Enhancing Mechanical Outcomes in Resistance Training:
The Impact of Different Warm-Up and Re-Warm-Up Strategies

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Book chapter

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Resumo

O aquecimento no treino de força revela-se fundamental na melhoria do desempenho dos seus praticantes. No entanto, ainda existem algumas lacunas a respeito da escolha do aquecimento ideal para a prática do treino de força. A par do aquecimento, também o reaquecimento é um tema pouco estudado neste tipo de treino. A presente tese visa aprofundar o conhecimento sobre como diferentes estratégias de aquecimento e reaquecimento influenciam o desempenho mecânico em exercícios de treino de força. Para concretizar estes objetivos foram realizados cinco estudos: i) uma revisão sobre a prática de aquecimento e reaquecimento durante o treino de força; ii) levantamento de práticas de aquecimento e reaquecimento por parte de praticantes e treinadores de força em Portugal; iii) comparação de duas estratégias de aquecimento (aquecimento específico *vs.* aquecimento geral seguido de aquecimento específico); iv) efeito do reaquecimento durante o treino de força realizado com os exercícios de supino e agachamento; v) variabilidade individual na resposta ao reaquecimento. Os resultados indicaram que i) não existem estudos que abordem o efeito do reaquecimento sobre o desempenho de força dinâmica em indivíduos treinados; ii) as práticas usuais revelam elevada adesão ao formato de aquecimento geral e específico (> 93 %), mas escassa utilização de reaquecimento intra-sessão (< 20 %); iii) não se observaram diferenças em variáveis mecânicas ou psicofisiológicas entre a realização de aquecimento geral e específico combinado ou realização de aquecimento somente específico num treino de força; iv) o reaquecimento melhora significativamente a velocidade média propulsiva e a potência no agachamento, mas não no supino; v) praticantes mais fortes, altos e pesados apresentam maior probabilidade de responder positivamente ao protocolo de reaquecimento. Assim, os trabalhos desenvolvidos sugerem que estratégias de aquecimento incluindo somente a componente específica ou adicionando uma componente mais geral poderão preparar adequadamente os praticantes, sendo que a escolha deve considerar o tempo disponível e os objetivos individuais. O reaquecimento durante o treino de força, apesar de pouco usado, mostra-se promissor e parece beneficiar indivíduos mais fortes, altos e com maior massa corporal, reforçando ainda a importância de protocolos personalizados.

Palavras-chave

Aquecimento; Reaquecimento; Força; Velocidade; Potência

Resumo Alargado

O treino de força é uma prática recorrente, quer como forma de preparação para um objetivo de competição, quer como no treino com objetivos recreativos. Independentemente do seu objetivo, o treino de força é influenciado por um conjunto de fatores que determinam a sua eficiência e eficácia. Neste âmbito, atualmente, é sabido que o aquecimento poderá influenciar positivamente a manifestação da força durante o treino, com resultados expressos na velocidade de execução e/ou na potência desenvolvida durante a realização dos exercícios de treino de força. No entanto, a escassez de informação específica relativa à estratégia de aquecimento ideal para o treino de força, propicia controvérsia nesta área. O reaquecimento também se demonstrou uma prática pouco estudada neste contexto, traduzindo desinformação generalizada dos treinadores e praticantes acerca dos seus benefícios, nomeadamente no treino específico de alguns movimentos. Neste sentido, o principal objetivo da presente tese foi avaliar o impacto de diferentes estratégias de aquecimento e reaquecimento nos resultados de desempenho mecânico em exercícios de treino de força, com o objetivo de estabelecer protocolos que maximizem a ativação neuromuscular.

Estudo 1

No estudo 1 foi realizada uma revisão com o objetivo de analisar e sintetizar a evidência sobre estratégias de aquecimento e/ou reaquecimento em treino de força e os seus efeitos no desempenho dinâmico subsequente em indivíduos do sexo masculino treinados. A pesquisa, realizada em três bases de dados eletrónicas (*PubMed, Web of Science* e *Scopus*), focou-se em artigos originais publicados até março de 2025. Foram incluídos estudos que compararam os efeitos agudos de diversas estratégias de aquecimento e/ou reaquecimento no desempenho dinâmico de força, reportando medidas de resultado como uma repetição máxima (1RM), velocidade de levantamento de barra, potência, número total de repetições ou carga-volume (i.e., produto das repetições totais pelo peso deslocado). Vinte estudos analisaram de que forma os aquecimentos em treino de força afetam o desempenho dinâmico subsequente. Apenas um estudo avaliou o impacto do reaquecimento na performance de força. Os resultados desta revisão mostraram que: i) o aquecimento parece aumentar a carga de 1RM em exercícios de membros inferiores; ii) cargas relativas baixas usadas durante o aquecimento, executadas à máxima velocidade intencional, otimizam a potência máxima a 40% de 1RM no supino; iii) aquecimentos de intensidade progressiva elevam a velocidade de levantamento a 80% de 1RM no supino

e no agachamento; iv) aquecer com cargas entre 45% e 90% de 1RM aumenta o número total de repetições a 70-75% de 1RM em vários exercícios de força. Os profissionais do exercício físico e praticantes devem conceber aquecimentos que integrem fases gerais e específicas, ajustadas às necessidades dos praticantes e ao exercício em causa.

Estudo 2

Observando os resultados apresentados no estudo de revisão foi importante perceber as práticas usuais dos treinadores e praticantes de treino de força relativamente ao aquecimento desportivo. Neste sentido, o estudo 2 teve como objetivo caracterizar as rotinas de aquecimento e reaquecimento entre praticantes e treinadores envolvidos no treino de força. Em 2025 foi realizado um inquérito transversal descritivo sobre rotinas de aquecimento e reaquecimento no treino de força. Uma amostra de 106 participantes (66 homens e 40 mulheres, praticantes ou treinadores em Portugal) forneceu dados demográficos, experiência desportiva e profissional (anos de treino, função de praticante e/ou treinador) e práticas recomendadas de aquecimento e reaquecimento. Os resultados demonstraram que o sexo não influenciou significativamente as rotinas de aquecimento ou reaquecimento, indicando adoção semelhante por homens e mulheres (aquecimento: 93.9% vs. 95.0%; reaquecimento: 18.2% vs. 15.0%). Observou-se ampla adesão ao aquecimento geral e específico, independentemente do sexo (63.1%) ou do papel profissional (treinador e praticante: 68.2%), refletindo consciência generalizada dos seus benefícios para o desempenho e redução do risco de lesões. Em contraste, as estratégias de reaquecimento foram pouco utilizadas, apesar de haver uma concordância de que estas são importantes por melhorarem a prontidão muscular durante pausas intra-sessão, otimizarem o desempenho e reduzirem riscos de lesão. De referir que os participantes com dupla função (praticante-treinador de força: 34.8%) adotaram mais frequentemente o reaquecimento, sublinhando o impacto da experiência prática na promoção de abordagens baseadas em evidência. Estes resultados oferecem informações valiosas sobre as práticas atuais, que podem ser utilizadas por praticantes e treinadores para rever e aprimorar individualmente as suas rotinas de aquecimento e reaquecimento, desenvolvendo protocolos inovadores e eficazes para sessões de treino de força.

Estudo 3

Face às lacunas encontradas nos estudos anteriores, foram desenvolvidos os estudos 3, 4 e 5. O estudo 3 teve o objetivo comparar os efeitos de duas estratégias de aquecimento na produção de força durante sessões de treino de força no supino e no agachamento.

Vinte e seis homens treinados (24.37 ± 5.83 anos; 75.48 ± 12.12 kg; 1.74 ± 0.07 m) realizaram uma sessão de treino de supino ou agachamento após: i) aquecimento específico (AE): 2 × 6 repetições a 32 % e 64 % de 1RM, respetivamente; ii) aquecimento geral seguido de específico (AGE+E): 10 min de corrida na passadeira (70 % da frequência cardíaca de reserva) seguidos do AE. A sessão de treino consistiu em 3 × 6 repetições a 80 % de 1RM. Foram avaliadas variáveis mecânicas (velocidade média propulsiva, potência média propulsiva e perda de velocidade), fisiológicas (frequência cardíaca e concentração de lactato sanguíneo) e psicofisiológicas (perceção subjetiva de esforço). Não se observaram diferenças significativas nas variáveis mecânicas e psicofisiológicas entre AE e AGE+E no supino e agachamento. Contudo, no supino, o AGE+E provocou maior resposta de frequência cardíaca após o aquecimento do que o AE (100.00 ± 16.93 bpm vs. 110.57 ± 9.69 bpm; $p = 0.03$; ES = 0.65). Tanto o AE como o AGE+E podem ser usados como atividades preparatórias para o supino e o agachamento sem restrições associadas. Estes resultados poderão orientar profissionais na escolha de estratégias de aquecimento de forma a maximizar o desempenho no treino de força.

Estudo 4

O estudo 4 teve como objetivo comparar os efeitos do reaquecimento vs. ausência de reaquecimento antes de agachamento (SQ) ou supino reto (BP) nas respostas mecânicas, fisiológicas e psicofisiológicas em indivíduos treinados. Vinte e dois participantes (22.80 ± 3.30 anos) completaram quatro sessões randomizadas com diferentes sequências de reaquecimento e exercício. Foram avaliadas a frequência cardíaca, lactato sanguíneo, temperatura timpânica e perceção subjetiva de esforço. As métricas de desempenho incluíram a velocidade média propulsiva, velocidade máxima, potência, perda de velocidade e índice de esforço. O reaquecimento antes do agachamento (W + BP + RW + SQ) aumentou significativamente a velocidade média propulsiva e a potência face à condição sem reaquecimento (W + BP + SQ) ($p \leq 0.05$; $d = 0.45–0.62$). Contudo, o reaquecimento antes do supino (W + SQ + RW + BP) não melhorou significativamente o desempenho mecânico comparativamente à sequência sem reaquecimento (W + SQ + BP) ($p > 0.05$; $d = 0.10–0.38$). A perda de velocidade e o índice de esforço foram superiores na terceira série de treino no supino na condição sem reaquecimento (W + SQ + BP) ($p < 0.05$; $d = 0.53–0.60$). Não se observaram diferenças estatisticamente significativas nas respostas fisiológicas ou psicofisiológicas entre as condições. O reaquecimento melhorou o desempenho mecânico no agachamento quando realizado após o supino, mas teve impacto mínimo no supino quando realizado após o agachamento. Estes resultados sugerem que o reaquecimento antes de exercícios de membros inferiores podem potenciar o desempenho mecânico, enquanto os benefícios são menos evidentes em exercícios de membros superiores.

Estudo 5

O estudo 5 teve como propósitos: i) analisar as respostas individuais na velocidade de levantamento de barra durante uma série de treino de força precedida pelo reaquecimento e ii) comparar as diferenças entre responsivos e não-responsivos em termos de antropometria, experiência de treino, força muscular e alterações fisiológicas e psicofisiológicas agudas durante o treino. Vinte e dois praticantes de treino de força do sexo masculino (22.77 ± 3.29 anos; 76.14 ± 12.62 kg; 1.78 ± 0.06 m) foram classificados como responsivos ou não-responsivos com base na diferença entre a velocidade média propulsiva (VMP) máxima atingida na primeira série após o reaquecimento e a VMP máxima na primeira série sem reaquecimento. Os participantes realizaram quatro sessões de treino de força, com ou sem reaquecimento após o primeiro exercício (supino ou agachamento). Consoante a condição, executaram um reaquecimento de 6 repetições a 40 % e 80 % da carga de treino ou passaram diretamente para o segundo exercício sem reaquecimento. Foram comparados responsivos e não-responsivos quanto à idade, massa corporal, altura, índice de massa corporal (IMC), experiência de treino, 1RM, força relativa, VMP, frequência cardíaca, lactato sanguíneo e perceção subjetiva de esforço. Os resultados revelaram que 45.50 % dos participantes responderam positivamente ao reaquecimento no supino, aumentando a sua VMP, enquanto 68.20 % responderam positivamente no agachamento. No supino, os responsivos apresentaram maior força e eram ligeiramente mais altos do que os não-responsivos, enquanto no agachamento os responsivos tinham maior massa corporal, IMC e 1RM do que os não-responsivos. Não foram encontradas diferenças significativas na idade, experiência de treino ou marcadores fisiológicos entre os grupos. A implementação de um reaquecimento antes do segundo exercício da sessão pode ser vantajosa para aumentar a velocidade de levantamento de barra, especialmente em indivíduos mais fortes.

Palavras-chave

Aquecimento; Reaquecimento; Força; Velocidade; Potência

Abstract

Warm-up in resistance training is essential to improve performance of practitioners. However, gaps remain in selecting the optimal warm-up protocol for resistance training. Alongside warm-up, re-warm-up is also an underexplored topic in this context. The present thesis seeks deepening understanding of how different warm-up and re-warm-up strategies influence mechanical performance during resistance training. To achieve these objectives, five studies were conducted: i) a review about warm-up and re-warm-up during resistance training; ii) interpretation and discussion of usual practices among strength coaches and practitioners in Portugal; iii) a comparison of two warm-up strategies (specific warm-up vs. general plus specific warm-up); iv) the effect of re-warm-up on bench press and squat performance during resistance training; v) individual variability on response to the re-warm-up. The results showed that i) no prior studies have addressed re-warm-up's effect on dynamic strength performance in resistance-trained individuals; ii) adherence to general and specific warm-up protocols was high (> 93 %), yet intra-session re-warm-up was seldom used (< 20 %); iii) no mechanical or psychophysiological differences emerged when combined general and specific warm-up or even specific warm-up were used during resistance training; iv) re-warm-up significantly enhanced mean propulsive velocity and power in the squat exercise, but not in the bench press exercise,; v) stronger, taller, and heavier athletes were reported to be more likely to respond positively to the re-warm-up protocol. Across these five developed studies, it was suggested that both specific warm-up and combined general and specific warm-up protocols can properly prepare athletes, once the selection of warm-up should consider the available time to perform the resistance training and the individuals' purposes. The re-warm-up during resistance training, although little used, shows promise and appears to benefit stronger, taller, and with higher body mass individuals, further reinforcing the importance of personalized protocols.

Keywords

Warm-up; Re-warm-up; Strength; Velocity; Power

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List of Acronyms

1RM	One Repetition Maximum
AE	Aquecimento Específico
AGE+E	Aquecimento Geral seguido de Específico
BD	Bar Displacement
BMI	Body Mass Index
bpm	Beats Per Minute
BP	Bench Press
CI	Confidence Interval
ES (d)	Effect Size
EI	Effort Index
FC	Frequência Cardíaca
FW-BP	Free-Weight Bench Press
FW-DL	Free-Weight Deadlift
FW-SQ	Free-Weight Squat
GSWU	General + Specific Warm-Up
HR	Heart Rate
HR_{max}	Maximal Heart Rate
HR_{res}	Heart Rate Reserve
ILP	Inclined Leg Press
IMC	Índice de Massa Corporal
LAC	Blood Lactate
LPD	Lat Pull-Down
MPP	Mean Propulsive Power
MPPmax total	Maximum Mean Propulsive Power (Total)
MPPmin total	Minimum Mean Propulsive Power (Total)
MPV	Mean Propulsive Velocity
MPVmax total	Maximum Mean Propulsive Velocity (Total)
MPVmin total	Minimum Mean Propulsive Velocity (Total)
PAPE	Post-Activation Performance Enhancement
PP	Peak Power
PV	Peak Velocity
R	Repetitions
RDF	Rate of Force Development
RMP	Relative Mean Power
RPM	Revolutions per Minute
RPP	Relative Peak Power
RWUP	Re-Warm-Up

SET	Set (in exercise sessions)
SM-BP	Smith Machine Bench Press
SM-SQ	Smith Machine Squat
SQ	Squat
SWU	Specific Warm-Up
Time to PV	Time to Peak Velocity
TL	Training Load
TPV	Time to Peak Velocity
ULP	Unilateral Leg Press
VL	Velocity Loss
$VL_{[total]}$	Total Velocity Loss
VMP	Mean Propulsive Velocity
$VO2_{max}$	Maximal Oxygen Uptake
WUP	Warm-Up
W+BP+SQ	Warm-Up + Bench Press + Squat
W+BP+RW+SQ	Warm-Up + Bench Press + Re-Warm-Up + Squat
W+SQ+BP	Warm-Up + Squat + Bench Press
W+SQ+RW+BP	Warm-Up + Squat + Re-Warm-Up + Bench Press

Chapter 1. General Introduction

Coaches, researchers, and athletes have recognized the warm-up as a fundamental phase of any training session and competitive event, essential for achieving top performance in sports (Fradkin et al., 2010; McGowan et al., 2015). Most of the benefits predominantly arise from the elevation of body temperature. This temperature increase potentially speeds up nerve impulse transmission, reduces viscosity within the muscle-tendon system, redirects blood flow, and optimizes oxygen diffusion within skeletal muscles (Bishop, 2003a, 2003b). Consequently, these physiological effects improve the function of aerobic and anaerobic metabolism and also contribute to reducing the likelihood of injuries (Bishop, 2003a, 2003b; McGowan et al., 2015; Neiva et al., 2014; Young & Behm, 2002).

The elevation of body temperature can be achieved through active and/or passive warming-up procedures, depending on the use of physical activity and associated energy expenditure (McGowan et al., 2015). Passive warming-up involves increasing body temperature through external mechanisms, such as hot showers, saunas, heated clothing, or massages (Nader et al., 2009). Active warming-up represents the predominant strategy employed by athletes, utilizing physical movement to induce metabolic alterations, such as an increased metabolic rate and increased availability of energy substrates (Bishop, 2003b; McGowan et al., 2015). The active warm-up benefits from the effects of performing previous physical activity, including the higher baseline levels of oxygen consumption before subsequent exercise (Atkinson et al., 2004) and improved range of motion resulting from the disruption of actin-myosin cross-bridges (Billington et al., 2014). The muscle contractions included in the warm-up routine can lead to circulatory adaptations, increasing blood flow and oxygen supply to the active musculature (Bishop, 2003b). Additionally, engaging in activities at maximal or submaximal intensities can trigger post-activation potentiation (PAP) effects, which increase motor neuron excitability and impact post-warm-up performance (Alves et al., 2021; Sale, 2002).

Based on the aforementioned effects of warm-up, prior studies have sought to understand the best practices and their primary impacts on sports performance (Junior et al., 2014; Ribeiro et al., 2014). Several investigations have been conducted to compare the effects of different warm-up protocols, varying the volume, intensity, recovery time after warm-up, and task specificity (McGowan et al., 2015; Neiva et al., 2014; Zois et al., 2011). Nonetheless, numerous factors remain that guarantee further clarification

(Wilson et al., 2013; Zois et al., 2011). Furthermore, the majority of studies demonstrating the benefits of warm-up have primarily focused on individual and team sports performance, as well as specific activities such as running and jumping, thereby identifying certain performance enhancements (Gourgoulis et al., 2003; Pojskic et al., 2015). Warm-up has been shown to enhance performance in sprinting (Marinho et al., 2017), swimming (Neiva et al., 2017), cycling (Burnley et al., 2005), and jumping (Burkett et al., 2005), identifying its role in performance optimization. However, little is known regarding its effects on strength performance and resistance training.

Although the beneficial effects of warm-up on sports performance are well established in the literature (McGowan et al., 2015; Silva et al., 2018), re-warm-up seems not to be well recognized. Re-warm-up interventions consist of short, active protocols applied after the initial warm-up (Silva et al., 2018). Their goal is to maintain or restore the optimal physiological state, especially when there is a significant gap between the warm-up and the main activity (Silva et al., 2018). In essence, the re-warm-up seeks to reestablish muscle temperature, neuromuscular activation, and metabolic readiness—factors that are crucial for ensuring continuous performance and for preventing abrupt declines in performance (González-Devesa, Vaquera, Suárez-Iglesias, & Ayán-Pérez, 2021). Some studies have highlighted the significant benefits of this practice. For example, Abade et al. (2017) demonstrated that various re-warm-up strategies in soccer players resulted in improvements in explosiveness and sprint capacity. Moreover, Silva et al. (2018) reported that short active re-warm-up strategies after transitions longer than 15 minutes can positively influence explosive performance. Indeed, systematic reviews, such as that by Silva et al. (2018), indicated that in team sports contexts, implementing a re-warm-up after prolonged intervals can mitigate declines in explosive efforts and agility, an effect also corroborated by the findings of Los Arcos et al. (2015) in soccer interval simulations.

Re-warming up contributes to maintaining the ability for repeated sprints in professional soccer players (Silva et al., 2018). Re-warm-up strategies should be used to preserve neuromuscular performance levels after periods of inactivity (Twomey et al., 2017). Additionally, González-Fernández et al. (2025) demonstrated that re-warm-up interventions not only benefit physical performance but also have a positive impact on cognitive function, an essential aspect for the competent execution of complex movements in competitive settings. However, it is important to note that, although the evidence supports the benefits of re-warm-up in highly explosive activities and team sports, studies specifically addressing re-warm-up in the context of resistance training remain limited. In this sense, further research is needed to understand what is reported about this topic in the literature (Study 1).

Complementarily, it is well-established that muscular strength is associated with time-related strength characteristics, such as the rate of force development and external mechanical power (Suchomel et al., 2016). Enhancing these mechanical variables is linked to improvements in sports performance and potentiation effects (Suchomel et al., 2016). Coaches and athletes have recognized that stronger athletes outperform their weaker counterparts in sports or events that rely on both strength, power, and endurance capacities (Aagaard et al., 2011; Haff & Nimphius, 2012). Consequently, there has been a growing interest in practices and methods to enhance the efficiency of resistance training (Andersen et al., 2010). Thus, the aim is not only to increase gains but also to reduce the time spent on resistance training, allowing for more time to be dedicated to recovery or the development of specific sports skills. Resistance training can benefit from efficient warm-up routines, as seen in various sports and tasks (Cormie et al., 2010; Styles et al., 2016). With a proper warm-up, each individual can optimize the activation of the muscular system involved in the specific sporting task and improve neural stimulation, thereby maximizing gains in resistance training (Hughes et al., 2018). Therefore, the influence of warm-up on resistance training and strength performance, and consequently, on overall performance, cannot be overlooked.

There is a real need to deepen our understanding of how warm-ups influence resistance training and strength performance, as well as to identify the practical strategies used in the field (Study 1). In addition to the scarce evidence on their effects, the current implementation of warm-up routines appears to be predominantly based on tacit knowledge and individual experiences acquired over time, rather than empirical evidence (McGowan et al., 2015; Neiva et al., 2014). Therefore, it is crucial to understand and analyze the modern practices employed by strength and conditioning coaches and athletes during resistance training, and to gather data to design robust studies that address warm-up and re-warm-up in an ecological context, aligning with the scientific evidence (Study 2). Most research in this area has explored the impact of general and/or specific warm-up on maximal dynamic strength (e.g., one-repetition maximum [1RM] load) and the number of repetitions with submaximal loads (e.g., % of 1RM load). The general warm-up involves activating major muscle groups and/or the entire body, raising body and muscle temperature, and priming the cardiovascular and pulmonary systems for subsequent activity (Junior et al., 2014). It is typically conducted using activities other than the main exercise. Conversely, the specific warm-up aims to stimulate the muscle groups involved in the training session through similar movements, but with lighter loads, to prepare the neuromuscular system (Di Alencar & Matias, 2010; Stewart & Sleivert, 1998). The specific warm-up may confer additional benefits to the targeted muscles, such as increased blood flow and greater recruitment of motor units, in line with the movement specificity required (Alves et al., 2021; Bishop, 2003b; Di Alencar & Matias, 2010; Fermino et al., 2005). For instance, Alves et al., (2021) found that individuals who underwent a specific warm-up completed a greater number of repetitions in the first and second sets of resistance training (11.5 ± 3.1 and 6.5 ± 1.9, respectively) compared to those who did not undergo any warm-up (10.4 ± 2.7 and 5.5 ± 1.8), suggesting that specific warm-up can be employed in resistance training to enhance total workload and potentially augment long-term outcomes. However, others have reported no significant differences between the use of general warm-up and specific warm-up on maximal strength of the upper and/or lower limbs (Barroso et al., 2013; Junior et al., 2014; Nader et al., 2009; Ribeiro et al., 2014).

Considering the evidence discussed above, research attention should be directed towards understanding the specific warm-up effect on resistance training (Barroso et al., 2013; McGowan et al., 2015). Hence, it appears pertinent to investigate the impact of specific warm-up on squat and bench press exercises (Study 3). These strength exercises are widely used in resistance training contexts and research. Despite previous studies suggesting the necessity of specific warm-up for achieving maximal strength performance, there still exist controversial findings and methodological shortcomings (Fradkin et al., 2010; Silva et al., 2018; Tillin & Bishop, 2009). For example, existing literature has predominantly assessed the effect of specific warm-up on the number of maximum repetitions or 1RM load (Abad et al., 2011; Ribeiro et al., 2014; Wilcox et al., 2006). However, one confounding factor in prescribing appropriate warm-up or resistance training is the determination of 1RM, which may inaccurately assess athletes' actual effort (González-Badillo et al., 2011). A valid and precise assessment of individual strength is crucial for determining functional capacity and monitoring training responses across populations (Brown & Weir, 2001; Garber et al., 2011). In this sense, movement velocity serves as a reliable variable that can be evaluated in a real resistance training setting with submaximal external loads and can be used to determine or estimate the individual maximal dynamic strength (1RM) (González-Badillo & Sánchez-Medina, 2010; González-Badillo et al., 2011). Complementarily, it seems pertinent to develop personalized approaches and determine appropriate and effective warm-up strategies to maximize the benefits that arise with resistance training practices.

Although re-warm-up activities have been extensively investigated in team sports (Abade et al., 2017; Silva et al., 2018), their specific assessment within the context of resistance training remains quite limited. This gap is especially relevant when considering key exercises such as the squat and bench press, where considering mechanical parameters (dynamic strength, rate of force development, and power) is fundamental for optimal performance (Neves et al., 2025). Thus, another issue addressed in this thesis is the need to determine whether combining warm-up routines with a brief active re-warm-up can optimize mechanical outcomes in resistance training, thereby preventing performance decline that may occur during rest intervals between sets or exercises (Study 4). Moreover, it would be interesting to understand whether factors such as muscle strength level, training experience, body mass, and height could affect the magnitude of the individual response in terms of mechanical performance during resistance training when preceded by a re-warm-up strategy. Therefore, it is essential to analyze the interindividual responses to a resistance training re-warm-up strategy, specifically focusing on its effect on barbell lifting velocity in the subsequent training set among trained individuals (Study 5).

Considering the points raised above, the general aim of this thesis was to evaluate the impact of different warm-up and re-warm-up strategies on mechanical performance outcomes in resistance exercises, to develop warm-up protocols that maximize strength performance. The principal hypothesis is that specific warm-up protocols, with a re-warm-up routine, should produce significant improvements in mechanical parameters when compared to general warm-up routines with or without re-warm-up routines. To accomplish the main aim, a series of studies was delineated, forming the structure of the thesis:

Chapter 2 presents a scoping review aiming to synthesize the scientific evidence on warm-up and/or re-warm-up strategies in resistance training settings, with a focus on subsequent dynamic strength performance in strength-trained males (Study 1). Subsequently, Chapter 3 consolidates the experimental research undertaken to fulfill the primary aim of the thesis, encompassing the following studies:

- Study 2 aimed to characterize warm-up and re-warm-up practices among Portuguese athletes and strength and conditioning coaches during resistance training.
- Study 3 compared the acute effects of two warm-up strategies on mechanical performance during bench press and squat resistance training sessions.

- Study 4 examined the effects of re-warm-up versus no re-warm-up before squat or bench press on mechanical, physiological, and psychophysiological responses in strength-trained men.
- Study 5 analyzed the interindividual responses in barbell lifting velocity during a resistance training set preceded by a re-warm-up and compared the differences between responders and non-responders in terms of anthropometry, training experience, muscle strength, and acute physiological and psychophysiological changes during training.

Subsequently, a comprehensive discussion of the results obtained across various studies is provided in Chapter 4, followed by the principal conclusions of the thesis in Chapter 5. Finally, Chapter 6 offers recommendations for future research.

Chapter 2. Literature Review

Study 1. Acute Effects of Resistance Training Warm-Up and Re-Warm-Up on Dynamic Strength Performance: A Scoping Review

Abstract

Purpose We aimed to analyze and synthesize the evidence on resistance training warm-up and/or re-warm-up strategies and their effects on subsequent dynamic strength performance in strength-trained males. Methods We searched three electronic databases for original articles from inception to March 2025, with updates in November 2025. We included studies comparing the acute effects of various warm-up and/or re-warm-up strategies on dynamic strength performance, reporting outcome measures such as one-repetition maximum (1RM), barbell lifting velocity, power, total repetitions, or volume load. Results Nineteen studies focused on how resistance training warm-ups affect subsequent dynamic strength performance, while one study analyzed the effects of resistance training re-warm-ups on strength performance. The main findings show that i) resistance training warm-ups increase 1RM loads in leg press and squat, ii) using low relative loads in warm-ups lifted at maximal intended velocities optimizes peak power at 40% 1RM in the bench press, iii) progressive-intensity warm-ups increase lifting velocity at 80% 1RM bench press and squat, iv) warming up with loads ranging from 45% to 90% 1RM increases the number of total repetitions completed at 70-75% 1RM in several strength exercises, and v) a re-warm-up improves squat mechanical performance. Conclusions: This review highlights the benefits of resistance training warm-ups on increasing 1RM load in lower-body exercises, peak power at light loads, propulsive velocity at heavy loads, and total repetitions at moderate loads. Nevertheless, a notable gap in research exists regarding re-warm-up strategies and their impact on strength performance, highlighting the need for further investigation.

