up and re-warm-up strategies to improve explosive performance in team sports.

Chapter 5. Overall Conclusions

The current thesis provides evidence that warm-up, post-warm-up, and re-warm-up are complementary and sequential phases within a unified preparatory continuum that must be designed to optimize performance of explosive efforts at all stages of competition. These phases initiate, maintain, and restore the athlete's physiological and neuromuscular readiness to perform explosive actions in dynamic, intermittent game environments. The post-warm-up phase, when not properly managed, may lead to a progressive decline in readiness, which can be effectively mitigated through brief, targeted re-warm-up routines.

From a practical perspective, coaches of team sports should view the warm-up and re-warm-up as integral elements of the same strategy to enhance explosive performance. Evidence indicates that:

- i. **Warm-up** should be multi-phase, dynamic, sport-specific, progressive in intensity, and ending with post-activation potentiation stimulus, while avoiding excessive duration or intensity that could lead to fatigue;
- ii. **Post-warm-up** periods, athletes should remain physically active whenever possible and employ complementary passive heat-maintenance strategies;
- iii. **Re-warm-up** serves to preserve or re-establish these benefits during inevitable periods of inactivity, such as extended pre-competition delays, half-time intervals, or player substitutions, when physiological readiness naturally declines. For longer transitions, perform brief intense re-warm-up exercises, such as plyometrics, to reactivate the neuromuscular system before returning to play.

Nevertheless, a persistent gap remains between scientific evidence and applied coaching practice in team sports for the improvement of explosive performance. Many coaches continue to rely on experience-based or traditional warm-up routines, overlooking the importance of managing transition phases and implementing structured reactivation strategies. Therefore, it is essential to disseminate evidence-based recommendations, promote reflective and research-informed practices, and provide coaches with the necessary tools to effectively integrate warm-up, post-warm-up, and re-warm-up protocols to improve explosive performance of team sports athletes.

Chapter 6. Suggestions for future research

The findings presented in this thesis are highly relevant to coaches of team sports seeking to improve explosive performance. However, several promising areas for future research emerge in relation to the identified limitations that could further advance our understanding of how warm-up, post-warm-up, and re-warm-up strategies influence the explosive performance of team sport athletes, and which protocol is best to apply.

Future research should:

- i. Address the limitations of small, homogeneous samples by including larger, more diverse populations encompassing different team sports, competitive levels, sexes, and age categories;
- ii. Develop individualized, context-dependent protocols that account for substantial variability in warm-up responses and post-activation potentiation effects among athletes;
- iii. Explore the chronic effects of systematically applying warm-up and re-warm-up routines throughout a competitive season;
- iv. Increase ecological validity by evaluating the effectiveness of warm-up, post-warm-up and re-warm-up protocols under real competitive conditions where tactical constraints, psychological stress, and environmental factors play a critical role;
- v. Integrate advanced monitoring technologies, such as infrared thermography, electromyography, wearable sensors, and real-time data analytics, to gain detailed insight into the physiological and neuromuscular mechanisms underlying warm-up, post-warm-up and re-warm-up responses;
- vi. Compare different re-warm-up formats and transition durations to determine the most effective combinations of exercise type, intensity, structure, and timing for maintaining or restoring performance;
- vii. Examine the effects of warm-up and re-warm-up strategies in female and youth athletes, considering the influence of maturation, hormonal fluctuations, and thermoregulatory differences on performance outcomes.

Chapter 7. References

Chapter 1, General Introduction

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Appendices

Appendix I. Study 2: Competition warm-up and re-warm-up questionnaire

These questions pertain to the warm-up, post-warm-up and re-warm-up strategies you provide to your athletes during competition. Select the most applicable option(s):

1. WARM-UP

1.1. How long have you been coaching basketball?

- a. 1 year or less
- b. 1-5 years
- c. 5-10 years
- d. 10-15 years
- e. +15 years

1.2. What formal coaching grade do you have?

- a. Grade I
- b. Grade II
- c. Grade III

1.3. Did you specialize in any particular aspect? (Please tick any that apply)

- a. Physical preparation
- b. Scouting
- c. Sports Management
- d. High performance training
- e. No specialization
- f. Other: _____

1.4. What is the highest level you train?

- a. Mini basketball
- b. Under-14/16/18
- c. Young Regional Teams
- d. Seniors (non-professional)
- e. Seniors (Professional)
- f. National Teams

1.5. What is the most common age of your team?

- a. 6-12 years
- b. 12-15 years
- c. 15-18 years
- d. 18-25 years
- e. 25-30 years
- f. 30+ years

1.6. Was or is a player?

- a. Yes
- b. No

1.7. If yes, what was the highest level you competed?

- a. Youth district/inter-district competition
- b. Youth national competitions
- c. National Senior Championship 1st/2nd Div.
- d. Professional league
- e. International club competitions
- f. National teams

1.8. What is the typical warm-up duration you advise to your athletes before competition?

- a. Do not program
- b. 10 min
- c. 15 min
- d. 20 min
- e. 30 min
- f. Other: _____

1.9. What is the purpose of your warm-up before the competition? (Please check any that apply)

- a. Physical/physiological preparation
- b. Mental preparation
- c. Technical preparation
- d. Tactical preparation
- e. Neurological preparation
- f. injury prevention

1.10. Do you have your athletes practice the warm-up used in competition in training?

- a. Yes
- b. No

1.11. How many phases does your warm-up program have?

- a. 1
- b. 2
- c. 3
- d. 4
- e. 5

1.12. Do you apply a general warm-up phase?

- a. Yes
- b. No

1.13. Volume:

- a. 5 minutes
- b. 10 minutes
- c. 15 minutes
- d. 20 minutes
- e. +20 minutes

1.14. Intensity:

- a. Moderate (55%-70%)
- b. Vigorous (70%-90%)
- c. Maximum (+90%)
- d. Self-controlled
- e. Not important

1.15. List up to 2 tasks you perform in the general warm-up phase.

- a. General aerobic
- b. Stretches
- c. Foam roller application
- d. Physical preparation exercises (e.g. squats, push-ups)
- e. Mental preparation exercises
- f. S.A.Q Exercises (Speed, agility and quickness)
- g. Small-sided games
- h. Repeated sprints
- i. Repeated jumps

j. Other: _____

1.16. Do you apply a specific warm-up phase?

- a. Yes
- b. No

1.17. Volume:

- a. 5 minutes
- b. 10 minutes
- c. 15 minutes
- d. 20 minutes
- e. +20 minutes

1.18. Intensity:

- a. Moderate (55%-70%)
- b. Vigorous (70%-90%)
- c. Maximum (+90%)
- d. Self-controlled
- e. Not important

1.19. List up to 2 tasks you perform in the specific warm-up phase.

- a. Technical-tactical exercises
- b. Physical preparation exercises (e.g. squats, push-ups)
- c. Mental preparation exercises
- d. S.A.Q Exercises (Speed, agility and quickness)
- e. Free Throw Series
- f. Small-sided games
- g. Repeated sprints
- h. Repeated jumps
- i. Other: _____

1.20. Do you apply a stretching phase?

- a. Yes
- b. No

1.21. If yes, what type of stretches?

- a. Static
- b. Dynamic
- c. Ballistic
- d. Proprioceptive neuromuscular facilitation (PNF)

1.22. Is there any difference in warming up by position?

- a. Yes
- b. No

1.23. What is the difference?

1.24. Is there a difference between the warm-up of the starting 5 and the substitutes?

- a. Yes
- b. No

1.25. If yes, what is the difference?

1.26. Depending on the game strategy, does the warm-up tend to be different?

- a. Yes
- b. No

1.27. In the final stretch of the warm-up, do you apply any additional strategy?

- a. Does not apply any additional strategy
- b. Reserves more time for tactical information
- c. Free throw series
- d. Repeated sprints
- e. Jump series
- f. Other: _____

1.28. If you answered *d.* and/or *e.*, how many series?

- a. 1
- b. 2
- c. 3
- d. 4
- e. 5

1.29. What is the indicated rest time between efforts?

- a. Not indicated / Not applicable
- b. 15 seconds
- c. 30 seconds
- d. 45 seconds
- e. 60 seconds