Keywords: Warm-up, pre-exercise, re-warm-up, strength training, muscle strength, power, physical performance

Introduction

The warm-up is designed to raise body temperature and improve muscle blood flow (McGowan et al., 2015), nerve impulse transmission efficiency (Pearce et al., 2012), and increase metabolic reactions for subsequent enhancement of strength performance (Afonso et al., 2024; McGowan et al., 2015). Athletes can undergo these physiological and biomechanical changes through active and passive warm-up strategies (Bishop, 2003a, 2003b). Passive warm-ups encompass methods such as hot water bags, short-wave therapy, hot baths, or saunas. This form of warm-up raises muscle and core body temperature without expending energy, using external heating methods. On the contrary, active warm-ups are dynamic, involving motor physical activities that require energy expenditure, such as running, cycling, jumping, swimming, exercising with external resistance, stretching, or mobility exercises (Bishop, 2003a, 2003b; Gil et al., 2019). One of the primary advantages of the active warm-up is its specificity, as it targets the muscles that will be actively involved in the subsequent activity of the conditioning phase (Afonso et al., 2024; Bishop, 2003a, 2003b; Gil et al., 2019). The characteristics of active warm-ups can differ according to the physiological and mechanical demands and specificities of the training type, game, or competition that will be performed (McGowan et al., 2015; Silva et al., 2018). For example, aerobic-based warm-ups, typically implemented in sports endurance events (e.g., marathon) (Haugen et al., 2022), primarily focus on activating the cardiovascular system for the main activity (Sople & Wilcox, 2025). On the other hand, resistance-based warm-ups are generally characterized by a specific focus on activating the neuromuscular system and increasing force production through the use of external resistance (Isbilir et al., 2025; Lee et al., 2025).

Nonetheless, the concomitant use of an aerobic and resistance-based warm-up approach at the beginning of a training session, pre-match or competition, is also a recurrent strategy adopted by coaches and athletes (McGowan et al., 2015; Silva et al., 2018). For example, in resistance training contexts, the warm-up configurations preceding the conditioning phase or main activity typically include both a general and a specific phase (El Hage et al., 2012; Krzysztofik et al., 2020; Mina et al., 2016). The general warm-up phase is more closely associated with aerobic activities of low to moderate intensity, such as 5-20 minutes of cycling or running at 50-70% of maximum heart rate (El Hage et al., 2012; Krzysztofik et al., 2020; Mina et al., 2016; Neves et al., 2024). In the specific warm-up phase, coaches typically select the resistance exercise that athletes will perform first in the conditioning phase. Athletes can perform these exercises by completing repetitions at low, moderate, or high relative loads, or by adopting a gradual increase in intensity over the sets (Alves et al., 2021; Barroso et al., 2013; El Hage et al., 2012; Luz Junior et al., 2014; Neves et al., 2024; Ribeiro et al., 2021). Multiple configurations of resistance training warm-up strategies have been analyzed in the past few years, and research has demonstrated their positive effects on subsequent strength performance, including an increase in the one-repetition maximum (1RM) load (Abad et al., 2011; Barroso et al., 2013; Mina et al., 2014, 2016), lifting barbell velocity (Ribeiro et al., 2020, 2021), or total repetitions performed in the session (Alves et al., 2021; Luz Junior et al., 2014).

However, discrepancies were also found between studies regarding the impact of resistance training warm-ups on strength performance. For example, while a warm-up of 6 repetitions at 80% of the training load in the squat appeared more beneficial than 6 repetitions at 40% of the training load to increase lifting velocity in the squat at 80% 1RM, the same warm-up strategy did not produce the same results for the bench press exercise (Ribeiro et al., 2020). Krzysztofik et al. (2020) also found no differences in bench press velocity at 60% 1RM when comparing a warm-up of 3 sets of 3 reps at 85% 1RM and a warm-up of 5 minutes of cycling, followed by mobility exercises, 15 repetitions at 20% 1RM, 10 repetitions at 40% 1RM, and 5 repetitions at 70% 1RM. On the other hand, El Hage et al. (2012) observed optimized barbell power production in the bench press at 40% 1RM when the warm-up strategy consisted of 4 repetitions at 20% 1RM, rather than 3 repetitions at 80% 1RM. Therefore, while the barbell lifting mechanics in the squat might benefit from warm-ups with moderate-to-high relative loads, the same strategy may not induce the same results in the bench press. When it comes to the total repetitions an athlete can perform with a given relative load, the results also seem somewhat controversial regarding the most appropriate warm-up strategy. For example, Luz Junior et al. (2014) observed that a warm-up of 2 sets of 2 repetitions at 90% 1RM was more effective than 15 repetitions at 40% 1RM for increasing the total repetitions at 70% 1RM in the bench press. In contrast, Alves et al. (2021) observed that a warm-up of 8 repetitions at 50% 1RM was more effective than the same warm-up plus 3 repetitions at 90% 1RM for increasing the total repetitions at 75% 1RM in the bench press.

Therefore, taken together, these results suggest that there is still inconclusive evidence regarding the most effective resistance training warm-up strategies to enhance subsequent strength performance. Specifically, there is limited understanding of which acute variables, such as volume, intensity, type of strength exercise, and even the rest period between the warm-up and the main activity, play a substantial role in optimizing subsequent strength performance. Furthermore, on a closely related topic, research has highlighted the importance of re-warm-up strategies in preventing the decline in neuromuscular performance that occurs during passive rest periods (Mohr et al., 2004; Silva et al., 2018). A re-warm-up refers to repeating a warm-up strategy during the training session or competition/game, when several physical efforts have been performed and a determined rest period has followed (Afonso et al., 2024; Silva et al., 2018). While a warm-up is performed at the beginning of a training session or competition/game, a re-warm-up occurs during these events (Afonso et al., 2024; Silva et al., 2018). Several studies have shown that during halftime in sports games, a re-warm-up involving strength exercises can prevent a decline in sports-specific tasks (e.g., jumping, sprinting, and changing direction) and even enhance athletic performance (Mohr et al., 2004; Sanchez-Sanchez et al., 2024; Silva et al., 2018; Yang et al., 2025). This approach may also be particularly relevant during resistance training sessions that include long pauses or transitions between muscle groups and exercises. However, due to the limited research on this topic, it is essential to thoroughly review the literature to gain a better understanding of the current knowledge on resistance training re-warm-ups and their impact on strength performance, and to identify future research directions.

Given the considerations above, this scoping review aimed to examine and synthesize the evidence on warm-up and/or re-warm-up strategies in resistance training settings, with a focus on subsequent dynamic strength performance in strength-trained males. Another important aim is to identify research gaps or discrepancies in the existing body of knowledge and provide suggestions for future investigations in this field. Furthermore, given the broader adoption of dynamic resistance training compared to isometric resistance training (Saeterbakken et al., 2025) and the higher rates of resistance training participation among young adult men than women or older age groups (Chevan, 2008; Nuzzo, 2020), this review aims to provide practical significance for this specific population by suggesting evidence-based guidance for designing tailored resistance training warm-up and/or re-warm-up strategies to optimize subsequent dynamic strength performance.

Methods

Literature search and eligibility criteria

We conducted a literature search to investigate the impact of various active resistance training warm-up and/or re-warm-up strategies on strength performance in strength-trained males. The search for articles was initially conducted in March 2025 and subsequently updated in November 2025 using the following electronic databases: PubMed, Web of Science, and Scopus. The Boolean search strategy used to retrieve the studies was the following: ("warm-up" OR "warming-up" OR "re-warm-up" OR "re-warming" OR "post-activation potentiation" OR "PAP" OR "post-activation potentiation enhancement" OR "post-activation performance enhancement" OR "PAPE") AND ("resistance training" OR "strength training") AND ("adult*" OR "young adult*"). The search was limited to articles written in English, Portuguese, Spanish, and French. We also conducted additional searches in our personal databases to identify related studies on the topic. We imported the extracted articles from the databases into the Rayyan software (Ouzzani et al., 2016) to identify and remove duplicates and select the potentially eligible studies. Table 1 presents the eligibility criteria. In brief, we included studies that compared the acute effects of various active resistance training warm-up and/or re-warm-up strategies on subsequent dynamic strength performance in strength-trained males. These interventions had to report one of the following outcome measures in dynamic free-weight or machine-based resistance exercises: 1RM weight, total repetitions, volume load, barbell velocity, power, or rate of force development (RFD).

Table 1. Inclusion and exclusion criteria.

PICOS	Inclusion Criteria	Exclusion Criteria
Population	Healthy trained males (at least 6 months of training experience) aged between 18 and 40 years.	Unhealthy individuals; untrained males; females; children; middle-aged and older adults.
Intervention	Acute effects of active resistance training warm-up and/or re-warm-up strategies on subsequent dynamic strength performance.	Acute effects of passive warm-up and/or re-warm-up strategies during resistance training; acute effects of interventions including isometric-only, stretching-only, aerobic/endurance-only, or blood flow restriction-only.
Comparator	Interventions that compared the acute effects of single or multiple active warm-up and/or re-warm-up strategies (e.g., two or more different warm-ups compared or warm-up vs. no warm-up compared) on strength performance during resistance training.	Interventions that only analyzed the effects of one warm-up and/or re-warm-up strategy (i.e., no comparator) on strength performance during a resistance training session.
Outcomes	At least one of the following measures in dynamic free-weight or machine-based resistance exercises (e.g., squat, leg press, bench press, deadlift): 1RM weight; total repetitions; volume load (total repetitions x weight); barbell velocity, power, or rate of force development.	Strength-related outcomes derived from isometric or isokinetic measures, elastic bands used in isolation, loaded and unloaded vertical jumps, resisted or unresisted sprints, repeated sprints, throws (e.g., barbell or medicine ball), or change of direction.
Study design	Cross-sectional or crossover studies.	Reviews and meta-analysis, longitudinal studies (randomized and non-randomized experimental studies), case studies.

1RM: one-repetition maximum.

Data extraction and analysis

The extracted data included i) the year of the study, ii) the country of origin of the study, iii) the number of participants, their age, years of training experience, body mass, and height, iv) characteristics of general and/or specific warm-ups and/or re-warm-ups, v) the transition time (i.e., the time between the completion of the warm-up or re-warm-up and the beginning of the main strength activity being evaluated), vi) type of evaluation post warm-up and respective outcome measures, and vii) main results. If a study expressed the relative intensity as maximum repetitions, we converted this value into a percentage of 1RM (e.g., 10RM to ~75% 1RM) based on the relationship between maximum repetitions and the percentage of 1RM (Nuzzo et al., 2024). The main results focused solely on comparisons between warm-up or re-warm-up conditions vs. other warm-up or re-warm-up conditions, or no warm-up conditions, in terms of dynamic strength performance. Furthermore, only comparisons between warm-up conditions that reached statistical significance ($p < 0.05$) were reported, along with the respective absolute difference in the outcome measure. When the values (e.g., mean) were not reported in the text or tables of the retrieved articles but were available in figures, we used the WebPlotDigitizer (v4) online tool to extract the data.

Results

Studies included in the review

The literature search on the online databases yielded 1018 articles (PubMed, n = 218; Web of Science, n = 155; Scopus, n = 645), out of which 485 were excluded for being duplicates and 518 due to their lack of alignment with the inclusion criteria (unrelated theme [n = 328]; studies that did not include healthy trained males aged between 18 and 40 years [n = 55]; studies that did not report the acute effects of active resistance training warm-up and/or re-warm-up strategies on subsequent dynamic strength performance [n = 56]; studies that did not report the outcome measures of interest [n = 79]). After searching our databases for related studies, we identified and included five studies. As a result, we included 20 studies (15 retrieved from online databases and 5 from personal databases) in this review. Through a meticulous analysis of these studies, we aimed to gain comprehensive insights into the potential impacts of active resistance training warm-up and/or re-warm-up interventions on dynamic strength performance. Nineteen studies focused on the effects of active resistance training warm-ups on subsequent strength performance, including 1RM load (Abad et al., 2011; Barroso et al., 2013; Mina et al., 2014, 2016), barbell lifting velocity and/or power (Cochrane et al., 2015; El Hage et al., 2012; Krzysztofik et al., 2020; Neves et al., 2024; Ribeiro et al., 2020, 2021; Ushirooka et al., 2023), and total repetitions and/or volume load (Alves et al., 2021; Enes et al., 2025; Gallo & Mello, 2017; Krzysztofik et al., 2020; Luz Junior et al., 2014; Nader et al., 2009; Ribeiro et al., 2014; Souza et al., 2024; Ushirooka et al., 2023; Viveiros et al., 2024). One study analyzed the impact of resistance training re-warm-ups on subsequent strength performance (Neves et al., 2025).

Effects of resistance training warm-ups on one-repetition maximum load

Table 2 presents four studies that examined the impact of warm-up strategies on 1RM load. Abad et al. (2011) showed that incorporating a general warm-up of 20 minutes of cycling at 60% maximum heart rate, followed by a specific warm-up of 8 repetitions at 50% 1RM plus 3 repetitions at 70% 1RM, increased the 1RM leg press load by more than 26 kg compared to just performing the specific warm-up. These findings were partly supported by Barroso et al. (2013), who also found that 15 minutes of cycling at 40% of maximum oxygen uptake (V̇O2max), followed by a specific warm-up of 8 repetitions at 50% 1RM plus 3 repetitions at 70% 1RM, increased the 1RM leg press load by more than 8-22 kg compared to the remaining four warm-up conditions (two warm-ups at 70% V̇O2max, one warm-up of 5 minutes at 40% V̇O2max, and a specific warm-up). For the 1RM squat, Mina et al. (2014) observed that a warm-up of 2 sets of 3 repetitions at 85% 1RM, using elastic bands in combination with the barbell, increased the 1RM load by more than 10 kg compared to the same warm-up without elastic bands. Furthermore, the same authors observed that a general warm-up of 5 minutes cycling at 65 revolutions per minute (rpm) plus 2 sets of 10 squats with 20 kg, followed by a specific warm-up of 2 sets of 3 repetitions at 85% 1RM, using chains in combination with the barbell, increased the 1RM load by more than 8 kg compared to the same warm-up without chains (Mina et al., 2016).

Table 2. Effects of Active Resistance Training Warm-up Strategies on 1RM Load.

Study	Country	Subjects	Warm-up + Transition + Evaluation	Main Results
Abad et al. (2011)	Brazil	N: 13 TE: 18 ± 7 mo Age: 27 ± 6 y BM: 72 ± 8 kg Height: 1.74 ± 0.6 m	**WUP#1:** 8 reps at 50% 1RM ILP + 2 min rest + 3 reps at 70% 1RM ILP **WUP#2:** 20 min cycling at 60% HRmax (60-70 rpm) + 3 min rest + WUP#1 **Transition:** 3 min **Evaluation post WUP:** 1RM ILP (kg)	**1RM ILP:** WUP#2 > WUP#1 (+26 kg) **→ Better WUP strategy for optimizing 1RM ILP load:** 20 min cycling at 60% HRmax (60-70 rpm) + 3 min rest + 8 reps at 50% 1RM ILP + 2 min rest + 3 reps at 70% 1RM ILP
Barroso et al. (2013)	Brazil	N: 16 TE: 16 ± 3 mo Age: 25 ± 3 y BM: 77 ± 8 kg	**WUP#1:** 8 reps at 50% 1RM ILP + 2 min rest + 3 reps at 70% 1RM ILP	**1RM ILP:** WUP#4 > WUP#1 (+9 kg), WUP#2 (+8 kg), WUP#3 (+9 kg), and WUP#5 (+22 kg)

		Height: 1.76 ± 0.8 m	**WUP#2:** 5 min cycling at 40% VO2max + 3 min rest + WUP#1 **WUP#3:** 5 min cycling at 70% VO2max + 3 min rest + WUP#1 **WUP#4:** 15 min cycling at 40% VO2max + 3 min rest + WUP#1 **WUP#5:** 15 min cycling at 70% VO2max + 3 min rest + WUP#1 **Transition:** 3 min **Evaluation post WUP:** 1RM ILP (kg)	**→ Better WUP strategy for optimizing 1RM ILP load:** 15 min cycling at 40% VO2max + 3 min rest + 8 reps at 50% 1RM ILP + 2 min rest + 3 reps at 70% 1RM ILP
Mina et al. (2014)	England	N: 16 TE: > 3 y Age: 26 ± 8 y BM: 83 ± 13 kg Height: 1.7 ± 0.2 m	**WUP#1:** 2 sets of 3 reps at 85% 1RM FW-SQ barbell (3 min rest between sets) **WUP#2:** 2 sets of 3 reps at 85% 1RM FW-SQ barbell + elastic bands (3 min rest between sets) **Transition:** 5 min (passive rest) **Evaluation post WUP:** 1RM FW-SQ (kg)	**1RM FW-SQ:** WUP#2 > WUP#1 (+10 kg) **→ Better WUP strategy for optimizing 1RM FW-SQ load:** 2 sets of 3 reps at 85% 1RM FW-SQ barbell + elastic bands (3 min rest between sets)
Mina et al. (2016)	England	N: 16 TE: > 3 y Age: 26 ± 8 y BM: 83 ± 13 kg Height: 1.73 ± 0.2 m	**WUP for all conditions:** 5 min cycling at 65 rpm with 1 kg + 2 min rest + 2 sets of 10 reps of FW-SQ with 20 kg **WUP#1:** 2 sets of 3 reps at 85% 1RM FW-SQ with barbell (3 min rest between sets) **WUP#2:** 2 sets of 3 reps at 85% 1RM FW-SQ with barbell + chains (3 min rest between sets) **Transition:** 5 min **Evaluation post WUP:** 1RM FW-SQ (kg)	**1RM FW-SQ:** WUP#2 > WUP#1 (+8 kg) **→ Better WUP strategy for optimizing 1RM FW-SQ load:** 5 min cycling at 65 rpm with 1 kg + 2 min rest + 2 sets of 10 reps of FW-SQ with 20 kg + 2 min rest + 2 sets of 3 reps at 85% 1RM FW-SQ with barbell + chains (3 min rest between sets)

> significant difference between warm-up conditions; 1RM: one-repetition maximum; BM: body mass; FW-SQ: free-weight squat; HRmax: maximal heart rate; ILP: inclined leg press; mo: months; rpm: revolutions per minute; TE: training experience; WUP: warm-up; y: years.

Effects of resistance training warm-ups on barbell lifting mechanics

Table 3 presents the impact of various warm-up strategies on barbell lifting velocity and power in the bench press (El Hage et al., 2012; Krzysztofik et al., 2020; Neves et al., 2024; Ribeiro et al., 2020, 2021; Ushirooka et al., 2023), squat (Neves et al., 2024; Ribeiro et al., 2020, 2021), and deadlift (Cochrane et al., 2015). For the bench press, the evidence is inconclusive regarding which warm-up strategy best improves lifting mechanics (i.e., velocity, power, or RFD) at 60% 1RM (Krzysztofik et al., 2020) and 80% 1RM (Neves et al., 2024; Ribeiro et al., 2020, 2021; Ushirooka et al., 2023). On the other hand, for 40% 1RM bench press, El Hage et al. (2012) found that a general warm-up of 5 minutes running plus 10 repetitions at 50% 1RM and 6 repetitions at 60% 1RM, followed by a specific warm-up of 4 repetitions at 20% 1RM, optimized power output when compared to no specific warm-up (difference of +60-93 W) or the general warm-up plus a specific warm-up of 3 repetitions at 80% 1RM (difference of +34-71 W). Regarding the squat, two studies (Neves et al., 2024; Ribeiro et al., 2020) found inconclusive evidence on which warm-up strategy optimizes subsequent barbell lifting velocity and power at 80% 1RM. However, Ribeiro et al. (2020) found a tendency for greater mean lifting velocities following a warm-up of 6 repetitions at 80% of the training load. When comparing a warm-up condition of 6 repetitions at 40% of the training load plus 6 repetitions at 80% of the training load versus a no warm-up condition, the former condition resulted in greater velocities at 80% 1RM than the latter condition (Ribeiro et al., 2021). For the deadlift, Cochrane et al. (Cochrane et al., 2015) found no differences in power output and RFD at 75% 1RM between 10, 8, and 5 loaded (30%, 40%, and 50% 1RM, respectively) and unloaded warm-up repetitions.

Table 3. Effects of Active Resistance Training Warm-Up Strategies on Barbell Lifting Velocity and Power.

Study	**Country**	**Subjects**	**Warm-up + Transition + Evaluation**	**Main Results**
El Hage et al. (2012)	Lebanon	N: 10 TE: ≥ 2 y Age: 26 ± 5 y BM: 94 ± 10 kg Height: 1.85 ± 0.7 m	**WUP for all conditions:** 5 min running + 2 min rest + 10 reps at 50% 1RM SM-BP + 2 min rest + 6 reps at 60% 1RM SM-BP **WUP#1:** No activity **WUP#2**: 4 reps at 20% 1RM SM-BP **WUP#3:** 3 reps at 80% 1RM SM-BP **Transition:** 0, 2, 4, and 8 min	**PP:** WUP#2 > WUP#1 (2-min: +85 W; 4-min: +60 W; 8-min: +93 W) and WUP#3 (2-min: +34 W; 4-min: +71 W); WUP#3 > WUP#1 (2-min: +51 W; 8-min: +77 W) **→ Better WUP strategy for optimizing PP at 40% 1RM SM-BP:** 5 min running + 2 min rest + 10 reps at 50% 1RM SM-BP + 2 min rest + 6

			Evaluation post WUP: 3 reps at 40% 1RM SM-BP after 0, 2, 4, and 8 min (PP [W])	reps at 60% 1RM SM-BP + 2-4 min rest + 4 reps at 20% 1RM SM-BP
Cochrane et al. (2015)	New Zealand	N: 12 TE: 6 ± 3 y Age: 26 ± 7 y BM: 86 ± 17 kg Height: 1.78 ± 0.1 m	**WUP#1:** 10 reps at 30% 1RM FW-DL + 1 min rest + 8 reps at 40% 1RM FW-DL + 1 min rest + 5 reps at 50% 1RM FW-DL **WUP#2:** 10 reps BW-SQ + 1 min rest + 8 reps BW-SQ + 1 min rest + 5 reps BW-SQ **Transition:** 30 s and 150 s **Evaluation post WUP:** 2 reps at 75% 1RM FW-DL (RPP [W/kg]; RMP [W/kg]; RFD [kN/s])	**RPP:** No significant differences between conditions **RMP:** No significant differences between conditions **RFD:** No significant differences between conditions **→ Better WUP strategy for optimizing RPP, RMP, and RFD at 75% 1RM FW-DL:** inconclusive
Krzysztofik et al. (2020)	Poland	N: 12 TE: 6 ± 2 y Age: 25 ± 2 y BM: 92 ± 9 kg Height: not reported	**WUP for all conditions:** 5 min cycling at ~130 bpm + 10 trunk rotations and side-bands + 10 internal and external shoulder rotations + 10 push-ups + 15 reps at 20% 1RM FW-BP + 10 reps at 40% 1RM FW-BP + 5 reps at 70% 1RM FW-BP **WUP#1:** 3 sets of 3 reps at 85% 1RM FW-BP (4 min rest between sets) **WUP#2:** No activity performed Transition: Individualized for each participant: 4, 8, 12, **and 16 min** **Evaluation post WUP:** 3 sets of maximum reps at 60% 1RM FW-BP (MV [m·s-1], PV [m·s-1], MP [W], PP [W])	**MV:** No significant differences between conditions **PV:** No significant differences between conditions **MP:** No significant differences between conditions **PP:** No significant differences between conditions **→ Better WUP strategy for optimizing mechanical performance at 60% 1RM FW-BP:** inconclusive
Ribeiro et al. (2020)	Portugal	N: 14 TE: ≥ 2 y Age: 24 ± 3 y BM: 78 ± 10 kg	**WUP#1:** 6 reps at 40% TL SM-SQ + 1 min rest + 6 reps at 80% TL SM-SQ **WUP#2:** 6 reps at 80% TL SM-SQ	**MPV:** WUP#2 > WUP#3 (SET2: +0.04 m·s-1; SET3: +0.03 m·s-1) **PV:** No significant differences between conditions

		Height: 1.76 ± 0.7 m	**WUP#3:** 6 reps at 40% TL SM-SQ **Transition:** 3 min **Evaluation post WUP:** 3 sets of 6 reps at 80% 1RM SM-SQ (MPV [m·s-1], PV [m·s-1], MPP [W])	**MPP:** No significant differences between conditions **→ Better WUP strategy for optimizing mechanical performance at 80% 1RM SM-SQ:** inconclusive, although 6 reps at 80% TL SM-SQ are better for optimizing MPV
Ribeiro et al. (2020)	Portugal	N: 26 TE: ≥ 2 y Age: 22 ± 2 y BM: 72 ± 8 kg Height: 1.77 ± 0.1 m	**WUP#1:** 6 reps at 40% TL SM-BP + 1 min rest + 6 reps at 80% TL SM-BP **WUP#2:** 6 reps at 80% TL SM-BP WUP#3: 6 reps at 40% TL SM-BP **Transition:** 3 min **Evaluation post WUP:** 3 sets of 6 reps at 80% 1RM SM-BP (MPV [m·s-1], PV [m·s-1], MPP [W])	**MPV:** No significant differences between conditions **PV:** No significant differences between conditions **MPP:** No significant differences between conditions **→ Better WUP strategy for optimizing mechanical performance at 80% 1RM SM-BP:** inconclusive
Ribeiro et al. (2021)	Portugal	N: 12 TE: ≥ 2 y Age: 24 ± 3 y BM: 78 ± 11 kg Height: 1.76 ± 0.1 m	**WUP#1:** 5 min rest (seated position) **WUP#2:** 6 reps at 40% TL SM-SQ + 1 min rest + 6 reps at 80% TL SM-SQ **Transition:** 5 min **Evaluation post WUP:** 3 sets of 6 reps at 80% 1RM SM-SQ (MPV [m·s-1], PV [m·s-1], and MPP [W])	**MPV:** WUP#2 > WUP#1 (SET1: +0.04 m·s-1) **PV:** WUP#2 > WUP#1 (ALL SETS: +0.12 m·s-1) **MPP:** No significant differences between conditions **→ Better WUP strategy for optimizing mechanical performance at 80% 1RM SM-SQ:** 6 reps at 40% TL SM-SQ + 1 min rest + 6 reps at 80% TL SM-SQ
Ribeiro et al. (2021)	Portugal	N: 22 TE: ≥ 2 y Age: 24 ± 2 y	**WUP#1:** 5 min rest (seated position)	**MPV:** WUP#2 > WUP#1 (SET1: +0.05 m·s-1)

		BM: 77 ± 9 kg Height: 1.76 ± 0.1 m	**WUP#2:** 6 reps at 40% TL SM-BP + 1 min rest + 6 reps at 80% TL SM-BP **Transition:** 5 min **Evaluation post WUP:** 3 sets of 6 reps at 80% 1RM SM-BP (MPV [m·s-1], PV [m·s-1], and MPP [W])	**PV:** No significant differences between conditions **MPP:** No significant differences between conditions **→ Better WUP strategy for optimizing mechanical performance at 80% 1RM SM-BP:** inconclusive, although 6 reps at 40% TL SM-BP + 1 min rest + 6 reps at 80% TL SM-BP are better for optimizing MPV
Ushirooka et al. (2023)	Japan	N: 14 TE: 5 ± 2 y Age: 23 ± 2 y BM: 74 ± 12 kg Height: 1.76 ± 0.1 m	**WUP#1:** 5 reps at 40% 1RM FW-BP + 2 min rest + 3 reps at 60% 1RM FW-BP + 2 min rest + 1 rep at 80% 1RM FW-BP **WUP#2:** 20 min cycling at 60% HRmax (60-70 rpm) + 2 min rest + WUP#1 **Transition:** 3 min **Evaluation post WUP:** 3 sets of maximum reps at 80% 1RM FW-BP (MPV [m·s-1])	**MPV:** No significant differences between conditions **→ Better WUP strategy for optimizing mechanical performance at 80% 1RM FW-BP:** inconclusive
Neves et al. (2024)	Portugal	N: 14 TE: ≥ 6 mo Age: 26 ± 7 y BM: 75 ± 6 kg Height: 1.77 ± 0.1 m	**WUP#1:** 6 reps at 40% TL SM-BP + 1 min rest + 6 reps at 80% TL SM-BP **WUP#2:** 8 min treadmill running at 50-55% HRres + 2 min treadmill running at 70% HRres + 1 min rest + WUP#1 **Transition:** Not specified **Evaluation post WUP:** 3 sets of 6 reps at 80% 1RM SM-BP (MPV [m·s-1], PV [m·s-1], and MPP [W])	**MPV:** No significant differences between conditions **PV:** No significant differences between conditions **MPP:** No significant differences between conditions **→ Better WUP strategy for optimizing mechanical performance at 80% 1RM SM-BP:** inconclusive

Neves et al. (2024)	Portugal	N: 12 TE: ≥ 6 mo Age: 22 y BM: 70 kg Height: 1.71 m	**WUP#1:** 6 reps at 40% TL SM-SQ + 1 min rest + 6 reps at 80% TL SM-SQ **WUP#2:** 8 min treadmill running at 50-55% HRres + 2 min treadmill running at 70% HRres + 1 min rest + WUP#1 **Transition:** Not specified **Evaluation post WUP:** 3 sets of 6 reps at 80% 1RM SM-SQ (MPV [m·s-1], PV [m·s-1], and MPP [W])	**MPV:** No significant differences between conditions **PV:** No significant differences between conditions **MPP:** No significant differences between conditions **→ Better WUP strategy for optimizing mechanical performance at 80% 1RM SM-SQ:** inconclusive

> significant difference between warm-up conditions; 1RM: one-repetition maximum; BM: body mass; bpm: beats per minute; FW-BP: free-weight bench press; FW-DL: free-weight deadlift; FW-SQ: free-weight squat; HRmax: maximal heart rate; HRres: heart rate reserve; mo: months; MPP: mean propulsive power; MPV: mean propulsive velocity; PP: peak power; PV: peak velocity; RFD: rate of force development; RMP: relative mean power; rpm: revolutions per minute; RPP: relative peak power; SM-BP: Smith machine bench press; SM-SQ: Smith machine squat; TE: training experience; TL: training load; WUP: warm-up; y: years.

Effects of resistance training warm-ups on total repetition

Table 4 shows the impact of different warm-up configurations on the total repetitions and/or volume load in the bench press (Alves et al., 2021; Enes et al., 2025; Gallo & Mello, 2017; Krzysztofik et al., 2020; Luz Junior et al., 2014; Nader et al., 2009; Ribeiro et al., 2014; Ushirooka et al., 2023; Viveiros et al., 2024), squat (Ribeiro et al., 2014; Souza et al., 2024), leg press (Enes et al., 2025; Luz Junior et al., 2014; Viveiros et al., 2024), lat pull-down (Viveiros et al., 2024), and arm curl (Ribeiro et al., 2014). For the bench press, there is inconclusive evidence on the most effective warm-up strategy to increase total repetitions at 60% 1RM (Krzysztofik et al., 2020) and 80% 1RM (Nader et al., 2009; Ribeiro et al., 2014; Ushirooka et al., 2023). On the other hand, at 70-75% 1RM bench press, the literature indicates either no differences in the effects of resistance training warm-up strategies on total repetitions and/or volume load (Enes et al., 2025; Gallo & Mello, 2017) or a broad spectrum of warm-up relative loads capable of increasing total repetitions and/or volume load (Alves et al., 2021; Luz Junior et al., 2014; Viveiros et al., 2024). Gallo & Mello (Gallo & Mello, 2017) found no additional benefits of performing a warm-up of 15 repetitions at 40% 1RM on the total repetitions performed at 70% 1RM when compared to a no warm-up condition. In the same line, Enes et al.

(Enes et al., 2025) did not observe additional benefits of either one or two warm-up sets of 3-4 repetitions at ~40 and ~55% 1RM on total repetitions and volume load at 75% 1RM bench press compared to a no warm-up condition. Additionally, Luz Junior et al. (2014) found that a warm-up of 2 sets of 2 repetitions at 90% 1RM resulted in a higher number of repetitions completed at 70% 1RM than a warm-up of 15 repetitions at 40% 1RM (+4 repetitions). Furthermore, Viveiros et al. (2024) found that a warm-up at 60% 1RM resulted in a greater increase in volume load at 75% 1RM bench press than a warm-up at 45% 1RM (difference of +124 kg). Finally, Alves et al. (2021) found that a warm-up of 8 repetitions at 50% 1RM was more effective in increasing total volume at 75% 1RM bench press than a warm-up of 8 repetitions at 50% 1RM plus 3 repetitions at 90% 1RM (difference of +1 rep).

For the squat, Ribeiro et al. (2014) found inconclusive evidence on the best warm-up strategy to increase total repetitions at 80% 1RM. On the other hand, although Souza et al. (2024) partly corroborate the latter findings for total repetitions, the authors observed that a warm-up of 8 repetitions at 45% 1RM plus 3 repetitions at 90% 1RM was better for optimizing volume load at 75% 1RM squat than only 8 repetitions at 45% 1RM (difference of +53 kg lifted).
In the inclined leg press, Luz Junior et al. (2014) found that a warm-up of 2 sets of 2 repetitions at 90% 1RM resulted in a greater increase in the total repetitions completed at 70% 1RM than a warm-up of 15 repetitions at 40% 1RM (+ 4 repetitions). On the other hand, although Viveiros et al. (2024) found no significant differences between three warm-up conditions in increasing the volume load at 75% 1RM leg press, the warm-up with 5 repetitions at 60% 1RM produced better results than the warm-ups with 10 repetitions at 45% 1RM (difference of +374 kg lifted) and with 15 repetitions at 30% 1RM (difference of +376 kg lifted). Finally, Enes et al. (Enes et al., 2025) found no significant benefits from completing a warm-up of one or two sets of 3-4 repetitions at light loads (~40 and ~55% 1RM) on total repetitions and volume load at 75% 1RM leg press compared to not warming up.

For the lat pull-down, Viveiros et al. (2024) found no differences between three warm-up conditions in increasing the volume load at 75% 1RM. However, when considering the session volume load (i.e., the combined volume load from the bench press, inclined leg press, and lat pull-down), Viveiros et al. (2024) found that a warm-up at 60% 1RM led to a significantly greater increase in volume load at 75% 1RM compared to warm-ups at 45% 1RM (+655 kg) and 30% 1RM (+543 kg). For the arm curl exercise, there is inconclusive evidence on the better warm-up strategy for optimizing total repetitions at 80% 1RM (Ribeiro et al., 2014).

Table 4. Effects of Active Resistance Training Warm-Up Strategies on Total Repetitions and/or Volume Load.

Study	Country	Subjects	Warm-up + Transition + Evaluation	Main Results
Nader et al. (2009)	Brazil	N: 9 TE: ≥ 6 mo Age: 24 ± 2 y BM: 78 ± 7 kg Height: 1.70 ± 0.1 m	**WUP#1:** 10 min treadmill running at 70% HRres **WUP#2:** 15 reps at 40% 1RMǂ FW-BP **Transition:** 90 s **Evaluation post WUP:** 3 sets of maximum reps at 80% 1RM FW-BP (Total Reps [n])	**Total Reps (All Sets):** No significant differences between conditions **→ Better WUP strategy for optimizing maximum reps at 80% 1RM FW-BP:** inconclusive
Junior et al. (2014)	Brazil	N: 16 TE: ≥ 3 y Age: 24 ± 4 y BM: 75 ± 7 kg Height: 1.76 ± 0.1 m	**WUP#1:** No activity **WUP#2:** 5 min treadmill walking at 50% VO2max **WUP#3:** 15 reps at 40% 1RM FW-BP **WUP#4:** 2 sets of 2 reps at 90% 1RM FW-BP **Transition:** 1 min **Evaluation post WUP:** 1 set of maximum reps at 70% 1RM FW-BP (Total Reps [n])	**Total Reps:** WUP#1 > WUP#3 (+2 reps); WUP#2 > WUP#3 (+2 reps); WUP#4 > WUP#1 (+2 reps), WUP#2 (+2 reps), and WUP#3 (+4 reps) **→ Better WUP strategy for optimizing maximum reps at 70% 1RM FW-BP:** 2 sets of 2 reps at 90% 1RM FW-BP
Junior et al. (2014)	Brazil	N: 14 males TE: ≥ 3 y Age: 27 ± 6 y BM: 76 ± 7 kg Height: 1.76 ± 0.1 m	**WUP#1:** No activity **WUP#2:** 5 min treadmill walking at 50% VO2max **WUP#3:** 5 min cycling at 50% VO2max **WUP#4:** 15 reps at 40% 1RM ULP **WUP#5:** 2 sets of 2 reps at 90% 1RM ULP **Transition:** 1 min	**Total Reps:** WUP#5 > WUP#1 (+6 reps), WUP#2 (+6 reps), WUP#3 (+3 reps), WUP#4 (+4 reps) **→ Better WUP strategy for optimizing maximum reps at 70% 1RM ULP:** 2 sets

			Evaluation post WUP: 1 set of maximum reps at 70% 1RM ULP (Total Reps [n])	of 2 reps at 90% 1RM ULP
Ribeiro et al. (2014)	Brazil	N: 15 TE: 8 ± 6 mo Age: 25 ± 5 y BM: 72 ± 14 kg Height: 1.76 ± 0.1 m	**WUP#1:** 10 min rest (seated position) **WUP#2:** 10 reps at 40% 1RM SM-BP, SM-SQ, and AC **WUP#3:** 10 min cycling at 40 km/h **WUP#4:** 10 min cycling at 40 km/h + 10 reps at 40% 1RM SM-BP, SM-SQ, and AC **Transition:** 30 s **Evaluation post WUP:** 4 sets of maximum reps at 80% 1RM SM-BP, SM-SQ, and AC (Total Reps [n])	**Total Reps (All Sets):** No significant differences between conditions **→ Better WUP strategy for optimizing maximum reps at 80% 1RM SM-BP, SM-SQ, and AC:** inconclusive
Gallo & Mello (2017)	Brazil	N: 15 TE: > 6 mo Age: 26 ± 5 y BM: 78 ± 6 kg Height: 1.72 ± 0.1 m	**WUP#1:** No activity **WUP#2:** 15 reps at 40% 1RM FW-BP **WUP#3:** 2 sets of 20 s of static stretching (pectoralis, deltoids, and triceps muscles) **WUP#4:** 5 min treadmill walking at 50% VO2max **WUP#5:** 5 min treadmill walking at 50% VO2max + 2 sets of 20 s of static stretching (pectoralis, deltoids, and triceps muscles) **Transition:** 1 min **Evaluation post WUP:** 1 set of maximum reps at 70% 1RM FW-BP (Total Reps [n])	**Total Reps:** WUP#5 > WUP#1 (+1 rep); WUP#4 > WUP#1 (+2 reps); WUP#3 > WUP#1 (+1 rep) **→ Better WUP strategy for optimizing maximum reps at 70% 1RM FW-BP:** 5 min treadmill walking at 50% VO2max OR 2 sets of 20 s of static stretching (pectoralis, deltoids, and triceps muscles) OR both
Krzysztofik et al. (2020)	Poland	N: 12 TE: 6 ± 2 y Age: 25 ± 2 y BM: 92 ± 9 kg Height: not reported	**WUP for all conditions:** 5 min cycling at ~130 bpm + 10 trunk rotations and side-bands + 10 internal and external shoulder rotations + 10 push-ups + 15 reps at 20% 1RM FW-BP + 10 reps at 40% 1RM FW-BP + 5 reps at 70% 1RM FW-BP	**Total Reps:** No significant differences between conditions **→ Better WUP strategy for optimizing mechanical performance at 60% 1RM FW-BP:** inconclusive

			WUP#1: 3 sets of 3 reps at 85% 1RM FW-BP (4 min rest between sets) **WUP#2:** No activity performed **Transition:** Individualized for each participant: 4, 8, 12, and 16 min **Evaluation post WUP:** 3 sets of maximum reps at 60% 1RM FW-BP (Total Reps [n])	
Alves et al. (2021)	Brazil	N: 14 TE: 5 ± 4 y Age: 25 ± 4 y BM: 90 ± 16 kg Height: 1.77 ± 0.1 m	**WUP#1:** 8 reps at 50% 1RM FW-BP **WUP#2:** 8 reps at 50% 1RM FW-BP + 1.5 min rest + 3 reps at 90% 1RM FW-BP **Transition:** 4 min for WUP#1; 10 min for WUP#2 **Evaluation post WUP:** 3 sets of maximum reps at 75% 1RM FW-BP (Total Reps [n])	**Total Reps:** WUP#1 > WUP#2 (SET1: +1 rep; SET2: +1 rep) → **Better WUP strategy for optimizing maximum reps at 75% 1RM FW-BP:** 8 reps at 50% 1RM FW-BP
Ushirooka et al. (2023)	Japan	N: 14 TE: 5 ± 2 y Age: 23 ± 2 y BM: 74 ± 12 kg Height: 1.76 ± 0.1 m	**WUP#1:** 5 reps at 40% 1RM FW-BP + 2 min rest + 3 reps at 60% 1RM FW-BP + 2 min rest + 1 rep at 80% 1RM FW-BP **WUP#2:** 20 min cycling at 60% HRmax (60-70 rpm) + 2 min rest + WUP#1 **Transition:** 3 min **Evaluation post WUP:** 3 sets of maximum reps at 80% 1RM FW-BP (Total Reps [n])	**Total Reps:** No significant differences between conditions → **Better WUP strategy for optimizing mechanical performance at 80% 1RM FW-BP:** inconclusive
Souza et al. (2024)	Brazil	N: 14 TE: 9 ± 5 y Age: 28 ± 4 y BM: 80 ± 14 kg Height: 1.70 ± 0.1 m	**WUP for all conditions:** SM-SQ: 8 reps at 45% 1RM **WUP#1:** 3 reps at 90% 1RM SM-SQ **WUP#2:** 6 reps at 45% 1RM SM-SQ **WUP#3:** No activity after the general WUP for all conditions	**Total Reps:** No significant differences between conditions **Volume Load:** WUP#1 > WUP#3 (SET1: +117 kg) → **Better WUP strategy for optimizing maximum reps at**

			Transition: 10 min after WUP#1 and WUP#2; 2 min after WUP#3 **Evaluation post WUP:** 3 sets of maximum reps at 75% 1RM SM-SQ (Total Reps [n]; Volume Load [kg])	**75% 1RM SM-SQ:** inconclusive, although 3 reps at 90% 1RM SM-SQ are better for optimizing volume load
Viveiros et al. (2024)	Brazil	N: 15 TE: ≥ 6 mo Age: 27 ± 4 y BM: 84 ± 13 kg Height: 1.79 ± 0.1 m	**WUP#1:** 15 reps at 30% 1RM* BP, ILP, and LPD (2 min rest between exercises) **WUP#2:** 10 reps at 45% 1RM** BP, ILP, and LPD (2 min rest between exercises) **WUP#3:** 5 reps at 60%1RM*** BP, ILP, and LPD (2 min rest between exercises) **Transition:** Not specified **Evaluation post WUP:** 3 sets of maximum reps at 75% 1RM**** FW-BP, ILP, and LPD (2 min rest between sets and exercises) (Volume Load [kg])	**Volume Load BP:** WUP#3 > WUP#2 (+124 kg) **Volume Load ILP:** No significant differences between conditions **Volume Load LPD:** No significant differences between conditions **Volume Load Session:** WUP#3 > WUP#1 (+543 kg) and WUP#2 (+655 kg) **→ Better WUP strategy for optimizing maximum reps (volume load) at 75% 1RM FW-BP, ILP, and LPD:** 5 reps at 60% 1RM BP, ILP, and LPD (2 min rest between exercises)
Enes et al. (2025)	Brazil	N: 29 TE: 5 ± 4 y Age: 23 ± 4 y BM: 79 ± 15 kg Height: 1.68 ± 0.1 m	**WUP#1:** No activity **WUP#2:** 3-4 reps at ~55% 1RM# SM-BP and ILP **WUP#3:** 3-4 reps at ~40% 1RM## + 3-4 reps at ~55% 1RM# SM-BP and ILP **Transition:** 2 min **Evaluation post WUP:** 4 sets of maximum reps at 75% 1RM**** SM-BP and ILP (2 min rest between sets and	**Total Reps:** No significant differences between conditions **Volume Load:** No significant differences between conditions **→ Better WUP strategy for optimizing maximum reps at**

	exercises) (Total Reps [n]; Volume Load [kg])	**75% 1RM SM-BP and ILP:** inconclusive

> significant difference between warm-up conditions; ǂ Reported by authors as 50% 8RM; * Reported by authors as 40% 10RM; ** Reported by authors as 60% 10RM; *** Reported by authors as 80% 10RM; **** Reported by authors as 10RM; 1RM: one-repetition maximum; # Reported by authors as 75% 10RM; ## Reported by authors as 55% 10RM; AC: arm curl; BM: body mass; BP: bench press; bpm: beats per minute; FW-BP: free-weight bench press; HRmax: maximal heart rate; HRres: heart rate reserve; ILP: inclined leg press; LPD: Lat pull-down; mo: months; NR: not reported; rpm: revolutions per minute; SM-BP: Smith machine bench press; SM-SQ: Smith machine squat; TE: training experience; ULP: unilateral leg press (dominant leg); V̇O2max: maximum oxygen uptake; WUP: warm-up; y: years.

Effects of Resistance Training Re-Warm-Ups on Barbell Lifting Mechanics

The study conducted by Neves et al. (Neves et al., 2025) observed that performing a re-warm-up before the squat (bench press performed as the first exercise of the session) elicited greater increases in barbell lifting velocity (+0.02-0.03 m·s1 for mean propulsive velocity and +0.05-0.06 m·s1 for peak velocity) and power (+17-19 W for mean propulsive power and +46-64 W for peak power) during training sets (3 sets of 6 repetitions at 80% 1RM) compared to the no re-warm-up condition (Table 5). On the other hand, performing a re-warm-up before the bench press (squat performed as the first exercise of the session) did not significantly increase barbell lifting mechanics during training sets compared to the no-re-warm-up condition.

Table 5 Effects of Active Resistance Training Re-Warm-Up Strategies on Barbell Lifting Velocity and Power.

Authors	Country	Subjects	Conditions (C#) + Transition + Outcomes	Main Results
Neves et al. (2025)	Portugal	N: 22 TE: ≥ 6 mo Age: 23 ± 3 y BM: 76 ± 13 kg Height: 1.78 ± 0.1 m	**WUP for all C#:** 8 min treadmill running at 50-55% HR_{res} + 2 min treadmill running at 70% HR_{res} + 6 reps at 40% TL SM-SQ or SM-BP + 6 reps at 80% TL SM-SQ or SM-BP **C#1:** 3 sets of 6 reps at 80% 1RM SM-BP (3 min rest between sets) + 6 reps at 40% TL SM-SQ + 1 min rest + 6 reps at 80% TL SM-SQ + 3 sets of 6 reps at 80% 1RM SM-SQ (3 min rest between sets) **C#2:** 3 sets of 6 reps at 80% 1RM SM-BP (3 min rest between sets) + 3 sets of 6 reps at 80% 1RM SM-SQ (3 min rest between sets) **C#3:** 3 sets of 6 reps at 80% 1RM SM-SQ (3 min rest between sets) + 6 reps at 40% TL SM-BP + 1 min rest + 6 reps at 80% TL SM-BP + 3 sets of 6 reps at 80% 1RM SM-BP (3 min rest between sets) **C#4:** 3 sets of 6 reps at 80% 1RM SM-SQ (3 min rest between sets) + 3 sets of 6 reps at 80% 1RM SM-BP (3 min rest between sets) **Transition:** 0 min **Outcomes assessed post-RWUP or No-RWUP:** MPV ($m{\cdot}s^{-1}$), PV ($m{\cdot}s^{-1}$), MPP (W), and PP (W)	**MPV**: C#1 > C#2 (SET1: +0.03 $m{\cdot}s^{-1}$; SET2: +0.02 $m{\cdot}s^{-1}$; SET3: +0.02 $m{\cdot}s^{-1}$) **PV:** C#1 > C#2 (SET1: +0.06 $m{\cdot}s^{-1}$; SET2: +0.05 $m{\cdot}s^{-1}$) **MPP:** C#1 > C#2 (SET2: +19 W; SET3: +17 W) **PP:** C#1 > C#2 (SET2: +64 W; SET3: +46 W) **→ RWUP or No-RWUP for optimizing mechanical performance at 80% 1RM SM-SQ?** RWUP with 6 reps at 40% TL SM-SQ + 1 min rest + 6 reps at 80% TL SM-SQ **→ RWUP or No-RWUP for optimizing mechanical performance at 80% 1RM SM-BP?** Inconclusive

> significant difference between conditions; 1RM: one-repetition maximum; BM: body mass; HRres: heart rate reserve; mo: months; No-RWUP: condition without re-warm-up; MPP: mean propulsive power; MPV: mean propulsive velocity; PP: peak power; PV: peak velocity; RWUP:

condition with re-warm-up; SM-BP: Smith machine bench press; SM-SQ: Smith machine squat; TE: training experience; TL: training load; WUP: warm-up; y: years.

Discussion

This study provides a review of research on the acute effects of active resistance training warm-up strategies on subsequent dynamic strength performance in strength-trained males. Overall, the results suggest that resistance training warm-ups have a positive influence on increasing 1RM load, with the evidence primarily limited to lower-limb strength exercises, such as the leg press and back squat. Regarding barbell lifting velocity, power, total repetitions, and volume load, the available evidence is limited to a few strength exercises (mainly bench press and squat) and relative loads (mainly 70% to 80% 1RM), restricting the development of well-established, evidence-based warm-up strategies to improve dynamic strength performance during training sessions. Additionally, only one study was found on the effects of resistance training re-warm-ups between exercises on dynamic strength performance, revealing a research gap that warrants further exploration. In summary, despite the promising results, there is still a significant need for research exploring how different warm-up and re-warm-up strategies affect strength performance, particularly with various volume configurations, a wider range of relative loads, and a detailed analysis of the transition time between warm-up or re-warm-ups and the main activity to optimize strength outcomes in strength-trained males.

Among the included studies in this review, two analyzed the impact of different warm-ups on 1RM inclined leg press load (Abad et al., 2011; Barroso et al., 2013) and two on 1RM back squat load (Mina et al., 2014, 2016). Both Abad et al. (2011) and Barroso et al. (2013) found that a specific warm-up of 8 repetitions at 50% 1RM plus 3 repetitions at 70% 1RM preceded by a general warm-up of 15-20 minutes cycling at light intensity resulted in greater increases on 1RM inclined leg press load than no general warm-up or a general warm-up of shorter or equal duration with higher intensities (> 70% maximum heart rate). The use of higher aerobic intensities in the general warm-up may be at the origin of the subsequent decrease in dynamic strength performance, as the greater contribution of the anaerobic system leads to a higher accumulation of muscle fatigue compared to lower intensities (Barroso et al., 2013). In this case, a transition time of more than 3 minutes (the time used in both studies) between the warm-up and the main activity may be required to achieve greater benefits from this warm-up strategy on 1RM leg press load. Future studies should investigate the time required to recover after warm-ups with higher aerobic intensities to optimize 1RM testing performance in lower and upper limb resistance exercises.

Still, about the impact of warm-up strategies on 1RM load, Mina et al. dedicated two studies to analyze the differences between warm-up strategies on 1RM back squat load. First, the authors found that a warm-up of 2 sets of 3 repetitions at 85% 1RM, using elastic bands in combination with the barbell, resulted in greater increases in the 1RM squat load than the same warm-up without elastic bands (+10 kg) (Mina et al., 2014). These findings were corroborated in a study conducted two years later (Mina et al., 2016). However, in that study, the authors introduced a general warm-up of 5 minutes of cycling at 65 rpm, followed by 2 sets of 10 squats with a 20 kg load, before the specific warm-up of 2 sets of 3 repetitions at 85% 1RM, using chains in combination with the barbell. In summary, adding elastic bands or chains to the barbell can be an effective way to increase 1RM load, as they help decrease the load near the "sticking point" at the start of the concentric phase and enable heavier loading later in that phase, thereby boosting force production without altering the lifting mechanics. Furthermore, the use of high relative loads (e.g., 80-90% 1RM), which appears to be a key factor in resistance training warm-ups for achieving greater immediate performance improvements in the subsequent main activity (Garbisu-Hualde & Santos-Concejero, 2021; Wilson et al., 2013), may also have played a significant role in potentiating the increases in 1RM load. Future studies should compare the general and specific warm-ups with elastic bands vs. chains to determine which approach is more effective in increasing the 1RM back squat load. Furthermore, there is a great need for research analyzing the impact of various warm-up conditions using traditional resistance exercises on 1RM load, including but not limited to the bench press, lat pull-down, deadlift, leg extension, and leg curl.

In this review, we examined different resistance training warm-up strategies and their impact on subsequent dynamic strength performance during training, including barbell lifting velocity and power. Here, it was evident that there is a lack of research on this topic, with studies primarily focusing on the bench press, squat, and deadlift, as well as on training sessions using high relative loads (80% 1RM). Most studies have found inconclusive evidence regarding the optimal warm-up strategy to enhance barbell lifting velocity and power during training sessions, except for three studies (El Hage et al., 2012; Ribeiro et al., 2020, 2021). El Hage et al. (2012) found that a general warm-up of 5 min running, followed by 10 repetitions at 50% 1RM, 6 repetitions at 60% 1RM, and a specific warm-up of 4 repetitions at 20% 1RM, optimized peak power at 40% 1RM bench press. This warm-up strategy showed better results than the general warm-up only (+85-93 W) or the general warm-up combined with a specific warm-up of 3 repetitions at 80% 1RM (+34-71 W). These results contradict some evidence indicating that heavier loads (i.e., ≥ 80% 1RM) are more effective than lower ones (e.g., 60-70% 1RM) in potentiating the subsequent dynamic strength performance, including barbell velocity and power (Garbisu-Hualde & Santos-Concejero, 2021; Wilson et al., 2013). Interestingly, it is worth noting that the differences in power production between the warm-up conditions with 20% 1RM and 80% 1RM were observed at minutes 2 and 4 after the warm-up, but not at minute 0 (immediately after the warm-up) or at minute 8. According to the authors, including light relative loads in the specific warm-up could have offered significant benefits to the neuromuscular system and, consequently, to force production, without increasing peripheral fatigue, unlike using high relative loads (El Hage et al., 2012). However, this statement may only apply to the second and fourth minutes post-warm-up, but not to the immediate instant after the warm-up or eight minutes after. Future research should extend the transition time to examine how warm-ups affect subsequent power performance at 40% 1RM over a 10-12 minute window, acknowledging that the potentiation effect varies among individuals and can occur at different times (Krzysztofik et al., 2020).

Ribeiro et al. (2020) found inconclusive evidence regarding the acute effects of different active resistance training warm-ups on lifting velocity and power at 80% 1RM bench press (3 sets of 8 repetitions). On the other hand, for the squat, although inconclusive evidence was also presented for power measures, there was a significant benefit in mean propulsive velocity at 80% 1RM following a warm-up condition of 6 repetitions at 80% of the training load (64% 1RM), in comparison to a warm-up of 6 repetitions at 40% of the training load (32% 1RM). Furthermore, no differences were found in barbell lifting velocity between the 6-repetition condition at 80% of the training load and the warm-up condition of 6 repetitions at 40% of the training load followed by 6 repetitions at 80% of the training load. These results suggest that for optimizing lifting velocity in the squat at 80%, a progressive-intensity specific warm-up can be an effective choice (Ribeiro et al., 2020). Indeed, the effectiveness of this warm-up strategy was further explored by the authors in a different experiment, where they observed optimized squat and bench press velocity at 80% 1RM following the warm-up of progressive intensity (6 repetitions at 40% of the training load, followed by 6 repetitions at 80% of the training load) (Ribeiro et al., 2021). However, it is worth noting that the comparison was made against a 5-minute rest condition, which underscores the need for further comparisons with different resistance training warm-up strategies, particularly in terms of volume, relative load, and transition time.

The impact of resistance training warm-ups on total repetitions and/or volume was also a theme of analysis in the current review. Four studies reported the positive effects of active warm-up strategies for the bench press (Alves et al., 2021; Gallo & Mello, 2017; Luz Junior et al., 2014; Viveiros et al., 2024), one for the leg press (Luz Junior et al., 2014), and one for the squat (Souza et al., 2024). Interestingly, most studies that reported positive effects analyzed the impact of warm-up strategies on strength performance at relative loads between 70% and 75% 1RM (Alves et al., 2021; Gallo & Mello, 2017; Luz Junior et al., 2014; Viveiros et al., 2024), except for Enes et al. (Enes et al., 2025), who did not find additional benefits of warm-ups with low volume and light loads on total repetitions and volume load at 75% 1RM compared to a no-warm-up condition. On the other hand, most studies that found inconclusive evidence analyzed the impact of warm-up conditions on strength performance at 80% 1RM (Nader et al., 2009; Ribeiro et al., 2014; Ushirooka et al., 2023), except for Krzysztofik et al. (Krzysztofik et al., 2020), who analyzed at 60% 1RM, specifically on the bench press. Although the results observed at 80% 1RM suggest that a heavier load is a critical factor, capable of offsetting any positive effects from the warm-up and thus hindering its transferability to the main activity, the results at 60% 1RM do not support this statement, considering the improvements seen at 70-75% 1RM. Therefore, more studies are needed to analyze the impact of different warm-up strategies (general and/or specific, with different combinations of volume and relative loads) on the total repetitions completed with different relative loads (60-90% 1RM) and strength exercises (upper- and lower-limbs), to clarify possible reasons for these discrepancies in results.