1.30. Consider the intensity of the warm-up exercise?

- a. Yes
- b. No

1.31. If so, how do you measure intensity?

- a. Time
- b. Heart Rate
- c. Stride cadence
- d. Rate of Perceived Exertion (RPE)
- e. Other: _____

1.32. Do you ask your athletes to use any device during warm-up?

- a. They do not use
- b. Heart Rate monitor
- c. GPS System
- d. Other: _____

2. POST-WARM-UP

2.1. After completing the warm-up, which athletes typically do before competition?

- a. They sit
- b. They listen to music
- c. They wear tracksuits or thermal clothing
- d. They wear tracksuits or thermal clothing
- e. Other: _____

2.2. Do you feel that the transition time between warm-up and the start of the competition is important to consider?

- a. Yes
- b. No

2.3. If so, what do you feel is the optimal time?

- a. 1 min
- b. 3 min
- c. 5 min
- d. 10 min
- e. 15 min
- f. 20 min

3. RE-WARM-UP

3.1. Any warm-up strategy for substitute players?

- a. Yes
- b. No

3.2. Duration?

- a. 1 min
- b. 2 min
- c. 3 min
- d. 4 min
- e. 5 min

3.3. Intensity?

- a. Moderate (55%-70%)
- b. Vigorous (70%-90%)
- c. Maximum (+90%)
- d. Self-controlled
- e. Not important

3.4. List up to 2 tasks you perform during the specific warm-up phase.

- a. Static stretches
- b. Dynamic stretches
- c. Stationary bike
- d. Physical conditioning exercises (e.g., squats, push-ups)
- e. Mental conditioning exercises
- f. Core activation exercises
- g. S.A.Q. exercises (speed, agility, and quickness)
- h. Sprint series
- i. Jump series
- j. Other: _____

3.5. Any warm-up strategy during half-time??

- a. Yes
- b. No

3.6. Delivers tactical briefing to the team in the locker room?

- a. Yes
- b. No

3.7. They use thermal blankets against the cold in the changing rooms?

- a. Yes
- b. No

3.8. Re-warm-up duration?

- a. 1 minute
- b. 3 minutes
- c. 5 minutes
- d. 7 minutes
- e. 10 minutes
- f. 12 minutes

3.9. Intensity?

- a. Moderate (55%-70%)
- b. Vigorous (70%-90%)
- c. Maximum (+90%)
- d. Self-controlled
- e. Not important

3.10. List up to 2 tasks you perform during the warm-up at halftime.

- a. Static stretching
- b. Dynamic stretching
- c. Stationary cycling
- d. Light jogging
- e. Physical conditioning exercises (e.g., squats, push-ups)
- f. Mental conditioning exercises
- g. Specific technical-tactical exercises
- h. Core activation exercises
- i. S.A.Q. exercises (Speed, agility, and quickness)
- j. Small-sided games
- k. Sprint series
- l. Jump series

m. Other: _____

Appendix II. Communication: The effects of warm-up strategies in repeated explosive efforts: a brief review

Abstract

Defining an ideal warm-up strategy for performance optimization remains difficult. From early on, warm-up routines have emerged based on experience, trial and error, and not on scientific evidence. Although some research presents data on the physiological responses to warm-up and suggests pre-competitive strategies, the mechanisms that cause positive responses and the ideal typology of warm-up tasks are still unclear. In team sports, such as basketball or soccer, short sequences of explosive efforts such as sprints, jumps, changes of direction and speed, interspersed with short recoveries (<60 seconds), are usually used. In fact, these repeated efforts, maximal or submaximal, called repeated sprint skill (RSA), are related to competitive performance, the competitive level of the practitioners, and interfere with each other. The analysis of research conducted on warm-up for repeated explosive efforts and their effects may provide coaches and sports researchers with valuable knowledge to optimize athletes' performance in training or competition, with recent research indicating that current routines may not be as effective as other methods. The objectives of this brief review were to provide an overview of: (i) the effects of warm-up on repeated explosive efforts in team sports; and (ii) to identify the best active and/or passive warm-up strategies for repeated explosive efforts in team sports. The ISI Web of Knowledge, PubMed, Scopus, and ScienceDirect databases were searched for articles published between 1981 and February 2017 that addressed active or passive warm-up interventions in team sports athletes, with performance assessments in repeated explosive efforts. In the initial search, 325 articles were considered relevant. After selection, 16 articles were chosen for analysis. The main results suggest that warm-up for optimization of repeated explosive efforts could consist of 10 minutes of running at ~55% HR_{max} , with 5 to 10 minutes of reduced games and/or sets of repeated sprints at ~90% HR_{max} . However, there is a certain scarcity of empirical research on the effects of specific strategies, making it complex to draw comparisons to support the theory and propose practical recommendations for coaches, due to the variety of investigations carried out.