Regarding the positive effects of warm-ups on total repetitions and/or volume load, it can be observed that for the bench press, warm-ups involving either 8 repetitions at 50% 1RM (Alves et al., 2021), 5 repetitions at 60% 1RM (Viveiros et al., 2024), or 2 sets of 2 repetitions at 90% 1RM (Luz Junior et al., 2014) are effective to increase the number of repetitions performed at 70-75% 1RM. Interestingly, Gallo & Mello (Gallo & Mello, 2017) corroborated the findings of Luz Junior et al. (Luz Junior et al., 2014), who also observed no additional benefits from a warm-up of 15 repetitions at 40% 1RM on the total repetitions completed at 70% 1RM. On the other hand, Gallo & Mello (Gallo & Mello, 2017) found that a general warm-up of 5 min treadmill walking at 50% V̇O2max, 2 sets of 20 s of static stretching, or a combination of both, potentiated strength performance by increasing the number of repetitions by up to 2 more than no warm-up in the subsequent activity at 70% 1RM. Future research is needed to analyze the combination of the proposed general warm-up by Gallo & Mello (Gallo & Mello, 2017) (e.g., warm-up of 5 min treadmill walking at 50% VO2max followed by 2 sets of 20 s of static stretching) followed by a specific warm-up of 2 sets of 2 repetitions at 90% 1RM (Luz Junior et al., 2014) on the maximum repetitions performed in the bench press at different relative loads (e.g., 70-90% 1RM).

Concerning the leg press, 2 sets of 2 repetitions at 90% 1RM were more effective in increasing the number of repetitions performed at 70% 1RM than 15 repetitions at 40% (Luz Junior et al., 2014). When comparing three warm-ups with lower loading magnitudes in the volume load at 75% 1RM, Viveiros et al. (2024) observed that the warm-up at 60% 1RM contributed to a greater volume load than the warm-ups at 30% and 45% 1RM, although the results were not statistically significant. Enes et al. (Enes et al., 2025) also found that performing warm-ups with low volumes (3-4 repetitions per set) and light loads (40-55% 1RM) also did not produce additional benefits on total repetitions and volume load at 75% 1RM leg press when compared to a no warm-up condition. For the squat, Souza et al. (2024) found that a warm-up of 8 repetitions at 45% 1RM, followed by 3 repetitions at 90% 1RM was more effective in increasing the volume load at 75% 1RM than just performing 8 repetitions at 45% 1RM. Nonetheless, no differences were found between the warm-up of 8 repetitions at 45% 1RM, followed by 3 repetitions at 90% 1RM, and 8 repetitions at 45% 1RM, followed by 6 repetitions at 45% 1RM, in terms of increasing volume load. Therefore, these findings reinforce the positive influence of a progressive-intensity warm-up on subsequent strength performance. Furthermore, the results reinforce the notion that a higher loading magnitude during the warm-up may be necessary to potentiate total repetitions and/or volume load in the leg press and squat exercises. Finally, for the lat pull-down, Viveiros et al. (2024) verified that a warm-up of 5 repetitions at 60% 1RM did not produce a significantly greater increase in the volume load at 75% 1RM than 15 repetitions at 30% 1RM (+75 kg), and 10 repetitions at 45% 1RM (+158 kg). However, when considering the combination of the volume load from the bench press, inclined leg press, and lat pull-down, it was evident that a warm-up at 60% 1RM elicited a greater increase in volume load at 75% 1RM compared to warm-ups at 30% and 45% 1RM (2024). Therefore, the results suggest that warming up with a relative load closer to the relative training load may induce greater benefits in terms of total training volume completed in the session.

While the acute effects of active resistance training warm-ups on strength performance have been explored and discussed, the influence of re-warm-up strategies between resistance exercises remains an underexplored topic, with only one study identified to date (Neves et al., 2025). The scientific evidence shows that during training sessions involving passive intervals (e.g., transitions between sets and exercises, or extended break periods), muscle temperature and neuromuscular activation can decline significantly, possibly impairing subsequent strength performance (Cowper et al., 2022). Therefore, re-warm-up strategies have been proposed to mitigate declines in strength performance. In this regard, studies have shown that brief and targeted re-warm-up activities, such as traditional strength and plyometric exercises, can help preserve or enhance athletic performance metrics, including jumping, sprinting, and changing direction (Mohr et al., 2004; Sanchez-Sanchez et al., 2024; Silva et al., 2018; Yang et al., 2025). However, despite these promising results on athletic performance, to date, only one study has explored the practical applicability and effects of active re-warm-up strategies on dynamic strength performance in resistance training contexts. Neves et al. (Neves et al., 2025) found that the re-warm-up improved barbell lifting mechanics in the squat when performed after the bench press, but had a minimal impact on the bench press when performed after the squat. Taken together, these preliminary results suggest that performing a re-warm-up before the squat may enhance its mechanical performance, as the large muscle groups involved (e.g., quadriceps femoris) can benefit from additional muscular activation. On the other hand, the benefits may be less evident in the bench press, given the smaller muscle groups involved compared to the squat, and the more demanding muscular activation that occurs during the squat. Given the promising results, future studies on resistance training are necessary to address a topic that has demonstrated benefits in maintaining and even improving strength-related outcomes in athletic settings.

Conclusion

This review highlighted important findings regarding the acute effects of active resistance training warm-ups on subsequent strength performance in strength-trained males. First, resistance training warm-ups have a positive influence on increasing 1RM load in lower-body strength exercises, such as the inclined leg press and back squat. Second, a specific warm-up with a low relative load, performed at the maximal intended velocity, optimizes peak power at 40% 1RM in the bench press. Furthermore, a progressive-intensity warm-up increases subsequent lifting velocity at 80% of 1RM in the bench press and squat. Third, performing a warm-up with a wide range of relative loads (45%, 50%, 60%, and 90% 1RM) increases the total repetitions and/or volume load performed at 70-75% 1RM in the bench press, leg press, and squat exercises. Table 6 provides evidence-based warm-up strategies to enhance subsequent dynamic strength performance in strength-trained males. Strength and conditioning professionals should consider integrating structured warm-ups that incorporate both general (usually aerobic-based with or without stretching and mobility exercises) and specific phases (single or multiple sets), tailored to the athlete's characteristics and exercise specificity. The inclusion of rest periods of 1-3 minutes between sets and exercises during the warm-up conditions is recommended, as it seems to be the most common strategy employed by strength coaches. However, it would be important to individualize these rest periods to optimize subsequent dynamic strength performance, as also suggested for the transition times between the warm-up and the main strength activity (Gołaś et al., 2016; Krzysztofik et al., 2020). Future studies should continue to explore optimal warm-up strategies with various configurations of volume (sets and repetitions), relative loads (ranging from 20% to 90% 1RM), recovery periods between sets and exercises, and the transition times for the main strength activity to maximize strength-related outcomes. Through this review, a significant knowledge gap has been highlighted concerning re-warm-up strategies during resistance training sessions and their effects on strength performance. To date, only one study has demonstrated an improvement in barbell mechanical performance during the squat exercise when preceded by a re-warm-up strategy; however, these findings are still preliminary and require further validation. Therefore, this research gap underscores the need for further investigation in this area to elucidate and better understand the potential impact of re-warm-up strategies in maintaining or optimizing strength performance throughout the resistance training session.

Table 6. Evidence-Based Warm-Up Strategies to Enhance Subsequent Dynamic Strength Performance.

Outcome measure	**Warm-up and transition time recommendations**	**Reference**
1RM inclined leg press	**General warm-up:** 15-20 min cycling at 55-70% HR_{max} + 3 min rest **Specific warm-up:** 8 reps at 50% 1RM + 2 min rest + 3 reps at 70% 1RM **Transition time:** 3 min	Abad et al. (2011) Barroso et al. (2013)
1RM free-weight squat	**General warm-up:** 5 min cycling at 65 rpm with 1 kg + 2 min rest + 2 sets of 10 reps with 20 kg + 2 min rest **Specific warm-up:** 2 sets of 3 reps at 85% 1RM with barbell + elastic bands or chains (3 min rest between sets) **Transition time:** 5 min	Mina et al. (2014) Mina et al. (2016)
Bench press power at 40% 1RM	**General warm-up:** 5 min running + 2 min rest + 10 reps at 50% 1RM + 2 min rest + 6 reps at 60% 1RM + 2-4 min rest **Specific warm-up:** 4 reps at 20% 1RM **Transition time:** 2-4 min	El Hage et al. (2012)
Bench press velocity at 80% 1RM	**General warm-up:** Unclear **Specific warm-up:** 6 reps at 40% TL + 1 min rest + 6 reps at 80% TL **Transition time:** 5 min	Ribeiro et al. (2021)
Squat velocity at 80% 1RM	**General warm-up:** Unclear **Specific warm-up:** 6 reps at 40% TL + 1 min rest + 6 reps at 80% TL **Transition time:** 5 min	Ribeiro et al. (2021)
Bench press total repetitions at 70% 1RM	**General warm-up:** 5 min treadmill walking at 50% VO_{2max} OR 2 sets of 20 s of static stretching (pectoralis, deltoids, and triceps muscles) OR a combination of both (aerobic activity followed by stretching) **Specific warm-up:** 2 sets of 2 reps at 90% 1RM **Transition time:** 1 min	Gallo & Mello (2017) Luz Junior et al. (2014)
Bench press total repetitions at 75% 1RM	**General warm-up:** Unclear **Specific warm-up:** 8 reps at 50% 1RM **Transition time:** 4 min	Alves et al. (2021)
Bench press volume load at 75% 1RM	**General warm-up:** Unclear **Specific warm-up:** 5 reps at 60% 1RM **Transition time:** Unclear	Viveiros et al. (2024)
Leg press total repetitions at 70% 1RM	**General warm-up:** Unclear **Specific warm-up:** 2 sets of 2 reps at 90% 1RM **Transition time:** 1 min	Luz Junior et al. (2014
Squat volume load at 75% 1RM	**General warm-up:** 8 reps at 45% 1RM **Specific warm-up:** 3 reps at 90% 1RM **Transition time:** 10 min	Souza et al. (2024)

1RM: one-repetition maximum; HR_{max}: maximum heart rate; rpm: revolutions per minute; TL: training load; VO_{2max}: maximum oxygen uptake

Chapter 3. Experimental Studies

Study 2. Warm-Up and Re-Warm-Up in Resistance Training: Usual Practices Among Strength and Conditioning Coaches and Athletes

Abstract

The warm-up is considered to enhance both physiological readiness and psychological focus, contributing to injury prevention and performance improvement. Even with its benefits, warm-up practices are often applied based on common sense, with insufficient scientific evidence to sustain it. This study aimed to characterize warm-up and re-warm-up practices among athletes and strength and conditioning coaches during strength training. A cross-sectional descriptive survey of warm-up and re-warm-up resistance training routines was conducted. One hundred-six participants (31.04 ± 9.53 years) provided responses to gather information on demographic details; role (i.e., athlete and/or coach); warm-up and re-warm-up recommended practices. Sex did not significantly influence warm-up or re-warm-up routines, suggesting similar habits adopted by male and female athletes (warm-up practice: 93.9% and 95.0%, respectively; no re-warm-up: 81.8% and 85.0%, respectively). The results confirmed a widespread adherence to general and specific warm-up routines across explanatory variables, as sex (males and females: 63.1%) and professional roles (both: 68.2%). In contrast, re-warm-up strategies were less chosen (male 18.2% and female 15.0%). Notably, individuals with dual roles were more expected to implement re-warm-up strategies ($p = 0.036$). Moreover, with each additional year of age, the chance of a person performing re-warm-up decreases (18.3%); a coach has 33.6% greater possibility of conducting a re-warm-up when compared to an athlete; and dual roles individuals have approximately 5.5 times greater possibility of re-warm-up when compared to athletes. This study seems to provide useful insights into modern practices for athletes and coaches to review and update their individual warm-up and re-warm-up practices.

Keywords: Questionnaire, physical fitness, re-warm-up, strength, resistance training

Introduction

For every type of training, it is well recognized that warm-up is an essential element to prepare the participant for the following actions and to optimize his performance (McGowan et al., 2015; Ribeiro et al., 2020). The warm-up (WU) activities performed before the main training session appear to enhance both physiological readiness and psychological focus, contributing to injury prevention and performance improvement (Bishop, 2003a; Fradkin et al., 2010; McGowan et al., 2015). However, over the years, the benefits of WU were assumed to be absolute truth, where it is often applied based on common sense with insufficient scientific evidence to sustain it.

Resistance training is a foundational component of athletic development, aimed at improving muscle strength, power, endurance, and overall physical capacity. Effective strength training sessions require not only appropriate exercise selection, load management, and recovery time but also include appropriate preparation routines such as WU and more recently discussed re-warm-up (RWU) strategies. Literature has been confronted by controversial results that warm-up designs (e.g.: typology, volume, intensity) need to be further documented. Each athlete is used to warm-up before any resistance training to acquire greater performance levels in each single session (Alves et al., 2019; Ribeiro et al., 2014). Recent research reported that specific WUs performed at loads close to the maximum (90% of maximal dynamic 1RM load) seems to be positively effective in the ability to develop maximal dynamic strength (Junior et al., 2014). Earlier meta-analyses have shown that well-designed WU routines can provide significant improvements in sprinting, jumping, and strength performance when intensity, duration, and specificity are particularly well-adjusted (Fradkin et al., 2010; Pliauga et al., 2015). Although strength performance seems to be improved when warm-up is applied, the optimal load (e.g.: intensity and/or volume) of the exercises during the WU remains unknown (Abad et al., 2011; Junior et al., 2014; Ribeiro et al., 2020).

WU protocols are typically divided into two phases: a general phase, involving low-intensity aerobic activity and dynamic mobility drills; and a specific phase, where movements closely replicate the biomechanical and metabolic requirements of the main training session (McCrary et al., 2015; Silva et al., 2018). In strength training, the specific phase often includes submaximal sets of the primary lifts, promoting neuromuscular activation while minimizing fatigue (McGowan et al., 2015). However, the effects of WU can quickly dissipate if followed by periods of inactivity, such as prolonged rest intervals or unpredictable pauses during training sessions (Faulkner et al., 2012; Neiva et al., 2014). In this sense, RWU strategies have gained interest in guaranteeing physiological readiness during these passive periods. RWU refers to short, low-intensity activities performed between efforts or during longer pauses, aiming to preserve muscle temperature and neuromuscular activation (Kilduff et al., 2013; Russell et al., 2015). Although RWU strategies have been explored in intermittent team sports, such as football and rugby, their application to resistance training settings remains uncertain in the literature. Additionally, contrary to these modalities, resistance training sessions frequently include rest intervals of 2–5 minutes between sets, or even longer in group settings with shared equipment. These pauses may lead to decreases in muscle temperature and compromise performance, particularly in exercises requiring maximal power output (Mohr et al., 2004; Silva et al., 2022). Some studies suggest that RWU activities, such as bodyweight movements, elastic band exercises, or isometric contractions, can mitigate these declines and preserve performance throughout the session (Silva et al., 2022).

From a practical perspective, the integration of RWU into resistance training is influenced by contextual and behavioral factors such as athlete education, coaching strategies, space facilities, time constraints, and cultural norms within the training environment (Wilson et al., 2013). Several strength and conditioning coaches and athletes remain unaware of the potential benefits of RWU, or even an unclear guideline to implement such strategies effectively. Furthermore, controversy in practice may be due to the absence of structured protocols supported by applied research in resistance training contexts. Therefore, to bridge the gap between theoretical knowledge and applied resistance training practice, it is essential to know and understand how WU and RWU routines are currently being used by sports professionals, athletes and strength and conditioning coaches. Descriptive studies of real-world training behaviors can offer valuable insights into the prevalence, structure, and rationale behind these practices, supporting to provide useful and effective future recommendations.

Accordingly, the present study aims to characterize WU and RWU practices athletes and strength and conditioning coaches during resistance training. Based on the application of a structured questionnaire and analysis of both quantitative and qualitative data, this study seeks to identify prevailing trends, motivations, and potential barriers to the WU and RWU implementation. To our best knowledge, this is the first comprehensive questionnaire of WU and RWU practices in resistance training context developed. It was hypothesized that WU would be reported as a necessary and commonly used practice, as opposed to the RWU practice. Ultimately, these findings may contribute to providing evidence-informed guidelines, encourage the adoption of effective performance strategies in strength training environments, and provide insights about the magnitude's impact of warm-up and re-warm-up routines in resistance training performance.

Methods

Study Design

This exploratory study was designed to provide comprehensive descriptive information concerning WU and re-warm-up RWU practices of athletes and strength and conditioning coaches in the context of resistance training. An observational study design was used with data collected through a self-administered questionnaire consisting of 15 multiple-choice questions and 7 open-ended questions. The open-ended items provided qualitative insights into the structure and rationale of WU and RWU protocols, while the closed-ended responses enabled quantitative analysis of trends and behavioral patterns. The questionnaire was designed to capture routines adopted by athletes and strength and conditioning coaches, as well as the decision-making processes underlying these practices in real-world training environments.

Participants

One-hundred six participants (n = 40 female adults, mean ± SD, 30.97 ± 9.59 years; n = 66 male adults, 31.04 ± 9.57 years) presently practicing resistance training as athletes or coaches in Portugal were informed of the benefits and risks of the research and provided their written informed consent to participate in the study. Participation was entirely voluntary. Eligibility criteria required individuals to be at least 18 years of age and actively engaged in resistance training either as athletes or coaches. A convenience sampling approach was employed, with participants recruited via social media, digital platforms, and academic networks. The ethical approval of this study was obtained from the Human Research Ethics Committee at the University of Beira Interior (CE-UBI-Pj-2021-018), and the study was conducted in accordance with the Declaration of Helsinki.

Data Collection Instrument

The questionnaire (see Supplementary Digital Content) was developed by the research team in consultation with three expert coaches in strength and conditioning training (holding National level coaching license), and designed to determine the current WU, and RWU practices of Portuguese strength and conditioning coaches and athletes during the resistance training sessions. To provide face validity and guarantee the appropriateness for use within this population, a pilot test of the questionnaire was conducted with three coaches (National level coaching license) before the start of the study. The feedback gathered from this pilot test was used to refine the questions and language to ensure the contemporary strength coaching terminology (no pilot study data was used in the present research). The questionnaire was applied using Google Forms and was available from March 24 to April 18, 2025. The questionnaire was structured into three main sections: (1) Demographic information about the resistance training athletes and/or coaches: age, gender, and geographic location; (2) Sport and professional experience: years of experience in training context, and role (i.e., athlete and/or strength and conditioning coach); (3) WU and RWU recommended practices detailed information of athletes and/or strength and conditioning coach: frequency of use, types of strategies adopted, reasons for implementation or omission, protocols including specific exercises, volume, intensity, and recovery intervals, and finally, the athletes and/or strength and conditioning coaches were invited to describe any warm-ups they used employ and any external factors they felt could influence the potential benefits of a WU or RWU routines.

Procedures

Participants were initially contacted via email sent to Portuguese health clubs database. The email included an introductory letter outlining the purposes of the study and a link to a Google Forms document containing the informed consent form and the questionnaire. Participants completed the questionnaire independently. No researcher team member interference during the process of filling out the questionnaire. These efforts to standardize contact procedures were implemented to reduce potential extraneous factors that could influence participants' responses.

Statistical Analysis

A cross-sectional descriptive survey of WU and RWU resistance training routines was conducted. Questionnaire responses were exported from Google Forms and organized using Microsoft Excel. All fixed response and open-ended question data were analyzed using frequencies to determine the percentage response from the cohort of the athletes and/or strength and conditioning coaches. Qualitative responses were analyzed through thematic coding to identify recurring patterns in WU and RWU strategies. The relationship between sex (female, male) and the practice of WU and RWU, as well as the type (general, specific, both), duration (<5 minutes, 5-10 minutes, 11-15 minutes, >15 minutes) and intensity (low, moderate, high) of the WU and RWU were analyzed using Chi-Square Test. Similarly, the relationship between professional role (coach, athletes, both) and these same variables were also assessed. A Binominal Logistic Regression models were used to assess the association between the participants' use of RWU (yes *vs.* no) and the explanatory variables: age, sex, professional role, years of experience, and type of WU. The forward stepwise (likelihood ratio) selection method was considered, and the results were reported using the odds ratio (OR) estimates and their 95% confidence intervals (CI). To assess the model's explanatory power, the Nagelkerke's R^2 was used; its interpretation was based on the following criteria: 0.02-0.13 small, 0.13-0.26 medium, and >0.26 large effect size (Cohen, 1988). The model's goodness of fit was assessed through the Hosmer-Lemeshow test and the area under the receiver operating characteristic (ROC) curve (AUC) was used to evaluate the discriminant capacity of the model. Statistical analyses were conducted using the statistical software IBM SPSS for Windows version 30.0 (IBM. Corp. Armonk, NY) and the significance level was set at $p \leq 0.05$.

Results

Most surveyed participants (> 90%), regardless of sex, considered the inclusion of WU fundamental before resistance training. On the other hand, the adoption of RWU was not frequent among males and females, with less than 20% of participants reporting its use. No significant relationship between sex and the practice of WU or RWU during the resistance training was found (Table 1).

Table 1. Relationship between sex and the practice of warm-up (WU) and re-warm-up (RWU).

Sex	WU before resistance training		p-value	RWU during resistance training		p-value
	Yes (%)	No (%)		Yes (%)	No (%)	
Male	62 (93.9)	4 (6.1)		12 (18.2)	54 (81.8)	
Female	38 (95.0)	2 (5.0)	0.819	6 (15.0)	34 (85.0)	0.672
Total	100 (94.3)	6 (5.7)		18 (17.0)	88 (83.0)	

*p< 0.05; ** p<0.001

In the participants' universe, more than half used both types of WU (i.e., general and specific WU) in their preparation for resistance training (63.1%). No significant relationship was found between sex and the type of WU ($p = 0.505$). Regarding to duration of the WU, majority of the male participants opted to perform between 5-10 minutes with less eminence to use < than 5 minutes or more than 15 minutes to WU. Females were exposed similar options to apply in the WU duration (> 40% chose 5-10 minutes to WU). No significant relationship was found between sex and the duration of the WU used when performed resistance training (Table 2). About the intensity of WU, there were no relationship between males and females (p = 0.895). However, males and females prefer to perform low (48.5% and 45.0%, respectively) and moderate intensity of WU (50.0% and 52.5%, respectively), with few reports to high intensity (1.50% and 2.50%, respectively).

Table 2. Relationship between sex and duration of warm-up (WU).

Sex	Duration of the WU				
	<5 minutes (%)	[5-10 minutes] (%)	[11-15 minutes] (%)	>15 minutes (%)	p-value
Male	7.0 (10.6)	39.0 (59.1)	17.0 (25.8)	3.0 (4.5)	0.278
Female	8.0 (20.0)	17.0 (42.5)	14.0 (35.0)	1.0 (2.5)	
Total	15.0 (14.2)	56.0 (52.8)	31.0 (29.2)	4.0 (3.8)	

*p< 0.05; ** p<0.001

When observing the practice of WU, regardless of the professional role, it is notorious that it is a relevant practice that is needed to implement before resistance training (> 90%). When analyzing the practice of RWU by professional role, participants who acted both as athletes and strength and conditioning coaches showed the highest adherence (34.8%), compared to athletes and strength and conditioning coaches only. The application of the Chi-Square test revealed a statistically significant association between professional roles and the likelihood of performing RWU (p = 0.036) (Table 3). Most participants reported performing both general and specific WU (63.1%). This trend was consistent among those who were athletes (62.0%) and those who combined the roles of athlete and strength and conditioning coach (68.2%). Among coaches exclusively, 40.0% reported performing only specific WU. The Chi-Square test did not show a statistically significant relationship between professional role and the type of WU performed (p = 0.286). When considering the duration of the WU, independently of the professional role, athletes, coaches or both, reported preference between 5-10 minutes (52.8% of the total sample). No relationship was found between the participants' professional role and the duration chosen to perform the WU before a resistance training (p = 0.203). If analyzing the intensity of the WU, it is noticeable that high intensity is less chosen (1.9% of the sample), and prevalence was on the low and moderate intensities (47.2% and 50.9% of the sample, respectively), regardless of the professional role (p= 0.554).

Table 3. Relationship between role and practice of re-warm-up (RWU).

Role	Practice of RWU		
	Yes (%)	No (%)	p-value
Coach	1.0 (10.0)	9.0 (90.0)	
Athlete	9.9 (12.3)	64.0(87.7)	0.036
Both	8.0 (34.8)	15.0 (65.2)	

*p< 0.05; ** p<0.001

The binary logistic regression model identified age and professional role as statistically significant variables (Table 4). The results showed that, with each additional year of age, the chance of a person performing RWU decreases by 18.3% (OR = 0.817); a coach has a 33.6% greater possibility of RWU when compared to an athlete (OR = 1.336); and those who are both athletes and coaches have approximately 5.5 times greater possibility of RWU when compared to those who are athletes only (OR = 5.473). The model presents an Nagelkerke's R2 = 0.332, corresponding to a large effect size. The model showed an adequate fit (p Hosmer-Lemeshow = 0.953) and a good discriminant capacity (AUC = 0.808).

Table 4. Logistic regression analysis for re-warm-up (RWU) practice.

	Coefficient	p-value	OR	CI 95% OR
Constant	3.420	0.031	30.560	-
Age	-0.202	0.002	0.817	[0.718; 0.929]
Coach	0.290	0.808	1.336	[0.129; 13.831]
Both (coach & athlete)	1.700	0.012	5.473	[1.449; 20.676]

*p< 0.05; ** p<0.001 CI: Confident Interval; Hosmer & Lemeshow p-value = 0.953; Nagelkerke's R^2 = 0.332; OR: Odds ratio; % Global Correct= 86.4%; AUC= 0.808 (CI 95% [0.708; 0.908]).

Regarding the WU prescribed by coaches and/or athletes with more than 10 years of experience and with less than 10 years of experience, responses were content analyzed, which resulted in the creation of four higher-order themes. Table 5 lists these higher-order themes, the total number of strength and conditioning coaches and/or athletes' responses to each theme and select representative raw data within each higher-order theme.

Table 5. Warm-up exercises prescribed by strength and conditioning coaches and/or athletes with more than 10 years of experience in training.

Higher-order themes	Number of responses	Select raw data representing responses to the question
Strength and conditioning coaches and/or athletes with more than 10 years of experience in training		
General activation/cardio exercises	11	3-10 minutes rowing/bicycle/treadmill
Dynamic exercises	15	circuit (jumping rope/ burpees/ jumping jacks/planks) (intensity: low to moderate)
Mobility (general and/or specific)	24	Articular mobility
Specific exercises (similar to the training exercises)	20	Specific exercises (modality/similar to the main training with elastic resistance bands/ body weight/bar/equipment) - volume 3x10 repetitions (no weight, 30-40% 1RM, 50-65% 1RM)
Strength and conditioning coaches and/or athletes with less than 10 years of experience in training		
Higher-order themes	**Number of responses**	**Select raw data representing responses to the question**
General activation/cardio exercises	26	5-10 minutes rowing/bicycle/treadmill
Dynamic exercises	24	circuit (jumping rope/burpees/jumping jacks/planks/mountain climbers) (intensity: low to moderate)
Mobility (general and/or specific)	53	Articular mobility
Specific exercises (similar to the training exercises)	45	Specific exercises (modality/similar to the main training with elastic resistance bands/ body weight/bar/equipment) - volume 3x8 repetitions (no weight, 40-45% 1RM, 50-65% 1RM / no weight, 40-45% 1RM, 60-70% 1RM)

RM: repetition maximum.

Discussion

This study aimed to characterize WU and RWU practices among athletes and strength and conditioning coaches during resistance training. In this sense, a questionnaire was applied. The results suggest that sex did not significantly influence the adoption of WU or RWU routines, indicating similar practices among male and female athletes. In addition, there was broad adherence to general and specific WU protocols across sex and professional roles. In contrast, RWU strategies were significantly less frequently adopted. Finally, individuals with dual roles as both athletes and strength and conditioning coaches were more likely to implement RWU strategies.

The present study observed high adherence to WU routines among both male and female participants prior to resistance training sessions. This aligns with existing literature emphasizing the universal recognition of WU benefits across sex, including increased muscle temperature, enhanced neuromuscular efficiency, and improved psychological readiness (McCrary et al., 2015). However, the implementation of RWU strategies was notably less prevalent. RWU activities are crucial for maintaining performance levels during extended rest periods or between training sets, as they help sustain muscle temperature and readiness (Silva et al., 2018). The low adoption rates observed may stem from a lack of awareness or understanding of these benefits among practitioners. It's important to note that while both sexes benefit from WU routines, studies have indicated that females may experience greater relative increases in upper-body strength following resistance training, despite male having higher absolute gains due to greater initial muscle mass (Roberts et al., 2020). This suggests that tailored WU and RWU protocols considering sex-specific physiological responses could further optimize training outcomes.

Analyzing the data based on participants' professional roles-athletes, coaches, or dual role individuals - revealed notable differences in WU practices. Individuals serving both as athletes and strength and conditioning coaches demonstrated higher engagement in RWU routines compared to those solely identified as athletes or strength and conditioning coaches. This suggests that dual role individuals may possess a more comprehensive understanding of training methodologies, leading to more holistic WU strategies (Washif et al., 2025). Regarding the structure of WU routines, most participants favored a combination of general and specific WU exercises. This approach is supported by research indicating that combined WUs effectively enhance performance by increasing core temperature and preparing specific muscle groups for upcoming activities (Fradkin et al., 2010). Accordingly, Suárez-Iglesias et al., (2024) reported that Elite, Sub-elite, and Regional Spanish basketball players opted to perform stretching /joint mobility exercises as WU structure before the match. Moreover, recent studies have highlighted the benefits of specific RWU strategies (González-Davesa et al., 2021; Matsentides et al., 2023; Silva et al., 2018). Complementarily, the importance of comprehensive WU routines, including RWU strategies, to optimize performance and reduce injury risk should be included in educational programs in sports sciences (Washif et al., 2025). For instance, incorporating change-of-direction exercises in RWU sessions has been shown to significantly enhance agility and ball shooting velocity in well-trained soccer players (Matsentides et al., 2023). These findings underscore the importance of tailoring WU and RWU protocols to the specific demands of the sport and the athlete's role.

In this study, curious possibilities were obtained, as for each additional year of age, the chance of a person performing RWU decreases; a strength and conditioning coach has a greater possibility of performing RWU when compared to an athlete; and those who are both coaches and athletes have greater possibility of RWU when compared to those who are athletes only. Contrarily, recent authors (Suárez-Iglesias et al., 2024) manifested that the practice of RWU is less used independently of the competition level (elite, sub-elite, and regional basketball players). Their findings indicated that athletes were twice as likely not to use RWU, citing the main reasons as a "perceived lack of need", "competing demands," and "time constraints" during breaks, neglecting the known benefits of active RWU strategies on explosive performance (González-Davesa et al., 2021; Silva et al., 2018). These results underscore the importance of educating athletes, in particular, about the benefits of implementing RWU strategies to enhance performance during periods of inactivity. Based on years of experience with resistance training, two WU protocols were developed. For individuals with more than 10 years of experience, the general activation/cardio exercises phase consisted of 3 to 10 minutes of rowing, cycling, or treadmill walking, while those with less than 10 years of experience performed 5 to 10 minutes of the same activities. All participants completed a dynamic exercise circuit composed of jumping rope, burpees, jumping jacks, planks, and mountain climbers, performed at low to moderate intensity. In addition, general and/or specific joint mobility exercises were advised for all. The specific phase of the warm-up included exercises that resembled the main training movements and were performed using elastic resistance bands, body weight, barbell, or training equipment. For individuals with more than 10 years of experience, the protocol involved 3 sets of 10 repetitions at either body weight, 30-40% of 1RM, or 50-65% 1RM. For those with less than 10 years of experience, the protocol included 3 sets of 8 repetitions at body weight, 40-45% 1RM, or 50-65% 1RM / 40-45% 1RM, 60-70% 1RM. This combined evidence should provide evidence-informed guidelines for sports professionals, athletes and strength and conditioning coaches and reducing the heterogeneous WUs structures, study designs and routines offered by the literature (McGowan et al., 2015; Czelusniak et al., 2021; Afonso et al., 2024).

To the best of our knowledge, this study is unique in its comparative analysis of WU and RWU practices pronounced by athletes and strength and conditioning coaches, considering variables such as sex, professional role, and practice of WU and RWU. In this sense, sex did not significantly influence WU or RWU routines, suggesting that these habits are similarly adopted by male and female athletes. The results confirmed a widespread adherence to general and specific WU routines across explanatory variables, as sex and professional roles, reflecting a general awareness of their benefits in enhancing performance and reducing injury risk. In contrast, RWU strategies were significantly less chosen, despite their known benefits in maintaining muscle readiness during intra-session rest periods, providing better performance, and reducing the risk of injuries. Notably, individuals with dual roles (athlete-coach) were more likely to implement RWU strategies, highlighting the importance of both professional experience in promoting evidence-based training practices. However, the overall low rates of RWU practices emphasize the need for further education and dissemination of best practices in strength and conditioning contexts. Future research should explore the effectiveness of different RWU modalities across varying resistance training protocols and populations. Additionally, intervention-based studies could assess how structured educational programs influence the implementation of these practices in both recreational and professional training environments. Ultimately, the integration of targeted WU and RWU strategies - tailored to the athlete's profile, role, and sport-specific demands - should be considered a critical component of resistance training program design.

Practical Applications

The present results seem to provide useful insights into modern practices and athletes and strength and conditioning coaches can use these bull points to review their individual WU and RWU practices, developing a viable and effective source for innovative designs and protocols for resistance training sessions. Moreover, the findings highlight the need for increased education and awareness regarding the benefits of RWU strategies. Implementing targeted educational programs and workshops can bridge this knowledge gap, promoting the adoption of comprehensive WU rand RWU routines across all practitioner levels. Additionally, fostering collaboration between coaches and athletes can facilitate the exchange of knowledge and best practices, enhancing overall training effectiveness. Encouraging dual role experiences may also contribute to more informed and holistic training approaches. Moreover, integrating specific RWU strategies, such as exercises sequences/order, can provide immediate performance benefits, particularly in sports requiring agility and rapid movements. Strength and conditioning coaches and sports professionals should consider incorporating these strategies and proposals into training sessions to maximize performance outcomes.

Study 3. The Impact of General and/or Specific Warm-Up on Power and Velocity During Squat and Bench-Press Training

Abstract

The study aimed to compare the effects of two warm-up strategies on mechanical force production during bench press and squat resistance training sessions. Twenty-six trained male subjects (24.37 ± 5.83 years, 75.48 ± 12.12 kg, 1.74 ± 0.07 m) performed a squat or bench press resistance training session after a specific warm-up (SWU) or general warm-up followed by a specific warm-up (GSWU). The SWU included 2x6 repetitions at 32% and 64% of the maximal load (1RM), respectively. The GSWU included 10 minutes of treadmill running (70% of heart rate reserve) followed by SWU. The resistance training session consisted of 3 x 6 with a load of 80% 1RM. Mechanical (mean propulsive velocity, mean propulsive power and velocity loss), physiological [heart rate (HR), blood lactate concentration], and psychophysiological variables (rating of perceived exertion) were evaluated. In the bench press and squat resistance training sessions, no differences were found in the mechanical and psychophysiological variables. When performing the bench press, the GSWU caused an increased HR response after warm-up (100.00 ± 16.93 bpm vs. 110.57 ± 9.69 bpm, $p = 0.03$; ES = 0.65, moderate effect). GSWU or SWU can both be used as preparatory activities for bench press and squat resistance training performance without related restrictions. These findings may be helpful for professionals to provide appropriate warm-up strategies to maximize resistance training.

Keywords: Pre-exercise, strength, t-force, velocity, physiology, resistance training

Introduction

Warm-up has been considered a fundamental practice to optimize performance and reduce the risk of injury (Bishop, 2003; Sánchez-Medina et al., 2017). Warm-up routines provide a reduction in discomfort at the start of an exercise program and a more motivating and proficient movement (Bishop, 2003; Nicoli et al., 2007). Although sports professionals and researchers are aware of the importance of warm-up and literature has shown positive effects of warm-up strategies in different sports and activities (Gil et al., 2019; Ribeiro et al., 2020), the effects of warm-up on resistance training performance are still unclear (McGowan et al., 2015). Only a few studies have attempted to understand the effects of different warm-ups on strength performance (Ribeiro et al., 2020; Wilcox et al., 2006). Considering the importance of resistance training for completing physical tasks and optimizing performance, deeper knowledge about the effects of warm-ups seems to be useful to assist in maximizing performance (Ribeiro et al., 2021).

The usual practices during warm-up include a general component (i.e., a brief period of submaximal aerobic activity, such as running at low intensity) followed by a specific warm-up (i.e., a short-term higher intensity stimulation of the main muscles that will be recruited) (Gil et al., 2019). The importance of these two components of warm-up constitutes a general belief of coaches and athletes (Gil et al., 2019; Ribeiro et al., 2021). A general warm-up before a specific warm-up could induce significant neuromuscular adjustments that increase muscle force production capacity during dynamic tasks (Abad et al., 2011). Indeed, performing a general warm-up followed by explosive force upper-body movements (i.e., 2 plyometric push-ups or 2 medicine-ball chest passes) before the bench press exercise resulted in optimized values of the one repetition maximum (1RM) load (Wilcox et al., 2006). Nevertheless, recent research has mainly focused on the study of the specific part of the warm-up (e.g., López-Álvarez & Sánchez-Sixto, 2021, Ribeiro et al., 2021). Specifically, considering resistance training, it was found that performing a specific warm-up only (i.e., included six repetitions with 40% of training load followed by six repetitions with 80% of training load in the bench press and squat exercises, with a one-minute interval before the resistance training) seems to enable higher movement velocity during the first training repetitions and greater peak velocities in less time in the bench press and squat training (Ribeiro et al., 2021). Comparing the impact of three distinct specific warm-ups (i.e., 2x6 repetitions with 40% and 80% of the training load vs. 6 x 80% of training load; vs. 6 x 40% training load), different responses were found depending on the type of resistance exercise used (Ribeiro et al., 2020). For example, the most favorable outcomes were observed after the warm-up with higher load in the squat and after progressive intensity in the bench press (Ribeiro et al., 2020). While there is scientific agreement on the positive influence of using warm-up before resistance exercises (Junior et al., 2014; Ribeiro et al., 2021; Wilcox et al., 2006), there are still some unclear conclusions about the most effective design of warm-up.

To the best of our knowledge, only a few studies tried to understand the effect of warm-up in resistance training sessions and most of them focused on the conventional 1RM load assessment (Junior et al., 2014; Ribeiro et al., 2020). However, it is known that 1RM load assessment can present several issues in the typical warm-up experimental research design. For example, a progressive increase of external loads is needed to evaluate the 1RM load and this compromises the experimental design by reducing the effectiveness of prior warm-up and/or increasing fatigue (Neiva & Marinho, 2023). However, research has been using mechanical variables (e.g., movement velocity, displacement) to monitor resistance exercise performance with accuracy (e.g., González-Badillo & Sánchez-Medina, 2010; Sánchez-Medina et al., 2017). The evaluation of the resistance exercise performance using these measures would allow a reliable analysis of the effect of previous warm-up procedures during an entire resistance training session. Furthermore, by using this linear position technology, it is possible to evaluate the response in each repetition of a submaximal resistance training set (González-Badillo & Sánchez-Medina, 2010; Sánchez-Medina et al., 2017).

Given that warm-ups can influence force production, it is important to analyze the effects of different warm-up routines to improve resistance training effectiveness. Therefore, the present study aimed to compare the effects of two warm-up routines (i.e., specific warm-up only, SWU vs. general followed by specific warm-up, GSWU) on the mechanical variables during different resistance training sessions using the bench press and squat exercises. It was hypothesized that a general warm-up followed by a specific warm-up would positively influence the mechanical responses, resulting from a greater ability to produce force in the resistance training session of the bench press and the squat exercises.

Materials and methods

Participants

Twenty-six physically active male subjects aged between 19 and 43 years volunteered to participate in the current study. Among these, fourteen men (mean ± SD: 26.21 ± 6.93

years of age, 75.28 ± 6.29 kg of body mass, 1.77 ± 0.07 m of height, and 1RM load of 76.07 ± 12.27 kg) were assessed using the bench press exercise, and twelve men (mean ± SD: 21.80 ± 2.20 years of age, 70.40 ± 15.75 kg of body mass, 1.71 ± 0.07 m of height, 1RM load of 81.17 ± 15.54 kg) were evaluated using the squat exercise. The division into groups was made according to the preference previously reported by the participants. Each participant was asked to report any previous illness, injury, or other physical problem that could impair their performance. All participants were verbally informed about the study procedures and read and signed a consent form. As inclusion criteria, participants should be male, over 18 years of age, have no limitations in the practice of physical activity, and have at least 6 months of experience in resistance training. Subjects who met the criteria and who voluntarily agreed to participate were included in the study. All procedures were in accordance with the Helsinki Declaration and approved by the local ethics board (Code n. º CE-UBI-Pj-2021-018:ID720).

Procedures

A crossover research design was used to determine the effects of warm-up on mechanical responses, mean propulsive velocity (MPV), mean propulsive power (MPP), bar displacement, physiological (heart rate: HR; and blood lactate concentration), and psychophysiological variables (rating of perceived exertion, RPE). The first session was used for anthropometric assessment (height and body mass) and familiarization with the procedures, one week before the application of the experimental protocols. Height and body mass were measured (Seca Instruments, Ltd, Hamburg, Germany). Then, each participant carried out some practice sets with progressive intensity loads in the bench press and squat exercises. An experienced personal trainer, with more than 5 years of teaching, demonstrated the correct techniques and explained the protocols. The second session was used to evaluate the individual load-velocity relationships and to establish the maximal dynamic load (1RM) of each participant in the bench press and squat exercises. The third and fourth sessions were used to evaluate the bench press or squat training after SWU or GSWU. Each warm-up was performed randomly before performing the bench press or squat training, ensuring more than 48 hours between conditions. During the experimental period, the participants were asked to keep their usual food intake, refrain from caffeine and alcohol ingestion, and any strenuous exercise. The exercises were performed using a Smith machine (Multipower Fitness Line, Perola, Murcia, Spain). A linear transducer sampling at 1000Hz (T-Force Dynamic Measurement System, Ergotech, Murcia, Spain) connected to a 16-bit analog to digital converter (Biopac MP100 Systems, Santa Barbara, CA, USA) was used to collect the bar displacement and velocity and automatically calculate the kinematic variables for every repetition (González-Badillo et al., 2011; Sánchez-Medina et al., 2017).

1RM assessment

In the bench press exercise, each participant lay in the supine position on a flat bench with feet flat on the floor and hands placed slightly wider than shoulder-width on the barbell. Participants were instructed to lower the barbell to the chest, just above the nipples, in a controlled manner and, after approximately one second of pause, start the concentric phase of the movement as fast as possible, as described elsewhere (Pallarés et al., 2014). Participants were not allowed to bounce the barbell off their chests or to raise their shoulders or trunks off the bench (González-Badillo et al., 2015; Sánchez-Medina & González-Badillo, 2011).

In the squat exercise, each participant started from an upright position with knees and hips fully extended, hands placed slightly wider than shoulder-width on the barbell, and the barbell resting on the back at the level of the acromion. Then, they began to descend in a continuous motion the tops of the thighs got below the horizontal plane (eccentric phase), then immediately reversed motion, and ascended back to the upright position at maximum intended velocity (concentric phase) (González-Badillo et al., 2015; Sánchez-Medina & González-Badillo, 2011). Trained professionals (i.e., two strength coaches) were on both sides of the barbell to ensure safety.

In both resistance exercises (i.e., bench press and squat), the evaluator and strength coaches controlled the movement to guarantee that all repetitions were performed in the required technique with a similar range of movement. The initial load was fixed at 17 and 20 kg for all participants in the bench press and squat exercises, respectively, and was gradually increased by 10 kg increments. Each participant performed 3 repetitions with each load and the best repetition at each load, according to the criteria of fastest MPV, was considered (González-Badillo et al., 2015). The test finished for each participant when they reached concentric MPV of 0.4 m. s-1 in the bench press and 0.6 m. s-1 in the squat exercise, corresponding to 85% 1RM in both (Sánchez-Medina et al., 2017; Sánchez-Medina & González-Badillo, 2011). Inter-set recoveries ranged from three minutes (light loads) to five minutes (heavy loads). The 1RM was determined from the last MPV obtained during the progressive loading test as follows: (100 x load) / (8.4326 x MPV2 – 73.501 x MPV + 112.33) for the bench press exercise (González-Badillo &

Sánchez-Medina, 2010), and (100 x load) / (-5.961 x MPV2 – 50.71 x MPV + 117) for the squat exercise (Sánchez-Medina et al., 2017).

Resistance Training Session

The participants were randomly allocated into each warm-up condition: SWU or GSWU. The SWU involved two sets of six repetitions, with the 1st set at 32% of the 1RM load and the 2nd set at 64% of the 1RM load. These loads used in the specific warm-up corresponded to 40% and 80% of the load to be used in the resistance training session (Ribeiro et al., 2021). A one-minute rest interval was observed between sets. In the GSWU, the general part of the warm-up comprised 10 minutes of cardiovascular exercise (i.e., running on the treadmill), starting slowly (i.e., 50-55% HR reserve) until reaching a maximum of 70% HR reserve (Wilson et al., 2013) in the last two minutes. After resting for one minute, the SWU was performed. After the warm-up (GSWU or SWU), each participant performed the resistance training session. The resistance training session consisted of three sets of six repetitions with a load of 80% 1RM, with three minutes of rest between sets. The intensity of 80% 1RM is commonly used in traditional resistance training, and it is included in the propitious range of relative intensities (30-80% 1RM) that have been reported to improve long-term muscular performance (Pallarés et al., 2014). All the subjects were asked to self-report their fatigue level at the start of each training session and if there was fatigue, they would be dismissed and assessed the following day. Participants were asked to perform the concentric phase always at the maximum intended velocity.

All velocity measures corresponded to the propulsive phase of each repetition (González-Badillo et al., 2011; González-Badillo & Sánchez-Medina, 2010). For the analysis, it was considered the MPV (i.e., mean propulsive velocity value from the start of the concentric phase until the acceleration of the bar is lower than gravity) over each set, and the minimum MPV value (MPVmin) and the maximum MPV values (MPVmax) of the training session, the relative magnitude of MPV loss (VL) within the set and the training (calculated as the percent loss in MPV from the fastest to the slowest repetition(Sánchez-Medina & González-Badillo, 2011), the peak velocity (PV: maximal instantaneous velocity value reached during the concentric phase at a specified load) (García-Ramos et al., 2018) and the time to achieve PV (Time to PV) in each repetition. The exercise bar displacement (Displacement) was also measured. The displacement was measured by the distance that the barbell performed during the concentric phase of the resistance exercise in each repetition (Hornsby et al., 2018). In addition, considering the propulsive velocity and load, other mechanical variables were analyzed from the software output, such as the MPP value (MPP) in each set and the minimum MPP (MPPmin) and the maximum MPP (MPPmax) values of the training session.

Physiological and psychophysiological variables

In all assessment sessions, participants were instructed to remain seated for five minutes without any effort. HR values were monitored with a polar watch (Polar, A300, Finland). HR values were recorded after five minutes of rest (resting HR), immediately after warm-up, and after completing the resistance training session. To determine blood lactate concentration, a portable lactate analyzer device (Lactate Pro 2, Japan) was used, with results obtained within ten seconds. The blood lactate values were obtained after five minutes of rest and immediately after the resistance training session. The 6-20 scale of Borg (Borg, 1998) was used after the warm-up condition and immediately after the resistance training session to obtain the individual perceived exertion.

Statistical Analysis

For data analysis, Microsoft Excel 2007 was first used to extract data from the T-Force System. Afterward, the Statistical Package for Social Sciences (IBM SPSS® statistics for Windows, Version 27.0, IBM Corp., Armonk, NY, USA) was used for statistical analysis. To verify the normality of the data, the Shapiro-Wilk test ($n < 30$) was performed. After the normal distribution of the data was verified, the parametric tests were adopted. To compare the warm-up conditions (SWU vs. GSWU), the Student's paired t-test was used. The effect size (ES) was calculated to determine the magnitude of the differences between conditions. For this, Cohen's dz (ES) for within-subject comparisons was calculated using Laken's Excel spreadsheet (Lakens, 2013) and considered trivial (0 – 0.19), small (0.20 – 0.59), moderate (0.60 – 1.19), large (1.20 – 1.99), very large (2.00 – 3.99), and extremely large (4.00 and higher) (Hopkins et al., 2009). The level of statistical significance was set at $p > 0.05$.

Results

The comparison of the effect of two warm-up strategies (SWU vs. GSWU) on mechanical force production, the mean values, standard deviations, differences, and effect sizes for mean propulsive velocity, velocity loss, peak velocity, time to peak velocity, displacement, and mean propulsive power in the first, second and third sets of the bench press exercise are presented in Table 1. No differences were found between the warm-up conditions in all variables assessed in the bench press resistance training session. Most of the effect sizes were found to be trivial, with some exceptions. For example, a greater effect size was found in the MPV during the first set (small), decreasing for the second and third sets (trivial). These results are supported by Figure 1 which shows an unclear tendency for comparisons between mean values throughout each repetition. For example, considering the mean, GSWU presented higher MPV values in four repetitions (out of six) during the first set, but only one in the second set and two in the third set.

Table 1. Mean values ± standard deviation of mechanical responses in bench press exercise. Differences and confidence intervals (95% CI), p-values and effect sizes (ES) are also reported.

	SWU	GSWU	SWU *vs.* GSWU		
			Mean ± CI (95%)	***p***	**ES**
MPV [set 1] ($m.s^{-1}$)	0.52 ± 0.14	0.54 ± 0.15	0.01 ± 0.04	0.14	0.43
MPV [set 2] ($m.s^{-1}$)	0.52 ± 0.16	0.51 ± 0.17	0.00 ± 0.05	0.91	0.17
MPV [set 3] ($m.s^{-1}$)	0.50 ± 0.17	0.50 ± 0.18	0.00 ± 0.05	0.88	0.01
MPVmin total ($m.s^{-1}$)	0.35 ± 0.16	0.34 ± 0.18	-0.01 ± 0.14	0.83	0.06
MPVmax total ($m.s^{-1}$)	0.53 ± 0.15	0.55 ± 0.15	0.02 ± 0.14	0.61	0.13
VL [set 1] (%)	0.09 ± 0.08	0.10 ± 0.05	-0.01 ± 0.06	0.38	0.15
VL [set 2] (%)	0.09 ± 0.07	0.11 ± 0.05	-0.01 ± 0.07	0.33	0.28
VL [set 3] (%)	0.11± 0.06	0.09 ± 0.05	0.01 ± 0.07	0.46	0.31
VL [total] (%)	24.76 ± 11.30	23.35 ± 10.56	1.40 ± 7.84	0.54	0.17
PV [set 1] ($m.s^{-1}$)	0.81± 0.18	0.82 ± 0.18	0.01 ± 0.09	0.47	0.10
PV [set 2] ($m.s^{-1}$)	0.80 ± 0.19	0.79 ± 0.21	0.01 ± 0.12	0.82	0.08
PV [set 3] ($m.s^{-1}$)	0.76 ± 0.22	0.75 ± 0.24	0.01 ± 0.09	0.64	0.10
PV [total] ($m.s^{-1}$)	0.83 ± 0.17	0.85 ± 0.19	0.01 ± 0.09	0.61	0.21
Time to PV [set 1] (s)	605.42 ± 168.89	637.42 ± 130.42	32.00 ± 145.61	0.42	0.21
Time to PV [set 2] (s)	568.57 ± 177.03	633.28 ± 221.34	64.71 ± 248.31	0.34	0.26
Time to PV [set 3] (s)	570.21 ± 250.23	626.78 ± 298.41	56.57 ± 340.40	0.54	0.16
Displacement [set 1] (m)	0.42 ± 0.06	0.43 ± 0.06	0.01 ± 0.02	0.29	0.37
Displacement [set 2] (m)	0.42 ± 0.07	0.42 ± 0.07	0.00 ± 0.04	0.67	0.01
Displacement [set 3] (m)	0.42 ± 0.07	0.43 ± 0.07	0.01 ± 0.03	0.26	0.33
MPP [set 1] (W)	262.86 ± 63.72	269.53 ± 62.98	6.66 ± 18.79	0.20	0.35
MPP [set 2] (W)	265.13 ± 71.49	254.67 ± 64.72	-10.46 ± 48.73	0.43	0.21
MPP [set 3] (W)	266.18 ± 65.07	270.25 ± 57.58	4.06± 21.05	0.51	0.19
MPPmin total (W)	170.96 ± 76.14	171.57 ± 71.13	0.60 ± 34.31	0.94	0.01
MPPmax total (W)	280.65 ± 84.80	281.41 ± 77.21	0.76 ± 35.97	0.93	0.02

*p< 0.05; ** p<0.001 SWU: Specific warm-up; GSWU: general plus specific warm-up; MPV: mean propulsive velocity; MPVmin total: mean propulsive velocity minimum total; MPVmax total: mean propulsive velocity maximum total; VL: velocity loss; VL [total]: velocity loss total; PV: peak velocity; Time to PV: time to peak velocity; Displacement: exercise displacement; MPP: mean propulsive power; MPPmin total: mean propulsive power minimum total; MPPmax total: mean propulsive power maximum total.

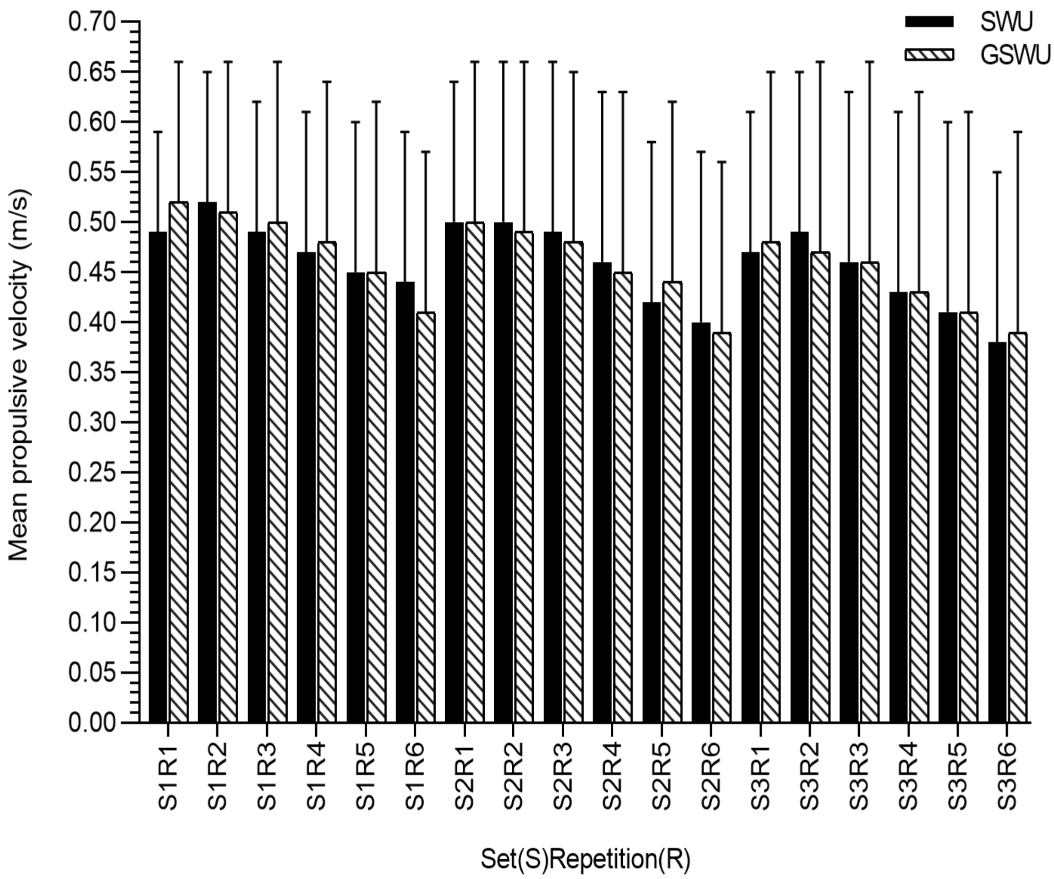

Figure 1. Mean propulsive velocity values in each repetition performed during bench press resistance training session. Values obtained in the six repetitions (R) during the first, second and third sets (S) of specific warm-up (SWU) and general plus specific warm-up (GSWU).

The mean values, standard deviations, differences, and effect sizes for the mean propulsive velocity, velocity loss, peak velocity, time to peak velocity, displacement, and mean propulsive power in the first, second, and third sets in the squat exercise are presented in Table 2. In the squat resistance training session, no differences were found between conditions in all variables. Small or trivial effect sizes were found in all comparisons. Like the bench press, the greater effect size between SWU and GSWU in the squat training session was found in MPV during the first set (small magnitude), decreasing for the second and the third sets (trivial). More detailed information about MPV for each repetition in SWU or GSWU can be found in Figure 2. It can be verified that GSWU presented higher MPV values in two repetitions (out of six) during the first set, five repetitions in the second set, and only two repetitions in the third set, highlighting the unclear differences between warm-ups. There were no differences between the SWU and the GSWU in displacement, either in the bench press (Table 1) or the squat (Table 2) which guarantees the performance of identical technical patterns.