Keywords: Collective sports; Pré-exercise; High-intensity actions

Appendix III. Communication: The effects of re-warm-up in team sports performance: a qualitative review

Abstract

The warm-up has been fundamental as a strategy to maximize sports performance. However, in the specific case of team sports competition, not all the athletes come into play shortly after the warm-up, being substitutes. Moreover, on average there is a rest period of 10-15 min during competition. Usually there are periods of inactivity during the games. In these periods, physical and cognitive reduction as well as an increased risk of injury has been reported previously. Therefore, the re-warm-up should be designed to optimize athletes' performance after longer transition phases, but a specific methodology with this purpose is not yet clear. The analysis of research carried out in the context of the effects of re-warm-up in team sports, may provide sports coaches and researchers with valuable knowledge to optimize athletes' performance at this most vulnerable stage. The aim of this qualitative review is to synthesize and analyse scientific evidence on the effects of re-warm-up strategies in the performance of athletes, highlighting the best methodologies. Databases (Web of Science, PubMed, Scopus and ScienceDirect) were searched for articles published until August 2017, which included active and/or passive re-warm-up interventions in athletes of team sports. A total of 8 articles fulfilled the inclusion criteria for analysis. Results were all recalculated to determine effect sizes. It was identified that research tends to recommend a passive strategy preceded by an active strategy with short-term explosive tasks. Therefore, we conclude that re-warm-up strategies are fundamental for maintaining the athletes' performance during the transitions, however empirical research is scarce to support the theory and propose practical recommendations. This project was supported by the Portuguese Foundation for Science and Technology and the European Union (UID/DTP/04045/2013; POCI-01-0145-FEDER-006969) and also through the NanoSTIMA project - Macro-to-Nano Human Sensing: Towards Integrated Multimodal Health Monitoring and Analytics (NORTE-01-0145-FEDER-000016).

Keywords: Collective sports; Enhancement; Reactivation

Appendix IV. Communication: The effects of post-warm-up strategies in team sports performance: a qualitative review

Abstract

In team sports, it is known that the warm-up improves acute explosive performance. However, the time delay between the warm-up and the start of the match (post-warm-up) could reduce the positive metabolic effects of the warm-up. Usually, it takes approximately 12 min of transition time. Knowing that after 6 min following the warm-up, the core temperature significantly decreases, and heart rate and muscle temperature returns to baseline values, the transition interval could negatively influence the performance. The analysis of the research carried out in this context may provide valuable knowledge to maintain optimised athletes' performance at this vulnerable stage. The aim of this qualitative review is to synthesise and analyse scientific evidence on the effects of post-warm-up strategies highlighting the best methodologies. Databases (Web of Science, Scopus, PubMed, and ScienceDirect) were searched for original research articles published until August 2017. A total of 5 articles fulfilled the inclusion criteria for analysis. Results were all recalculated to determine effect sizes. It was identified in research that inactivity during the post-warm-up interval would lead to losses in explosive performance. Therefore, studies tend to recommend the use of heated garments, resulting in better outcomes than simple rest (-0.89% , $d = 0.39$). Still, if the transition is longer than 15 min, it can lead to a loss of 15,4% in explosive performance. Therefore, before entering the match, performing a re-warm-up with short-term explosive tasks to reactivate is the most effective approach (-1.97% , $d = -0.86$). It was verified that post-warm-up strategies are fundamental for maintaining the athletes' performance during the transitions, however empirical research is scarce to support the theory and propose practical recommendations.