Table 2. Mean values ± standard deviation of mechanical responses in squat exercise. Differences and confidence intervals (95% CI), p-values and effect sizes (ES) are also reported.

	SWU	GSWU	SWU *vs.* GSWU		
			Mean ± CI (95%)	***p***	**ES**
MPV [set 1] ($m.s^{-1}$)	0.66 ± 0.07	0.68 ± 0.07	0.02 ± 0.05	0.41	0.40
MPV [set 2] ($m.s^{-1}$)	0.63 ± 0.05	0.64 ± 0.07	0.01 ± 0.06	0.61	0.19
MPV [set 3] ($m.s^{-1}$)	0.63 ± 0.06	0.62 ± 0.09	-0.01 ± 0.07	0.60	0.15
MPVmin total ($m.s^{-1}$)	0.46 ± 0.11	0.48 ± 0.08	0.01 ± 0.10	0.53	0.19
MPVmax total ($m.s^{-1}$)	0.67 ± 0.06	0.68 ± 0.06	0.01 ± 0.04	0.59	0.23
VL [set 1] (%)	19.89 ± 8.47	22.12 ± 10.22	2.23 ± 6.88	0.28	0.32
VL [set 2] (%)	23.47 ± 12.02	19.92 ± 12.03	-3.55 ± 9.42	0.21	0.38
VL [set 3] (%)	24.54 ± 14.84	21.25 ± 8.87	-3.29 ± 16.33	0.50	0.20
VL [total] (%)	31.43 ± 15.86	29.66 ± 10.14	-1.77 ± 15.17	0.69	0.23
PV [set 1] ($m.s^{-1}$)	1.15 ± 0.12	1.17 ± 0.08	0.02 ± 0.06	0.31	0.27
PV [set 2] ($m.s^{-1}$)	1.12 ± 0.08	1.13 ± 0.09	0.01 ± 0.05	0.85	0.27
PV [set 3] ($m.s^{-1}$)	1.08 ± 0.15	1.11 ± 0.10	0.03 ± 0.11	0.41	0.25
PV [total] ($m.s^{-1}$)	1.15 ± 0.09	1.17 ± 0.08	-0.01 ± 0.04	0.75	0.25
Time to PV [set 1] (s)	649.66 ± 182.20	733.08 ± 140.41	84.14 ± 240.75	0.25	0.26
Time to PV [set 2] (s)	711.50 ± 185.11	642.91 ± 234.79	-68.59 ± 311.23	0.46	0.17
Time to PV [set 3] (s)	726.25 ± 120.46	699.33 ± 185.22	-26.91 ± 223.58	0.68	0.12
Displacement [set 1] (m)	0.61 ± 0.06	0.62 ± 0.05	0.01 ± 0.05	0.31	0.21
Displacement [set 2] (m)	0.60 ± 0.07	0.61 ± 0.08	0.01 ± 0.03	0.54	0.35
Displacement [set 3] (m)	0.60 ± 0.07	0.61 ± 0.06	0.01 ± 0.04	0.57	0.23
MPP [set 1] (W)	410.25 ± 68.46	412.95 ± 82.79	2.70 ± 38.15	0.81	0.10
MPP [set 2] (W)	390.05 ± 69.27	392.83 ± 72.39	2.78 ± 35.85	0.79	0.10
MPP [set 3] (W)	387.35 ± 63.78	379.79 ± 78.26	-7.56 ± 42.16	0.54	0.17
MPPmin total (W)	280.21 ± 79.49	295.30 ± 80.24	15.09 ± 75.21	0.50	0.20
MPPmax total (W)	415.76 ± 68.40	416.40 ± 80.00	0.63 ± 28.76	0.94	0.02
MPP [total] (W)	6286.25 ± 1117.81	6343.44 ± 1430.44	57.19 ± 689.34	0.77	0.08

*$p < 0.05$; ** $p < 0.001$ SWU: Specific warm-up; GSWU: general plus specific warm-up; MPV: mean propulsive velocity; MPVmin total: mean propulsive velocity minimum total; MPVmax total: mean propulsive velocity maximum total; VL: velocity loss; VL [total]: velocity loss total; PV: peak velocity; Time to PV: time to peak velocity; Displacement: exercise displacement; MPP: mean propulsive power; MPPmin total: mean propulsive power minimum total; MPPmax total: mean propulsive power maximum total. MPP total: mean propulsive power total.

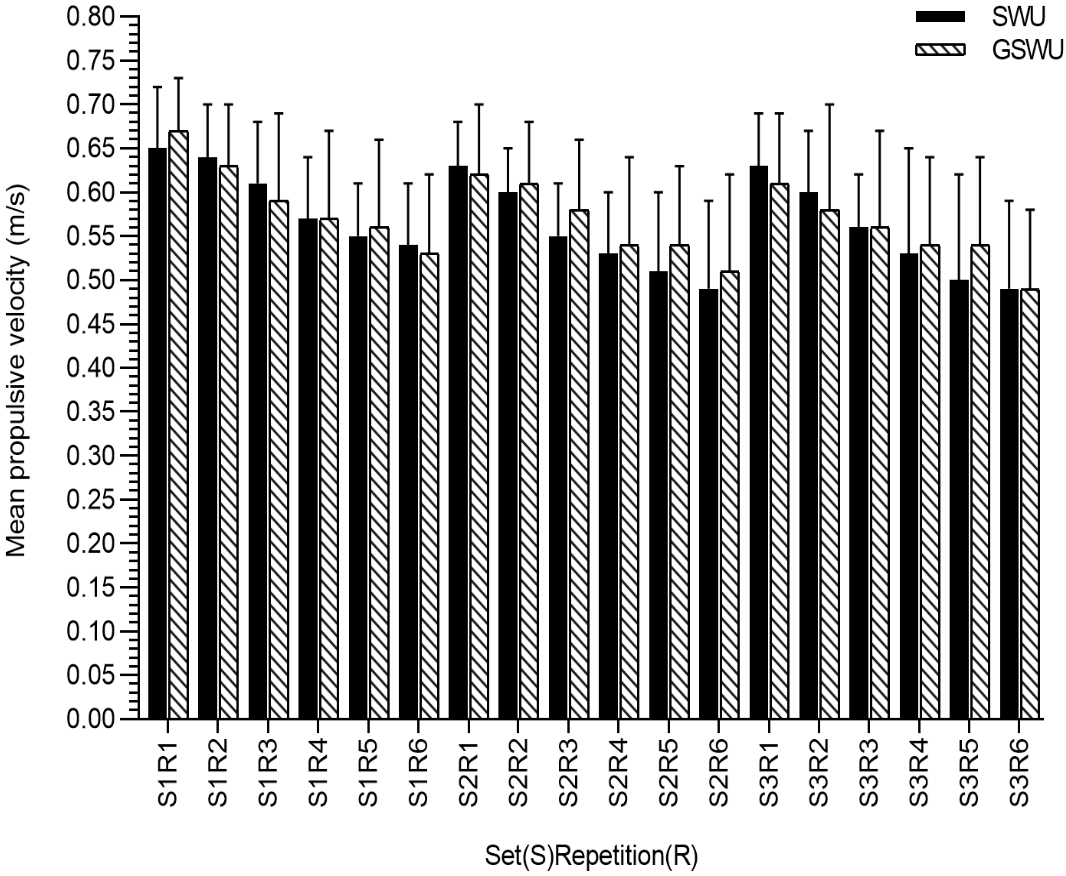

Figure 2. Mean propulsive velocity values in each repetition performed during squat resistance training session. Values obtained in the six repetitions (R) during the first, second and third sets (S) of specific warm-up (SWU) and general plus specific warm-up (GSWU).

In the physiological variables, differences were found in the HR between the SWU and the GSWU after the warm-up in the bench press resistance training (HR during SWU: 100.00 ± 16.93 bpm and HR during GSWU: 110.57 ± 9.69 bpm, p= 0.03, ES= 0.65, moderate effect). No differences were reported in the other physiological and psychophysiological variables in the bench press and the squat resistance training (Figure 3).

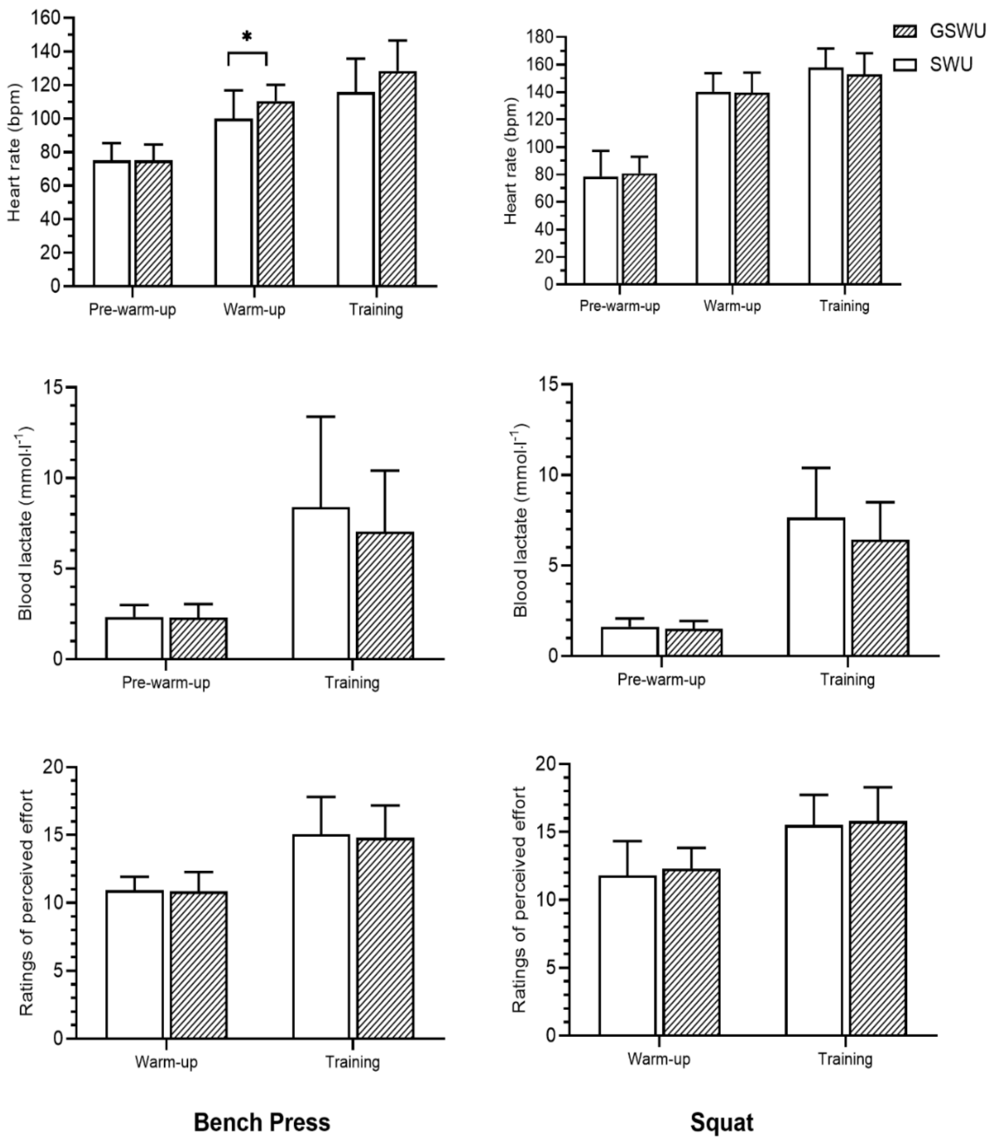

Figure 3. Physiological (heart rate and blood lactate concentration) and psychophysiological (rating of perceived effort) variables of specific warm-up (SWU) and general plus specific warm-up (GSWU) in bench press and squat resistance training before warm-up, after warm-up and after the resistance training session. * $p < 0.05$.

Discussion

The present study aimed to compare the effects of two different warm-up strategies, specifically, SWU and GSWU, on the mechanical responses of force production in the bench press and squat resistance exercises during resistance training. No differences were observed between the two conditions (i.e., GSWU and SWU) either for the bench press resistance training or the squat resistance training, which did not confirm our hypothesis. These results suggested that the general warm-up followed by a specific warm-up or just a specific warm-up can both be used as preparatory activities for bench press and squat resistance training performances.

The role of resistance performance is unequivocal to the exercise related to competitive movement, as well as to the components related to physical fitness, such as the ability to perform daily activities (Garber et al., 2011). In this sense, the preparation for a competitive event or training session can determine the success or failure of practitioners in achieving their goals. Increasing strength performance and optimizing resistance training should be a primacy for athletes, coaches, and sports scientists. In this sense, warm-ups could be helpful to optimize performance (Wilcox et al., 2006). However, there is a controversy on the use of general warm-up when applied before resistance training. Some authors reported that general warm-up may impair the development of power (Wilson et al., 2013), while others revealed positive results on muscle force production using a combination of general with specific warm-up (Abad et al., 2011). Considering the specific warm-up, Weineck (1991) highlighted the importance of including exercises that aim to warm-up the muscles that are directly related to the sport to be performed. Fermino et al. (2005) also explained that specific warm-ups can provide increases in the speed of contraction and relaxation of muscles, as well as increase the mechanical efficiency of muscle contraction due to the decreased viscosity at the cellular level. Costa (2014) investigated the acute effect of specific warm-up before resistance training and the results showed a significant increase in strength values for leg press exercise.

In the present study, no differences were found in the mechanical variables between GSWU and SWU during bench press or squat resistance training sessions. This may be explained by the small stimuli caused by the general warm-up component that was implemented (i.e., 10 minutes of treadmill running at 70% of heart rate reserve). This explanation was first addressed by Gil et al. (2015) after they found no differences between the use of a general warm-up followed by a specific warm-up or a specific warm-up only in the 1RM values of leg press and bench press exercises. On the opposite, Abad et al. (2011) suggested that including a general warm-up before the specific one induced neuromuscular adjustment that increased muscle force production capacity and resulted in higher 1RM values in leg press exercise. These contradictory facts can be explained by the different methodologies used by the different studies (i.e., testing protocols, exercise used, and variables assessed). It is important to highlight that, in the current study, no discrepancies were identified in the bar displacement, both in the bench press and squat resistance training sessions, between warm-ups. Considering that the range of motion can significantly affect muscle activity and barbell velocity (Krzysztofik et al., 2021), the non-existence of differences in the bar displacement between conditions ensures that the range of motion was maintained between sessions.

A general warm-up is expected to raise body temperature, oxygen uptake, and heart rate, contributing influence oxygen diffusion in the muscles (Nicoli et al., 2007). Examining the physiological changes induced by warm-up in the current study, the combination of general warm-up plus specific warm-up caused a higher response of HR, with increased values when compared to the specific warm-up. This difference was found in the bench press but not in the squat resistance training session. The squat exercise is known to require more muscle mass recruitment and cause a higher acute hemodynamic and metabolic response than the bench press (Andrade et al., 2022). This way, when performing the squat SWU, it is expected that the HR raise more than a bench press, leading to trivial effects of additional general warm-up. However, in the bench press exercise, the inclusion of a general warm-up led to increased HR response after the warm-up, perhaps because of the lack of stimuli caused by the SWU. Nevertheless, the blood lactate concentration and the RPE values were not different between the GSWU and the SWU, in both exercises. These physiological and psychophysiological responses were probable, considering the non-existence of differences in the resistance training performances, and according to recent findings (Ushirooka et al., 2023). We can hypothesize that the differences between the two warm-ups (i.e., adding a general warm-up before the specific warm-up) were not enough to cause a detectable metabolic effect.

Some limitations should be addressed in the current study: i) one should be aware that only bench press and squat exercises were analyzed, therefore caution should be taken when generalizing the present findings to other resistance training exercises. Nonetheless, both exercises are two of the most used exercises in strength-related studies and resistance training contexts; ii) a small sample of men was used in the study, and a larger sample of both sexes would provide clearer conclusions in some of the analyzed variables and support the effects of different warm-ups approaches in males and females; iii) one should acknowledge possible unknown variation in day-to-day performance, despite the counterbalanced distribution of the participants. Further research should analyze additional variables such as hormonal responses and core temperature, which seem to be pertinent and helpful to better understand the effects of different warm-up routines in the selected resistance exercises' performance.

Conclusion

The current study revealed that GSWU or SWU can both be used as preparatory activities for bench press and squat resistance training sessions. Notoriously, the general warm-up can positively influence muscle force production, and positive results in resistance training sessions of the bench press and the squat exercises can be obtained using GSWU or just SWU. However, if the participant needs to do a shorter training due to limited time to training, it seems to be more useful to do a specific warm-up instead of a general with a specific warm-up. These findings may be useful to professionals (i.e., coaches, strength and conditioning specialists, sports scientists) in providing appropriate warm-up strategies to maximize resistance training.

Study 4. Impact of Re-Warm-Up During Resistance Training: Analysis of Mechanical and Physiological Variables

Abstract

This study examined the effects of re-warm-up versus no re-warm-up before squat or bench press on mechanical, physiological, and psychophysiological responses in recreationally trained men. Twenty-two participants (23 ± 3 years) completed four randomized sessions involving different re-warm-up and exercise sequences. Measurements included heart rate, blood lactate, tympanic temperature, and perceived exertion. Key performance metrics such as mean propulsive velocity, peak velocity, power, velocity loss, and effort index were analyzed. Findings revealed that re-warming up before squat (W+BP+RW+SQ) significantly enhanced propulsive velocity and power compared to no re-warm-up (W+BP+SQ) ($p \leq 0.05$; d=0.45-0.62). However, re-warming up before the bench press (W+SQ+RW+BP) did not improve mechanical performance compared to the standard sequence (W+SQ+BP) ($p > 0.05$; d=0.10-0.38). Notably, velocity loss and effort index were higher in the third bench press set under the W+SQ+BP condition ($p \leq 0.05$; d=0.53-0.60). No significant differences in physiological or psychophysiological responses were found between conditions. Overall, re-warm-up effectively improved squat mechanical performance when performed after the bench press but had minimal impact on the bench press when performed after squats. These findings suggest that re-warming up before lower-body exercises may enhance mechanical performance, while its benefits may be less pronounced for upper-body exercises.

Keywords: Pre-exercise, specific warm-up, strength training, propulsive velocity, power output, heart rate, lactate, rate of perceived exertion, exercise sequence, young adults

Introduction

Warm-up exercises are crucial in recreational training and competition as they prepare the body physiologically and psychologically, reduce injury risk, and enhance performance across individual and team sports (Ayala et al., 2016; Barnes et al., 2017; Neiva et al., 2014; Zois et al., 2015). Different warm-up strategies have been investigated, and research tends to agree regarding their positive impact on physical performance (Fradkin et al., 2010; Gil et al., 2021; McGowan et al., 2015; Silva et al., 2018). For instance, warm-up by running or cycling for 15 min at 80% of maximum oxygen uptake improves vertical jump performance immediately and in the following 20 min post-warm-up (Chiba et al., 2022; Tsurubami et al., 2020). Furthermore, warm-up by running 500 m at 70% running intensity followed by 3 x 250 m at 100% running intensity significantly benefits running performance in the 5000 m in trained endurance runners (Alves et al., 2023).

In resistance training, extensive research has been conducted to analyze the impact of post-activation potentiation (PAP), the role of general and/or specific warm-up procedures, and the effects of various warm-up protocols (e.g., varying volumes and intensities). Studies have documented the PAP effect following various exercises, including maximal loaded, submaximal loaded, and unloaded exercises (Chaouachi et al., 2010; Kilduff et al., 2008; Wilson et al., 2013). According to Wilson et al. (2013), the potentiation of warm-up can be optimized with multiple sets performed at moderate intensities (i.e., 60-84% of 1RM) and rest periods between 7-10 minutes in practitioners with at least one year of resistance training background. Furthermore, combining general and specific warm-ups improves force production and increases strength in the one-repetition maximum (1RM) test compared to just performing a specific warm-up during 1RM testing procedures (Abad et al., 2011). A study by Barnes et al. (2017) demonstrated that a specific warm-up tailored to the exercise led to a more significant enhancement in peak power for the high pull than a general warm-up.

While many previous studies have shown the benefits of warming up before resistance training, few have explored different strategies, including monitoring movement velocity, to quantify training intensity and the level of effort following specific warm-up strategies (Neves et al., 2024; Ribeiro et al., 2020; Ribeiro, Pereira, Alves, et al., 2021). Measuring movement velocity in real-time in a resistance training setting offers a reliable and regular means of monitoring exercise intensity and effort (González-Badillo et al., 2022). The measurement of repetition velocity is an accurate and objective indication of the actual exertion and level of effort experienced by the practitioner during training, providing valuable information to strength and conditioning coaches (González-Badillo et al., 2022). Following this velocity-monitored resistance training approach, recent findings demonstrated that specific warm-ups comprising two sets of six repetitions performed with maximal intended velocities at 40% and 80% of the training load (i.e., 32 and 64% of 1RM) enhance neuromuscular function, enabling higher movement velocity outputs in the initial squat and bench press repetitions and achieving peak velocities more quickly (Ribeiro, Pereira, Alves, et al., 2021). Furthermore, a specific warm-up of one set of six repetitions performed with maximal intended velocities at 80% of 1RM seems more effective in potentiating mechanical performance in the squat than at 40% of 1RM in resistance-trained males (Ribeiro et al., 2020). On the other hand, a specific warm-up involving two sets of six repetitions performed with maximal intended velocities with progressive loads (40% to 80% of 1RM) may be more effective in increasing mechanical performance in the bench press than a single set (Ribeiro et al., 2020).

Although efforts have been made to understand the effect of warming up in its various forms (e.g., general and specific) on force production and strength performance (Abad et al., 2011; Ribeiro et al., 2014; Ribeiro, Pereira, Neves, et al., 2021), resistance training is typically not just a single exercise but a sequence of different exercises targeting the same or different muscle groups. In this respect, it stands out that it is important to understand whether re-warming up for the following strength exercises has benefits on mechanical (i.e., velocity) and physiological performance (e.g., heart rate and lactate responses). However, little is known about the need to re-warm-up during the session using specific warm-ups to enhance subsequent exercise performance. This need is even more evident when the muscle groups that are most stimulated are not the same in the following exercises to be performed. Therefore, considering that the warm-up effect may decrease throughout the session, especially during inactivity (Kapnia et al., 2023) and if the intensity is low (Chiba et al., 2022; Tsurubami et al., 2020), an effective and practical solution to avoid this decline becomes necessary. It is important to balance the free time available in sessions and improve physical performance through re-warming strategies between exercises, primarily when focusing on different muscle groups during sessions.

Therefore, considering the research gap about the impact of re-warming-up in the subsequent strength exercises, this study aimed to analyze the effects of different re-warm-up strategies before the squat or bench press on mechanical, physiological, and psychophysiological responses in recreational-trained men. It was hypothesized that performing a specific rewarm-up following the first strength exercise of the session would improve mechanical performance in the squat and bench press and produce a similar physiological and psychophysiological response in recreational-trained men.

Materials and Methods

Participants

Twenty-two male sport sciences students aged between 19 and 32 (22.8 ± 3.3 years, 76.1 ± 12.6 kg, and 1.78 ± 0.06 m; 1RM bench press: 78.5 ± 11.6 kg; 1RM squat: 96.0 ± 23.1 kg) volunteered to participate in this study. Each participant reported no previous illness, injury, or other physical problems that could impair their performance during resistance training sessions. All participants were verbally informed about the study procedures and signed a consent form. The inclusion criteria comprised male participants aged 18 or over, without physical limitations or restrictions to perform resistance exercises, and at least 6 months of resistance training experience, especially in the bench press and squat. Participants who met the criteria and voluntarily agreed to participate in the study were included. All procedures followed the recommendations of the Declaration of Helsinki and were approved by the Ethics Committee of the University of Beira Interior (approval number: CE-UBI-Pj-2021-018).

Experimental design

In a crossover design, participants performed four resistance training sessions with or without re-warm-up conditions following the first strength exercise in a randomized order with at least 48 hours of rest between each. The experimental conditions were: i) Warm-Up + Squat + Bench Press (W+SQ+BP); ii) Warm-Up + Squat + Re-Warm-Up + Bench Press (W+SQ+RW+BP); iii) Warm-Up + Bench Press + Squat (W+BP+SQ); iv) Warm-Up + Bench Press + Re-Warm-Up + Squat (W+BP+RW+SQ). Heart rate, blood lactate, and tympanic temperature (physiological variables) were measured at baseline and immediately after the last exercise of the session. The rate of perceived exertion (RPE; psychophysiological variable) was also collected immediately after the last exercise of the session. In all sessions, participants performed three sets of six repetitions at 80% of 1RM in the squat and bench press. A linear velocity transducer (T-Force Dynamic Measurement System, Ergotech, Murcia, Spain) with the cable connected to the barbell of a Multipower (Multipower Fitness Line, Perola, Murcia, Spain) collected all mechanical variables during the execution of repetitions. Mechanical variables included mean propulsive velocity (MPV), peak velocity (PV), time to peak velocity (TPV), velocity loss (VL), mean propulsive power (MPP), peak power (PP), and bar displacement. The degree of fatigue was expressed as the effort index (EI) (Rodríguez-Rosell et al., 2018). The experimental procedures of the study lasted three weeks, with two sessions performed per week. The first was to familiarize the participants with the testing protocols and measure height and body mass (Seca Instruments, Ltd, Hamburg, Germany). Then, participants performed a progressive loading test in the second session to determine the 1RM load in the bench press and squat. In the following sessions, participants performed experimental conditions. Figure 1 il-lustrates the experimental design.

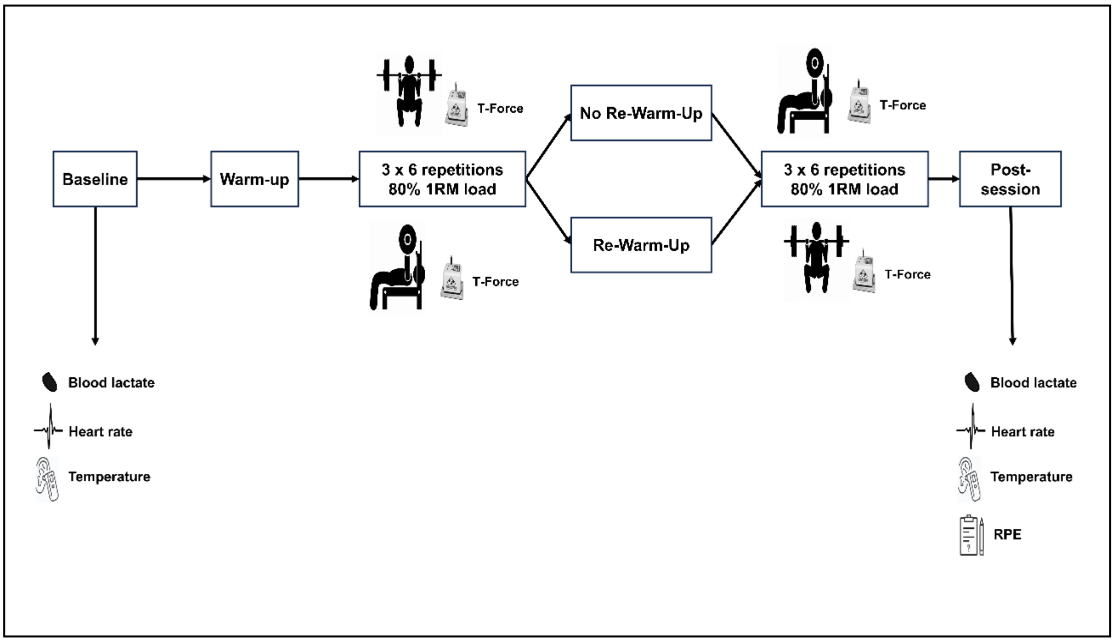

Figure 1. Experimental procedures and timeline of data collection.

Progressive loading test in the bench press and squat

In the bench press test, participants lay supine on a flat bench with feet on the floor and hands placed slightly wider than shoulder-width on the barbell (Pallarés et al., 2014; Sánchez-Medina et al., 2014). They lowered the barbell to the chest, just above the nipples, in a controlled manner, and after approximately one second of pause, they performed the concentric phase as fast as possible (Pallarés et al., 2014). Participants were not allowed to bounce the barbell off the chest or to raise the shoulders or trunk off the bench (Sánchez-Medina & González-Badillo, 2011). In the squat, participants started from an upright position with knees and hips fully extended, hands placed slightly wider than shoulder-width on the barbell, and the barbell resting on the back at the level of the acromion (Sánchez-Medina et al., 2017). Then, they began to descend until the tops of the thighs were below 90º in continuous movement (eccentric phase), and immediately after, they ascend at maximum velocity to the initial position (concentric phase) (Sánchez-Medina et al., 2017). Two experienced strength coaches were on both sides of the barbell to ensure safety. In both exercises, the first researcher and strength coaches controlled the movement to guarantee that all repetitions were performed with the required technique and a similar range of movement. The initial load was fixed at 17 kg and 20 kg for all participants in the bench press and squat, respectively, and gradually increased by 10 kg. The test finished when participants reached a concentric MPV of 0.40 m. s-1 in the bench press and 0.60 m. s-1 in the squat, corresponding to 85% 1RM in both exercises (González-Badillo & Sánchez-Medina, 2010; Sánchez-Medina et al., 2017). Inter-set recoveries ranged from 3 minutes (light loads) to 5 minutes (heavy loads). The 1RM load was determined from the last MPV obtained during the test as follows: (100 x Load) / (8.4326 x MPV2 – 73.501 x MPV + 112.33) for the bench press (González-Badillo & Sánchez-Medina, 2010), and (100 x load) / (-5.961 x MPV2 – 50.71 x MPV + 117) for the squat (Sánchez-Medina et al., 2017).

Resistance training protocols

The warm-up included 10 minutes of treadmill running, starting at 50-55% of heart rate reserve until reaching 70% in the last 2 minutes, followed by two sets of six repetitions at 32% and 64% of 1RM in the squat or bench press (Neves et al., 2024). After a three-minute pause for physiological and psychophysiological variables, participants performed three sets of six repetitions at 80% of 1RM in the bench press or squat, with a three-minute interval between sets. Then, depending on the experimental condition, participants either performed a re-warm-up of two sets of six repetitions at 32% and 64% of 1RM in the squat or bench press or immediately performed the second exercise without re-warm-up. All concentric repetitions were performed with the maximal intended velocity, while the eccentric phase was controlled (~3 seconds). The first researcher and two strength coaches (each coach on each side of the barbell to spot participants) supervised all sessions to guarantee a correct execution technique and encourage participants to exert maximum effort during all repetitions.

Measurement of physiological and psychophysiological parameters

Heart rate was monitored during all sessions with a Polar watch (Polar Vantage NV, Kempele, Finland). Blood lactate concentration was measured using a hand-held portable device (Lactate Pro 2 LT-1730, Arkray Inc., Tokyo, Japan). After cleansing the site with 70% alcohol, the fingertip was punctured using a disposable lancet. The first drop of blood was discarded, and a tiny blood sample was collected for analysis (Marques et al., 2019). Tympanic temperature was measured with an infrared thermometer to estimate the central body temperature (Braun Thermoscan IRT 4520, Kronberg, Germany) (Resende et al., 2020). RPE values were measured using a 15-grade scale (Borg scale 6-20) (Borg, 1982).

Statistical Analysis

Considering an expected difference in MPV of 0.04 ± 0.03 m·s-1 between experimental conditions with versus without re-warm-up (Ribeiro, Pereira, Alves, et al., 2021), a significance level of 0.05, a statistical power of 80%, and a drop-out rate of 20%, an estimated sample size of 12 participants was required (Arifin, 2017). Microsoft Office Excel (Microsoft Inc., Redmond, WA, USA) was used to collect physiological and psychophysiological results and extract data from the T-Force software. Afterward, data was analyzed in SPSS (v27.0, IBM Corp., Armonk, NY, USA). Descriptive data are presented as mean ± standard deviation and 95% confidence intervals (CI). The Shapiro-Wilk test analyzed the normality of the data. After confirming the assumption of data normality, paired t-tests were used to compare experimental conditions with vs. without re-warm-up (W+SQ+BP vs. W+SQ+RW+BP; W+BP+SQ vs. W+BP+RW+SQ) in mechanical, physiological, and psychophysiological variables. The significance level was set at $p \leq 0.05$. The effect size (ES) was calculated using Cohen's d to determine the magnitude of the differences be-tween conditions. The ES was interpreted 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), and extremely large (> 4.00) (Hopkins et al., 2009). Figures were generated in GraphPad Prism (v7.0, GraphPad Inc., San Diego, CA, USA).

Results

Mechanical differences between experimental conditions with vs. without re-warm-up

Table 1 shows significant differences between W+BP+SQ vs. W+BP+RW+SQ conditions on MPV (first set: $t_{21} = -2.43$, $p = 0.02$, ES = 0.52; second set: $t_{21} = -2.25$, $p = 0.04$, ES = 0.48; third set: $t_{21} = -2.09$, $p = 0.05$, ES = 0.45), PV (first set: $t_{21} = -2.89$, $p = 0.01$, ES = 0.62; second set: $t_{21} = -2.69$, $p = 0.01$, ES = 0.57), MPP (second set: $t_{21} = -2.57$, $p = 0.02$, ES = 0.55; third set: $t_{21} = -2.10$, $p = 0.05$, ES = 0.45), and PP (second set: $t_{21} = -3.11$, $p = 0.01$, ES = 0.66; third set: $t_{21} = -2.18$, $p = 0.04$, ES = 0.47).

Table 1. Comparison between condition with warm-up + bench press + squat vs. condition with warm-up + bench press + re-warm-up + squat on mechanical parameters. The results correspond to the second exercise performed in the session (squat).

	W+BP+SQ	W+BP+RW+SQ	95% CI	p-value	ES (d)
SET 1					
MPV (m.s^{-1})	0.58 ± 0.10	0.61 ± 0.09	(-0.05, 0.00)	0.02*	0.52
PV (m.s^{-1})	1.10 ± 0.18	1.16 ± 0.14	(-0.10, -0.02)	0.01*	0.62
VL (%)	17.22 ± 8.69	14.57 ± 5.48	(-0.29, 5.60)	0.08	0.40
TPV (ms)	615.14 ± 106.14	586.64 ± 97.59	(-18.78, 75.78)	0.22	0.27
EI	9.84 ± 4.44	8.93 ± 3.46	(-0.56, 2.39)	0.21	0.27
MPP (W)	431.03 ± 79.33	447.67 ± 100.16	(-43.82, 10.54)	0.22	0.27
PP (W)	957.32 ± 231.93	1006.28 ± 229.01	(-108.12, 10.20)	0.10	0.37
BD (cm)	49.04 ± 7.40	48.76 ± 7.13	(-1.88, 2.43)	0.79	0.06
SET 2					
MPV (m.s^{-1})	0.58 ± 0.10	0.60 ± 0.09	(-0.04, 0.00)	0.04*	0.48
PV (m.s^{-1})	1.08 ± 0.16	1.13 ± 0.13	(-0.09, -0.01)	0.01*	0.57
VL (%)	14.93 ± 6.41	15.31 ± 6.78	(-3.12, 2.36)	0.78	0.06
TPV (ms)	608.50 ± 94.25	585.36 ± 104.10	(-16.37, 62.65)	0.24	0.26
EI	8.40 ± 3.35	8.95 ± 3.45	(-2.05, 0.95)	0.46	0.16
MPP (W)	425.66 ± 88.50	445.75 ± 96.07	(-36.34, -3.84)	0.02*	0.55
PP (W)	930.17 ± 217.11	993.68 ± 222.62	(-105.92, -21.09)	0.01*	0.66
BD (cm)	48.55 ± 6.87	48.06 ± 7.52	(-1.16, 2.14)	0.54	0.13
SET 3					
MPV (m.s^{-1})	0.58 ± 0.11	0.60 ± 0.09	(-0.05, 0.00)	0.05*	0.45
PV (m.s^{-1})	1.09 ± 0.18	1.13 ± 0.13	(-0.08, 0.00)	0.06	0.43
VL (%)	16.40 ± 7.81	14.64 ± 6.76	(-1.65, 5.18)	0.30	0.23
TPV (ms)	603.00 ± 116.46	568.00 ± 96.76	(-11.54, 81.54)	0.13	0.33
EI	9.31 ± 3.82	8.83 ± 4.14	(-1.56, 2.51)	0.63	0.10
MPP (W)	429.85 ± 80.85	447.75 ± 86.41	(-35.60, -0.21)	0.05*	0.45
PP (W)	949.00 ± 242.39	995.35 ± 220.93	(-90.51, -2.17)	0.04*	0.47
BD (cm)	48.11 ± 7.63	47.75 ± 7.33	(-1.37, 2.08)	0.67	0.09

* p-value < 0.05; Data are presented as means ± SD unless otherwise stated. Bold values denote significant differences. W+BP+SQ: warm-up + bench press + squat; W+BP+RW+SQ: warm-up + bench press + specific rewarm-up + squat; BD: bar displacement; CI: confidence intervals; ES: effect size Cohen's d; MPV: mean propulsive velocity; PV: peak velocity; VL: velocity loss; TPV: time to achieve peak velocity; EI: effort index; MPP: mean propulsive power; PP: peak power.

Table 2 shows significant differences between W+SQ+BP vs. W+SQ+RW+BP on VL (third set: $t_{21} = 2.48$, $p = 0.02$, ES = 0.53), TPV (second set: $t_{21} = 2.98$, $p = 0.01$, ES = 0.64), and EI (third set: $t_{21} = -0.23$, $p = 0.01$, ES = 0.60).

Table 2. Comparison between condition with warm-up + squat + bench press vs. condition with warm-up + squat + re-warm-up + bench press on mechanical parameters. The results correspond to the second exercise performed in the session (bench press).

	W+SQ+BP	W+SQ+RW+BP	95% CI	p-value	ES (d)
SET 1					
MPV ($m.s^{-1}$)	0.46 ± 0.11	0.45 ± 0.07	(-0.04, 0.06)	0.66	0.10
PV ($m.s^{-1}$)	0.74 ± 0.22	0.69 ± 0.12	(-0.05, 0.13)	0.35	0.21
VL (%)	24.68 ± 9.21	28.43 ± 10.41	(-10.65, 3.17)	0.27	0.24
TPV (ms)	637.45 ± 238.77	669.59 ± 208.30	(-160.57, 96.30)	0.61	0.11
EI	11.05 ± 3.93	12.66 ± 4.44	(-4.45, 1.23)	0.25	0.25
MPP (W)	276.87 ± 58.92	278.60 ± 63.77	(-27.63, 24.18)	0.89	0.03
PP (W)	475.03 ± 150.10	449.77 ± 99.62	(-39.32, 89.84)	0.43	0.17
BD (cm)	40.92 ± 4.32	40.04 ± 3.56	(-0.35, 2.10)	0.15	0.32
SET 2					
MPV ($m.s^{-1}$)	0.46 ± 0.08	0.43 ± 0.07	(-0.01, 0.07)	0.13	0.34
PV ($m.s^{-1}$)	0.70 ± 0.18	0.64 ± 0.11	(-0.01, 0.14)	0.09	0.38
VL (%)	29.86 ± 12.44	31.41 ± 11.70	(-8.11, 5.02)	0.63	0.10
TPV (ms)	599.32 ± 265.85	438.22 ± 223.70	(48.54, 273.64)	0.01*	0.64
EI	13.29 ± 4.78	13.55 ± 5.52	(-2.62, 2.09)	0.82	0.05
MPP (W)	282.02 ± 60.60	266.63 ± 59.64	(-8.65, 39.43)	0.20	0.28
PP (W)	456.02 ± 142.37	410.35 ± 86.52	(-15.66, 107.00)	0.14	0.33
BD (cm)	40.74 ± 3.95	39.77 ± 4.58	(-0.50, 2.44)	0.18	0.29
SET 3					
MPV ($m.s^{-1}$)	0.45 ± 0.11	0.43 ± 0.07	(-0.03, 0.06)	0.44	0.17
PV ($m.s^{-1}$)	0.70 ± 0.20	0.65 ± 0.12	(-0.04, 0.13)	0.28	0.24
VL (%)	30.72 ± 11.74	26.02 ± 6.96	(0.76, 8.64)	0.02*	0.53
TPV (ms)	498.36 ± 259.04	532.73 ± 258.87	(-143.16, 74.43)	0.52	0.14
EI	13.76 ± 5.83	11.29 ± 3.50	(0.63, 4.31)	0.01*	0.60
MPP (W)	274.94 ± 64.94	266.46 ± 59.35	(-15.42, 32.37)	0.47	0.16
PP (W)	460.10 ± 146.43	411.45 ± 90.56	(-10.35, 107.64)	0.10	0.37
BD (m)	40.51 ± 4.50	39.09 ± 3.79	(-0.02, 2.85)	0.06	0.44

* p-value < 0.05; Data are presented as means ± SD unless otherwise stated. Bold values denote significant differences. W+SQ+BP: warm-up + squat + bench press; W+SQ+RW+BP: warm-up + squat + specific re-warm-up + bench press; BD: bar displacement; CI: confidence intervals; ES: effect size Cohen's d; MPV: mean propulsive velocity; PV: peak velocity; VL: velocity loss; TPV: time to achieve peak velocity; EI: effort index; MPP: mean propulsive power; PP: peak power.

Physiological and psychophysiological differences between experimental conditions with vs. without re-warm-up

Figure 2 shows no significant differences in physiological and psychophysiological parameters between W+SQ+BP vs. W+SQ+RW+BP and W+BP+SQ vs. W+BP+RW+SQ at baseline and post-session.

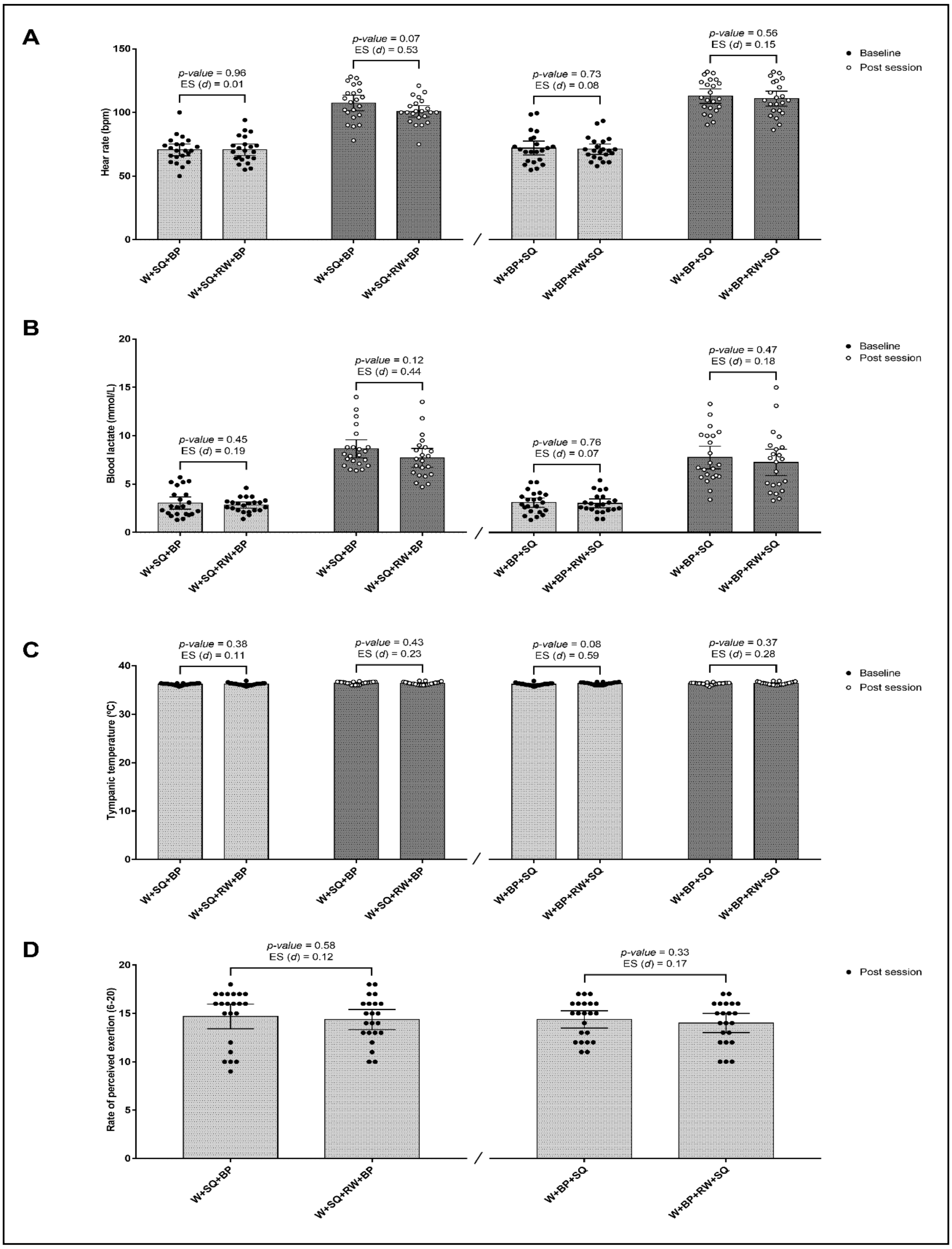

Figure 2. Differences between conditions with and without re-warm-up on heart rate (A), blood lactate (B), tympanic temperature (C), and rate of perceived exertion (D) at baseline and post-session. W+SQ+BP: warm-up + squat + bench press; W+SQ+RW+BP: warm-up + squat + re-warm-up + bench press; W+BP+SQ: warm-up + bench press + squat; W+BP+RW+SQ: warm-up + bench press + rewarm-up + squat. ES: Cohen's d effect size.

Discussion

This study aimed to analyze the effects of re-warm-up after the first strength exercise of the session (bench press or squat) on mechanical, physiological, and psychophysiological parameters in recreational-trained men. The hypothesis that the re-warm-up would improve mechanical performance in the squat and bench press was partially confirmed by the present findings. Re-warming up between the bench press and squat (W+BP+RW+SQ condition) was shown to be more favorable for enhancing MPV and PV during the first two sets of squats than not performing sets of re-warm-up (W+BP+SQ condition). Moreover, the power-related variables were higher in the second and third sets when the re-warm-up was performed. On the other hand, the re-warm-up between the squat and bench press (W+SQ+RW+BP condition) did not show differences in the propulsive velocity compared to the no-re-warm-up condition (W+SQ+BP condition). However, the relative VL and EI were higher in the third set of the bench press when no re-warm-up was completed after the squat. The comparison between experimental conditions with vs. without re-warm-up revealed no significant differences in physiological and psychophysiological parameters, confirming our second hypothesis that an additional warm-up in the session would not cause a disturbance in physiological parameters. These results highlight the importance of re-warming up during the resistance training session to optimize mechanical performance, primarily when the following exercise works different muscle groups compared to the previous exercise.

In our study, the re-warm-up effect optimized the mechanical performance in the squat exercise, which aligns with previous studies that observed similar mechanical responses (Ribeiro et al., 2020; Ribeiro, Pereira, Alves, et al., 2021). This result can occur because the squat recruits large muscle groups, such as the quadriceps femoris and gluteus maximus (Contreras et al., 2016), which may benefit from a pre-activation to maximize force production and propulsive velocity. Contrarily, when the re-warm-up was performed between the squat and bench press (W+SQ+RW+BP condition), it did not result in any additional effect on the mechanical performance of the bench press. This result may be explained because the bench press, contrary to the squat, involves smaller muscle groups than the squat (Rodríguez-Rosell et al., 2018; Sanchis-Moysi et al., 2010), which may benefit from the muscular activation performed in the previous and different exercises, including the squat.

Over the years, the warm-up phase has been considered a critical component of a training session to potentiate the performance of athletes in different sports (McGowan et al., 2015). It is well-known that the warm-up routine increases body temperature, pre-paring the body for the following activity, which can supply positive effects in physio-logical parameters, such as the increment of the metabolic efficiency or nerve conduction rate and a decrease in muscular stiffness (Bishop, 2003a, 2003b). Despite the benefits of the warm-up, some uncertainties remain regarding re-warm-ups effects in specific resistance training activities (Alves et al., 2021; Ribeiro et al., 2014). Following the American College of Sports Medicine guidelines (Ratamess et al., 2009) for resistance training prescription in novice and untrained individuals, it is recommended to prescribe exercises focusing on full-body, and a special preference to apply a general warm-up at the beginning of the session. However, there is still a gap in the literature about the contribution of warm-up or re-warm-up in resistance training performance.

Our results reported that re-warming up between the squat and bench press (W+SQ+RW+BP) seemed indifferent to obtaining better physical performance, as the propulsive velocity did not report differences between the experimental condition without re-warm-up (W+SQ+BP). However, the TPV in the bench press was inferior in the second set using the re-warm-up condition, which can be important for practitioners who aim to increase the ability to produce force quickly. Furthermore, it is relevant to highlight the lower VL and EI measured in the last set performed on the bench press when the re-warm-up was used after the squat. Considering that EI is a powerful indicator of neuromuscular fatigue (Rodríguez-Rosell et al., 2018), the current results may support the relevance of the re-warm-up in the sense that it can contribute to attenuating fatigue levels and preserving the ability to produce force for longer within the training session.

Although no differences were found between experimental conditions with vs. without re-warm-up in physiological responses, re-warm-up after the squat or bench press resulted in slightly, not significantly, lower blood lactate concentrations compared to conditions without re-warm-up. These results might be related to the decrease in volume and relative intensity during the re-warm-up phase, which may also enable the body to recover between exercises. Therefore, if the metabolic responses following the re-warm-up strategies were slightly lower, they do not negatively influence the performance of the subsequent exercise. Since no more differences were found in other physiological and psychophysiological (RPE) variables between conditions with and without re-warm-up, future studies must employ a detailed analysis using, for example, muscle temperature, hormonal responses, and motor control after exercise for a deeper analysis.

Some limitations should be addressed in this study. First, a small sample size of men was used, and a larger sample including both sexes would provide more evident conclusions in the analyzed variables and support the effects of different warm-up approaches, including re-warm-up routines. Second, only the squat and bench press were included in the study. Usually, resistance training is not constituted by only these two exercises, reinforcing the need to include more exercises in future research. Lastly, including additional physiological variables (e.g., creatine kinase, testosterone, cortisol) would allow us to analyze the impact of different re-warm-up strategies more deeply. Even conscious of the study's limitations, the current findings are important for re-searchers and strength and conditioning coaches to provide evidence about the warm-up methodologies and their effects on resistance training performance. Future research should include additional resistance training exercises (e.g., knee extension and biceps curls) or even supplementary variables such as muscle temperature and hormonal responses to enrich the knowledge of the warm-up phenomenon in resistance training performance. These analyses could be pertinent and helpful in increasing the under-standing of the effects of different warm-up routines in recreational contexts and sports performance.

This study has practical implications for researchers and strength and conditioning coaches when implementing interventions in recreational-trained males. Based on the results, when combining the bench press and squat in the same resistance training session, performing a re-warm-up following the bench press might be indicated to improve the squat's propulsive velocity. Furthermore, introducing a re-rewarm-up between the squat and bench press might be indicated to decrease the magnitude of fatigue in the last sets and preserve mechanical performance over the sets. Finally, performing a re-warm-up in both protocols will not induce a more significant increase in heart rate, blood lactate, tympanic temperature, and RPE when compared to not performing a re-warm-up.

Conclusions

The current study highlights the potential benefits of re-warm-up for improving mechanical performance during resistance training, particularly in the squat, in recreational trained men. When the squat was performed after the bench press, the re-warm-up demonstrated a notable increase in propulsive velocity, indicating its positive influence on physical performance outcomes. However, when the bench press followed the squat, the impact of the re-warm-up appeared less pronounced. Considering physiological and psychophysiological parameters, no differences were found between experimental conditions with vs. without re-warm-up. The current results highlight the positive impact of re-warm-up between exercises in mechanical performance, emphasizing the need for personalized approaches to optimize resistance training outcomes.

Study 5. Interindividual Responses to a Resistance Training Re-Warm-Up Strategy

Abstract

This study aimed to i) analyze individual responses in barbell lifting velocity during a resistance training set preceded by a re-warm-up, and ii) compare differences between responders and non-responders in terms of anthropometry, training experience, muscle strength, and acute physiological and psychophysiological changes during training. Twenty-two strength-trained males (22.77 ± 3.29 years; 76.14 ± 12.62 kg; 1.78 ± 0.06 m) were classified as responders or non-responders based on the difference between the fastest mean propulsive velocity (MPV) achieved in the first set following the re-warm-up and the fastest MPV in the first set without the re-warm-up. Participants completed four resistance training sessions, with or without a re-warm-up after the first exercise (bench press or squat). Depending on the condition, they either performed a re-warm-up of 6 repetitions at 40% and 80% of the training load or proceeded directly to the second exercise without re-warming. Responders and non-responders were compared regarding age, body mass, height, body mass index (BMI), training experience, 1RM, relative strength, MPV, heart rate, blood lactate, and rate of perceived exertion. The results showed that 45.5% of participants responded positively to the re-warm-up in the bench press by increasing their MPV, while 68.2% responded positively in the squat. Bench press responders were stronger and slightly taller than non-responders, whereas squat responders had higher body mass, BMI, and 1RM than non-responders. No significant differences were found in age, training experience, or physiological markers across responder groups. Implementing a re-warm-up before the second exercise of the session may be beneficial for increasing barbell lifting velocity, especially for stronger individuals.

Keywords: Re-warm-up, strength training, squat, bench press, movement velocity, physical performance

Introduction

Long breaks or periods of inactivity during competitive events can lead to a decline in subsequent sports performance (Kapnia et al., 2023; Mohr et al., 2004; Zois et al., 2013). Studies have shown that prolonged inactivity after warm-up or during halftime can lead to reduced muscle strength and athletic performance, negatively impacting vertical jump and sprint times (González Fernández et al., 2023; Kapnia et al., 2023; Mohr et al., 2004; Zois et al., 2013). To counteract these adverse effects, many coaches and researchers recommend incorporating re-warm-up strategies during these periods of inactivity (Flórez-Gil et al., 2025; González Fernández et al., 2023; Silva et al., 2018). Re-warming up helps athletes restore or maintain the physical performance levels achieved before inactivity (Flórez-Gil et al., 2025; Mohr et al., 2004), and in some cases, can even enhance athletic performance (Silva et al., 2018). Therefore, this strategy should be considered in sports settings to optimize sports performance and minimize athletes' performance losses.

Despite the positive evidence regarding re-warm-up strategies and their impact on athletic performance, research on this topic in resistance training contexts is almost nonexistent. To date, only one known study has investigated the effects of resistance training re-warm-up before resistance exercises, such as the squat and bench press, on mechanical, physiological, and psychophysiological performance in strength-trained young adults (Neves et al., 2025). The results showed that mechanical squat performance, specifically the barbell lifting velocity, improved significantly after the re-warm-up compared to the condition without the re-warm-up. However, for the bench press, re-warming up did not produce greater benefits in mechanical performance compared to the condition without re-warming up. This first study on the effect of resistance training re-warm-up on strength performance suggests that the benefits of re-warm-up are specific to the exercised muscle group, with improvements more pronounced in the lower limbs.

A complementary analysis that has been considered to deepen knowledge about the effect of resistance exercises on subsequent physical performance is the identification of responders and non-responders. On this topic, most studies have found a high degree of variability in how individuals respond to previous physical conditioning activities (Koźlenia & Domaradzki, 2024; Krzysztofik et al., 2023; Pisz et al., 2023; Poulos et al., 2018; Sañudo et al., 2020; Seitz & Haff, 2016). In a meta-analysis conducted almost 10 years ago, the authors found that individuals with higher strength levels exhibited better performance in athletic activities (e.g., jumps and sprints) after physical conditioning activities involving single sets and high relative loads (≥ 80% of one-repetition maximum [1RM]) (Seitz & Haff, 2016). From then on, several studies have corroborated this evidence, demonstrating that athletes who usually achieve the best athletic performance levels after conditioning activities with high relative loads tend to have higher strength levels (Koźlenia & Domaradzki, 2024; Poulos et al., 2018; Sañudo et al., 2020). Additionally, factors such as training experience, body mass, height, and body mass index (BMI) can also significantly influence how individuals respond to an athletic activity (e.g., jumping or sprinting) when preceded by conditioning activities (Koźlenia & Domaradzki, 2024). However, to date, no study has analyzed interindividual responses to re-warm-up strategies during resistance training, specifically how they affect barbell lifting velocity. This analysis is crucial for understanding how factors such as the type of resistance exercise, strength level, training experience, and anthropometrics influence individual responses during the execution of training sets preceded by a re-warm-up.

Therefore, given the points raised above, this study aimed to analyze individual responses to a resistance training re-warm-up strategy, specifically focusing on its impact on barbell lifting velocity in the subsequent training set among strength-trained males. Additionally, we aimed to compare responders and non-responders in terms of anthropometry, training experience, muscle strength, and acute physiological and psychophysiological changes during training. We hypothesized that some individuals would respond to the re-warm-up by increasing their lifting velocity in the first training set, while others would not. Furthermore, we hypothesized that there would be differences between responders and non-responders, particularly in terms of muscle strength, with stronger athletes presenting a higher level of responsiveness to the re-warm-up strategies.

Methods

Study Design

In this crossover design, we conducted a secondary analysis of the results published by Neves et al. (2025) to examine the interindividual responses to re-warm-up strategies, specifically in terms of barbell lifting velocity performance in the first training set. The study design and experimental procedures are detailed in Neves et al. (2025). Briefly, the study spanned three weeks, consisting of two sessions per week: familiarization, progressive load tests to determine the 1RM load, and experimental conditions with and without re-warm-up. Participants underwent four resistance training sessions, with or without a re-warm-up after the first resistance exercise, in a randomized order. Conditions included: i) Warm-Up + Squat + Bench Press; ii) Warm-Up + Squat + Re-Warm-Up + Bench Press; iii) Warm-Up + Bench Press + Squat; iv) Warm-Up + Bench Press + Re-Warm-Up + Squat. Participants performed three sets of six repetitions at 80% 1RM in the squat and bench press. Immediately after the second exercise, heart rate, blood lactate, and rate of perceived exertion (RPE) were measured. In this study, we analyzed heart rate, blood lactate, and RPE post-conditions, as well as the fastest mean propulsive velocity (MPV) reached in the first training set of the second exercise performed in the session.

Participants

Twenty-two strength-trained males (age: 22.77 ± 3.29 years; body mass: 76.14 ± 12.62 kg; height: 1.78 ± 0.06 m) participated in this study. Participants had resistance training experience in the squat and bench press of 44.18 ± 18.66 months (ranging from 24 to 96 months), with a 1RM bench press load of 78.45 ± 11.59 kg (bench press relative strength: 1.05 ± 0.20) and a 1RM squat load of 96.00 ± 23.06 kg (squat relative strength: 1.27 ± 0.27). Every participant stated that they had no prior illnesses, injuries, or physical issues that could affect their performance during resistance training sessions. All participants were verbally informed about the study procedures and signed an informed consent that detailed all procedures. This study adhered to the principles outlined in the Declaration of Helsinki and was approved by the Ethics Committee of the University of Beira Interior (approval number: CE-UBI-Pj-2021-018:ID720; approval date: June 2021).

Measurements of Movement Velocity, Heart Rate, Blood Lactate, and Rating of Perceived Exertion

First, participants performed progressive loading bench press and squat tests, following strict technique and safety measures described elsewhere (Sánchez-Medina et al., 2017; Sánchez-Medina & González-Badillo, 2011). They lay on a bench or stood upright, descending the barbell with controlled velocity, then ascending with the maximum intended concentric velocity. Initial loads were 17 kg or 20 kg, increasing by 10 kg until reaching 85% 1RM, as determined from MPV data (0.40 m·s-1 for the bench press and 0.60 m·s-1 for the squat). 1RM bench press and squat loads were estimated using validated regression equations (González-Badillo & Sánchez-Medina, 2010; Sánchez-Medina et al., 2017). Rest periods ranged from 3 to 5 minutes in duration. Researchers monitored exercise technique to ensure proper form and maximal effort. Regarding physiological parameters, heart rate was monitored using a Polar watch (Polar Vantage NV, Kempele, Finland), and blood lactate concentration was measured with a portable device (Lactate Pro 2 LT-1730, Arkray Inc., Tokyo, Japan). After cleaning the site with 70% alcohol, a disposable lancet punctured the fingertip. The first blood drop was discarded, and a small sample was collected for analysis. Finally, RPE values were recorded using a 15-point scale (Borg scale 6-20) (Borg, 1982).

Experimental Conditions

In each experimental condition, participants performed a general warm-up of 10 minutes of treadmill running, starting at 50-55% of heart rate reserve and increasing to 70% in the last 2 minutes. Participants then completed a specific warm-up consisting of two sets of six repetitions at 40% (32% 1RM) and 80% (64% 1RM) of the training load in the squat or bench press (Neves et al., 2025). After a 3-minute rest, participants performed three sets of six repetitions at 80% 1RM in the squat or bench press, with 3-minute rests between sets. Depending on the condition, participants either performed a re-warm-up equal to the specific warm-up or proceeded directly to the second exercise without re-warm-up. All concentric repetitions were performed with the maximal intended concentric velocity, and the eccentric phase was controlled (~3 seconds). The first researcher, along with two strength coaches, each on either side of the barbell, supervised sessions to ensure proper technique and effort. A linear velocity transducer (T-Force Dynamic Measurement System, Ergotech, Murcia, Spain) connected to the barbell of a Multipower (Multipower Fitness Line, Perola, Murcia, Spain) collected the MPV of all repetitions during sessions.

Statistical Analysis

All statistical analyses were conducted using SPSS (version 27.0, IBM Corp., Armonk, NY, USA). The normality of the data was assessed using the Shapiro-Wilk test, and the homogeneity was evaluated with Levene's test. Data are presented as mean ± standard deviation. Responsiveness to the re-warm-up was calculated as the difference between the fastest MPV in the first set following the re-warm-up and the fastest MPV in the first set without it. Responders were identified as those with a positive difference (MPV difference > 0.00 $m \cdot s^{-1}$), and non-responders as those with a zero or negative difference (≤ 0.00 $m \cdot s^{-1}$). An Independent Samples T-Test was used to compare responders and non-responders in age, body mass, height, BMI, training experience, 1RM, relative strength, MPV, heart rate, blood lactate, and RPE. These comparisons were conducted for re-warm-up effects in the bench press and squat conditions. The significance level was set at $p < 0.05$. Effect sizes were calculated using Hedge's g, interpreted as trivial (g: 0.00–0.19), small (g: 0.20–0.59), moderate (g: 0.60–1.19), large (g: 1.20–1.99), very large (g: 2.00–3.99), and extremely large (g > 4.00) (Hopkins et al., 2009).

Results

Interindividual Responses to Re-Warm-Up Conditions

Figure 1 indicates that 10 out of 22 participants (45.5%) responded positively to the re-warm-up condition in the bench press.

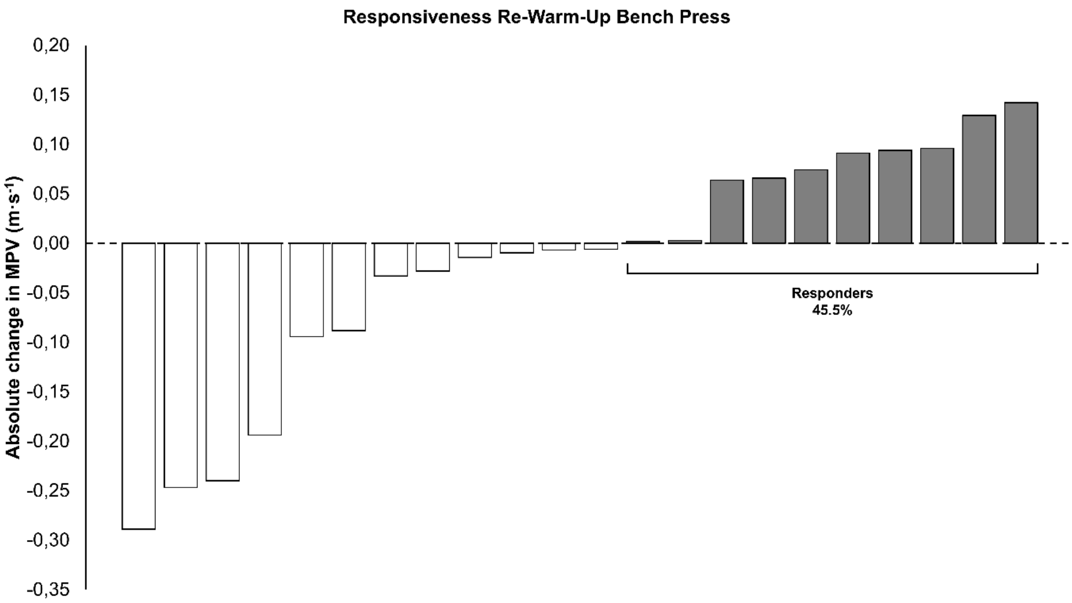

Figure 1. Interindividual responses in terms of mean propulsive velocity (MPV) to the re-warm-up in the bench press. Responsiveness was calculated as the difference between the fastest MPV in the first set following the re-warm-up and the fastest MPV in the first set without it.

Figure 2 indicates that 15 out of 22 participants (68.2%) responded positively to the re-warm-up condition in the squat.

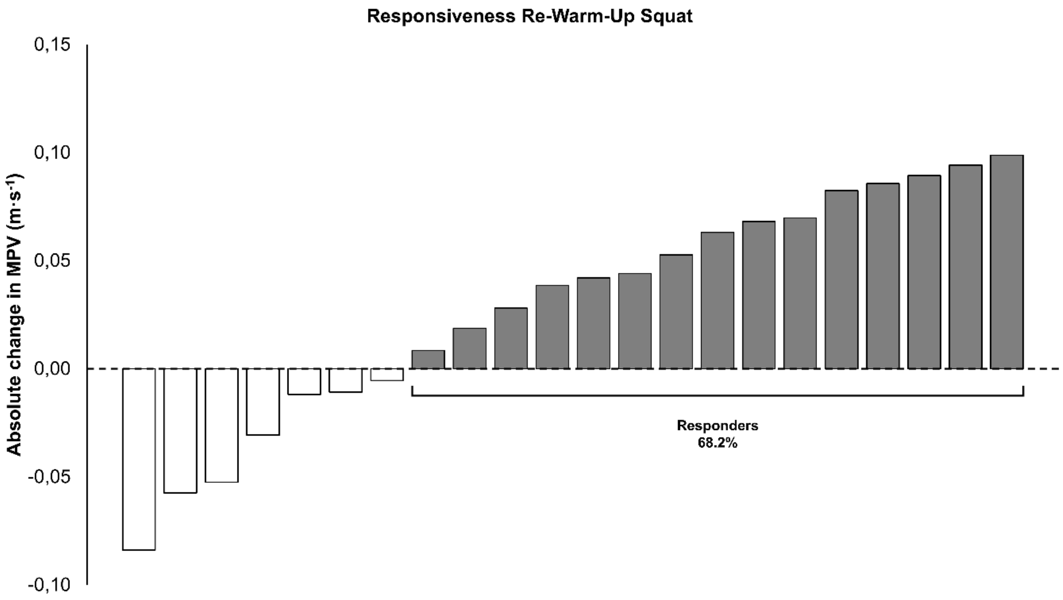

Figure 2. Interindividual responses in terms of mean propulsive velocity (MPV) to the re-warm-up in the squat. Responsiveness was calculated as the difference between the fastest MPV in the first set following the re-warm-up and the fastest MPV in the first set without it.

Differences between responders and non-responders

Table 1 shows significant differences of large magnitude in the absolute differences of the fastest MPV in the bench press between responders and non-responders. Responders present a significantly faster MPV in the first set after the re-warm-up condition compared to the no re-warm-up condition. Regarding heart rate, blood lactate, and RPE, there were trivial to small non-significant differences between groups. There were significant differences of moderate magnitude in 1RM bench press between responders and non-responders (average difference of 10.17 kg, favoring the responders). Although not significant, there was a moderate difference in height between responders and non-responders (average difference of 0.04 m, favoring the responders). There were trivial to small non-significant differences between the two groups for age, body mass, BMI, training experience, and bench press relative strength.

Table 1. Comparison between responders and non-responders to re-warm-up and no-re-warm-up conditions in the bench press.

	Responders (n = 10)	**Non-Responders (n = 12)**	***p*-value**	**ES (interpretation)**
Age (y)	21.90 ± 1.79	23.50 ± 4.10	0.241	0.471 (small)
Body mass (kg)	78.30 ± 12.36	74.33 ± 13.09	0.476	0.299 (small)
Height (m)	1.80 ± 0.06	1.76 ± 0.04	0.063	0.811 (moderate)
BMI (kg/m^2)	24.01 ± 3.15	23.97 ± 3.94	0.973	0.014 (trivial)
Training experience (mo.)	43.20 ± 18.07	45.00 ± 19.90	0.828	0.091 (trivial)
1RM bench press (kg)	84.00 ± 12.92	73.83 ± 8.29	**0.049***	0.920 (moderate)
Relative strength (kg/kg)	1.08 ± 0.15	1.03 ± 0.23	0.489	0.290 (small)
Absolute differences (RWUP – No RWUP)				
MPV ($m{\cdot}s^{-1}$)	0.08 ± 0.05 *	-0.08 ± 0.10	**< 0.001****	1.857 (large)
HR (bpm)	-8.10 ± 19.48	-5.08 ± 12.95	0.669	0.179 (trivial)
LAC (mmol/L)	-1.52 ± 3.20	-0.46 ± 2.25	0.373	0.375 (small)
RPE	-1.10 ± 3.00	0.33 ± 2.31	0.220	0.522 (small)

Data are presented as mean ± standard deviation, unless otherwise stated. *$p< 0.05$; ** $p<0.001$, significant differences between re-warm-up and no re-warm-up conditions. BMI: body mass index; ES: Hedge's g effect size; HR: heart rate; LAC: blood lactate; MPV: mean propulsive velocity; RM: repetition maximum; RPE: rate of perceived exertion; RWUP: re-warm-up.

Table 2 shows significant differences of very large magnitude in the absolute differences of the fastest MPV in the squat between responders and non-responders. Responders present a significantly faster MPV in the first set after the re-warm-up condition compared to the no re-warm-up condition. Regarding blood lactate, heart rate, and RPE, there were small and non-significant differences between groups, with the responders showing a lower RPE following the re-warm-up condition. There were significant differences of moderate magnitude in body mass and BMI between responders and non-responders (average difference of 11.93 kg and 3.27 kg/m2, respectively, favoring the responders). Although not significant, there was a moderate difference in 1RM squat between responders and non-responders (average difference of 19.70 kg, favoring the responders). There were trivial to small non-significant differences between the two groups for age, height, training experience, and squat relative strength.

Table 2. Comparison between responders and non-responders to re-warm-up and no-re-warm-up conditions in the squat.

	Responders (n = 15)	**Non-Responders (n = 7)**	***p*-value**	**ES (interpretation)**
Age (y)	23.20 ± 3.71	21.86 ± 2.12	0.386	0.390 (small)
Body mass (kg)	79.93 ± 11.80	68.00 ± 10.91	**0.035***	0.994 (moderate)
Height (m)	1.79 ± 0.05	1.76 ± 0.06	0.361	0.412 (small)
BMI (kg/m²)	25.03 ± 3.56	21.76 ± 2.31	**0.039***	0.975 (moderate)
Training experience (mo.)	46.40 ± 19.70	39.43 ± 16.56	0.428	0.356 (small)
1RM squat (kg)	102.27 ± 22.85	82.57 ± 18.29	0.060	0.878 (moderate)
Relative strength (kg/kg)	1.29 ± 0.25	1.24 ± 0.33	0.714	0.164 (trivial)
Absolute differences (RWUP – No RWUP)				
MPV ($m \cdot s^{-1}$)	0.06 ± 0.03 *	-0.04 ± 0.03	**< 0.001****	3.215 (very large)
HR (bpm)	-5.00 ± 14.85	4.57 ± 16.28	0.187	0.602 (moderate)
LAC (mmol/L)	-0.77 ± 2.38	0.04 ± 4.85	0.685	0.237 (small)
RPE	-0.80 ± 1.37 *	0.57 ± 2.07	0.078	0.817 (moderate)

Data are presented as mean ± standard deviation, unless otherwise stated. *p< 0.05; ** p<0.001 , significant differences between re-warm-up and no re-warm-up conditions. BMI: body mass index; ES: Hedge's g effect size; HR: heart rate; LAC: blood lactate; MPV: mean propulsive velocity; RM: repetition maximum; RPE: rate of perceived exertion; RWUP: re-warm-up.

Discussion

The aims of the current study were i) to analyze the interindividual responses to re-warm-up in the following training set, focusing on the barbell lifting velocity in the bench press and squat, and ii) to compare the differences between responders and non-responders in terms of anthropometry, training experience, muscle strength, and acute physiological and psychophysiological changes during training. The main findings showed that: i) re-warm-up improved subsequent barbell lifting velocity performance in 45.5% of participants for the bench press and 68.2% for the squat, ii) bench press responders had higher 1RM and were slightly taller than non-responders, while squat responders had significantly higher body mass, BMI, and moderately higher 1RM than non-responders, iii) no differences in age, training experience, and relative strength were reported between responders and non-responders, and iv) heart rate, blood lactate, and RPE differences were small and non-significant, though squat responders reported slightly lower RPE following the re-warm-up condition. Overall, these results suggest that individual responsiveness to re-warm-up, as reflected in barbell lifting velocity of the subsequent exercise, varied according to resistance exercise and individual characteristics, favoring stronger and heavier strength-trained males.

The results of the present study revealed that 45.5% (10/22) of participants responded positively with increased MPV during the first training set after the bench press re-warm-up condition, while 68.2% (15/22) responded positively after the squat re-warm-up condition. These findings therefore suggest a difference in responders to the re-warm-up depending on the type of resistance exercise, with greater positive responses observed during the squat compared to the bench press. One possible reason for these differences may be the greater muscle volume engaged during the squat compared to the bench press, which enables handling higher training volumes and workloads before reaching muscular fatigue (Mangine et al., 2015; Romagnoli & Piacentini, 2022; Shimano et al., 2006). Since the optimal rest period for enhancing athletic performance in a specific exercise preceded by a conditioning activity varies among athletes (Gołaś et al., 2016; Krzysztofik et al., 2021, 2023), further research is needed to determine if those who respond positively to the re-warm-up require different transition periods based on the exercise type. Such analyses could help optimize strength performance, particularly in terms of barbell lifting velocity during resistance training, and eventually benefit competition-specific performance.

The comparative analysis between responders and non-responders to re-warm-up showed that responders had higher 1RM load values in the bench press (~10 kg; $p < 0.05$) and squat (~20 kg; $p > 0.05$) than non-responders. Although there are no previous studies on individual responses in barbell lifting velocity after resistance training re-warm-up strategies, these results align with previous evidence suggesting that baseline strength level is a key performance indicator differentiating responders from non-responders (Chiu et al., 2003; Koźlenia & Domaradzki, 2024; Poulos et al., 2018; Sañudo et al., 2020). For instance, Chiu et al. (2003), when comparing athletes from various sports modalities with recreationally trained individuals, found that athletes performed better in vertical jumps when this task was preceded by a conditioning activity of 5 sets of one repetition at 90% 1RM in the squat. Similarly, Poulos et al. (2018) observed that individuals with higher strength levels demonstrated better vertical jump performance after completing a conditioning activity consisting of 10 sets of 3 repetitions at 67% and 87% 1RM in the squat. Sañudo et al. (2020) compared stronger and weaker individuals and found that athletes with greater strength levels had faster times in the 10 m sprint when this task was preceded by 3 repetitions at 90% 1RM in the squat. Lastly, Koźlenia & Domaradzki (2024) found that individuals with higher strength levels tended to perform better in the vertical jump after completing 3 sets of 5 repetitions of band-assisted jumps. Possible reasons for these differences are that stronger individuals often exhibit increased phosphorylation levels of the myosin regulatory light chain, a higher proportion of type II muscle fibers, and greater neuromuscular excitation than weaker individuals (Chiu et al., 2003; Poulos et al., 2018; Seitz & Haff, 2016). Together, these factors may contribute to a stronger athletic response after the conditioning activity (e.g., warm-up or re-warm-up strategies).

Previous evidence suggests that anthropometric factors, such as body mass and BMI, may also play a distinguishing role in how individuals respond to athletic activities when preceded by a conditioning activity (Koźlenia & Domaradzki, 2024). In this study, we observed a significant influence of anthropometric variables on the response to re-warm-up, depending on the type of resistance exercise. For the bench press, although no significant differences were found between responders and non-responders for any anthropometric variable, responders were taller (~4 cm; moderate effect size) than non-responders. These results suggest a positive association between body height and mechanical performance during the bench press; however, their isolated analysis cannot provide definitive conclusions. A supplementary analysis that includes measurements of body segment lengths, such as legs, thighs, arms, forearms, and trunk, would provide a better understanding of their impact on mechanical performance during the bench press and draw more reliable conclusions about how they differentiate responders from non-responders (Caruso et al., 2012; Ferland et al., 2020). Regarding the squat performance, it was found that body mass and BMI were the two variables that distinguished responders from non-responders. Specifically, responders were heavier and had a higher BMI than non-responders, supporting previous findings that heavier athletes tend to be stronger (Falch et al., 2023; Vidal Pérez et al., 2021; Winwood et al., 2012). Overall, these results suggest that responders are generally stronger, taller, and heavier than non-responders. However, further research is needed to determine the role of body segment lengths and other body composition variables (e.g., fat-free mass, body fat, and bone mass) on mechanical performance and how they can discriminate between responders and non-responders to re-warm-up strategies.

Apart from differences in MPV during bench press and squat between responders and non-responders, further comparisons of subjective and physiological measures did not show significant differences between the two groups. Small to trivial differences were observed between responders and non-responders in the absolute changes of heart rate, blood lactate, and RPE during the bench press conditions (with versus without re-warm-up). In the squat, no significant differences emerged between responders and non-responders, although a moderate effect size was noted for the differences in heart rate and RPE, with lower heart rate and RPE values in the responder group. These findings suggest that responders experienced less physiological and psychophysiological strain during the training set following the re-warm-up compared to non-responders. Therefore, it is likely that stronger, taller, and heavier athletes could benefit from a re-warm-up strategy to improve their subsequent barbell lifting velocity in the squat. However, further research is needed to examine the impact of various re-warm-up strategies involving different volumes, relative loads, and resting time configurations (transition between re-warm-up and main activity) on subsequent strength performance, as well as on physiological measures (heart rate and blood lactate) and psychophysiological measures (RPE).

This study has some limitations that need to be addressed. First, the criterion used to classify participants as responders and non-responders was based on the differences observed between the re-warm-up and no re-warm-up conditions. Typically, a cut-off value is defined based on the typical measurement error, which requires measuring the dependent variable at baseline and after the conditioning activity. Since MPV was only measured after re-warm-up in this study, future research should include baseline measurements to provide a more standardized classification of responders and non-responders, considering the typical measurement error. A second limitation concerns the sample size and its diversity. Including a larger sample that also features female participants would enhance statistical power and allow for more precise determination of differences between responders and non-responders in both sexes and across various variables. Third, the inclusion of variables, such as body segment lengths, bioimpedance analysis, and physiological markers related to muscle damage (e.g., creatine kinase, testosterone, and cortisol), would help clarify their roles in characterizing effort induced by interventions and distinguishing responders from non-responders. Finally, using only two resistance exercises, one re-warm-up protocol, and two resistance training protocols limits the generalizability of the findings. As a result, further research is needed to investigate the impact of different volumes, relative loads, and exercise configurations during re-warm-up and resistance training, in order to gain a better understanding of how individuals respond to these training stimuli.

Conclusion

The results of this study showed that a resistance training re-warm-up improved barbell lifting velocity in 45.5% of participants during the bench press and 68.2% during the squat. Responders were generally stronger, taller, and also heavier (with higher body mass and BMI) than non-responders. No significant differences were found in age, training experience, or physiological markers, suggesting that individual responsiveness to the re-warm-up on subsequent barbell lifting velocity depends more on strength level and anthropometric profile than on other factors. Therefore, for stronger individuals, strength and conditioning coaches and researchers should consider implementing a re-warm-up before the second exercise of the session, involving 6 repetitions at 40% of the training load, followed by 6 repetitions at 80% of the training load, for the bench press and squat exercises to enhance subsequent barbell lifting velocity in the resistance training set.

Chapter 4. General Discussion

The general aim of this doctoral thesis was to investigate the impact of different warm-up and re-warm-up strategies on mechanical performance during resistance training in young adults with prior training experience. To achieve this general aim, we defined a sequence of studies with the following specific aims:

1. To analyze, through a scoping review, the effects of different warm-up and/or re-warm-up strategies during resistance training on mechanical performance.
2. To characterize, through an online questionnaire directed to Portuguese practitioners and strength coaches, the warm-up and re-warm-up routines during resistance training.
3. To examine, through a crossover study, the acute effects of two warm-up strategies on mechanical, physiological, and psychophysiological performance during resistance training in the bench press and squat exercises.
4. To compare, through a crossover study, the acute effects of re-warm-up and no re-warm-up on mechanical, physiological, and psychophysiological performance during resistance training in the bench press and squat exercises.
5. To analyze the interindividual responses on barbell lifting velocity during the first resistance training set in the bench press and squat, preceded by the re-warm-up, as well as to compare the differences between responders and non-responders in terms of anthropometry, training experience, muscle strength, and physiological and psychophysiological acute changes during resistance training.

The first study of the thesis was a scoping review that focused on the analysis of the impact of different warm-up and/or re-warm-up strategies in outcome measures such as the maximum weight lifted during one-repetition maximum (1RM) test, the barbell lifting velocity or power, and the number of maximum repetitions performed against a determined relative load (% 1RM). Regarding performance in the 1RM test, it was observed that the general warm-up, followed by the specific warm-up, favored an increase in 1RM weight in the leg press (Abad et al., 2011; Barroso et al., 2013) and squat (Mina et al., 2014, 2016). For the leg press, it was found that a general warm-up with moderate intensities (i.e., between 55% and 70% of maximum heart rate [HR_{max}]), followed by a specific warm-up with progressive intensity (50-70% 1RM) produced greater increases in 1RM weight than high intensities (>70% HR_{max}) maintained during the general warm-up (Abad et al., 2011; Barroso et al., 2013). These results suggest that high intensities during a 15-20 minute cardiorespiratory activity do not yield better 1RM results than lower intensities. The greater predominance of the anaerobic system during high-intensity activities and the consequent use of bioenergetic substrates, such as creatine phosphate and glycogen, may affect anaerobic performance in subsequent strength activities (Sahlin, 2014). Therefore, if the aim is to increase the maximum weight lifted in the 1RM leg press test, coaches should consider performing warm-up with moderate intensities or increasing rest time after high-intensity activities on the bicycle to restore creatine phosphate and glycogen stores (Murray & Rosenbloom, 2018). In the squat, it was found that using elastic bands or chains on the barbell during the warm-up allowed for greater increases in the maximum weight lifted in the 1RM test compared to the same warm-up protocol without elastic bands or chains (Mina et al., 2014, 2016). The use of this material appears to decrease the magnitude of the load in the initial phase of the concentric phase ("sticking point region") and gradually increase it throughout the concentric phase, thus allowing more weight to be moved (Mina et al., 2014, 2016).

In this review, it was also possible to understand that the available evidence on the effects of different warm-up strategies on mechanical performance during resistance training is limited. Only seven studies were identified, with analyses focusing on the bench press (El Hage et al., 2012; Krzysztofik et al., 2020; Neves et al., 2024; Ribeiro et al., 2020, 2021; Ushirooka et al., 2023), squat (Neves et al., 2024; Ribeiro et al., 2020, 2021), and deadlift (Cochrane et al., 2015). Of these studies, only three reported significant differences between warm-up strategies in improving mechanical performance during resistance training (El Hage et al., 2012; Ribeiro et al., 2020, 2021). El Hage et al. (2012) observed that a general warm-up of 5 minutes of running, followed by a specific warm-up at 20% 1RM, was more effective in optimizing peak power at 40% 1RM in the bench press than the same general warm-up, but followed by a specific warm-up at 80% 1RM. It is important to highlight that the differences were significant at minutes 2 and 4 after the warm-up, but not at minutes 0 and 8 after the warm-up, indicating that the responses to different warm-up protocols in subsequent strength exercises vary over time. Ribeiro et al. (2020) found that a warm-up protocol of 6 repetitions at 80% of the training load (64% 1RM) was more effective than 6 repetitions at 40% of the training load (32% 1RM) in increasing barbell lifting velocity during squat training at 80% 1RM. Conversely, the authors found that a progressive intensity warm-up (6 repetitions at 40% of the training load [32% 1RM] followed by 6 repetitions at 80% of the training load [64% 1RM]) was more effective in improving subsequent mechanical performance in bench press training at 80% 1RM than a warm-up of 6 repetitions at 40% of the training load. The same authors also found, in a later study, that the progressive intensity warm-up (i.e., 2 sets of 6 repetitions at 40% and 80% of the training load) increased barbell lifting velocity during resistance training at 80% 1RM in the squat and bench press (Ribeiro et al., 2021). Although the results of these studies indicate the effectiveness of a warm-up strategy with progressive intensity in improving mechanical performance during resistance training, it became clear that new studies were needed to compare the impact of warm-up strategies with progressive intensities that integrate general warm-up followed by specific warm-up and only specific warm-up (problematic inherent to Study 3 of the doctoral thesis).

Regarding the number of maximum repetitions performed with a given relative load (which was between 70-75% 1RM), it was found that most studies included in this review analyzed warm-ups with relative loads ranging from 45% to 90% 1RM in exercises such as bench press (Alves et al., 2021; Krzysztofik et al., 2020; Junior et al., 2014; Ribeiro et al., 2014; Ushirooka et al., 2023; Viveiros et al., 2024), squat (Ribeiro et al., 2014; Souza et al., 2024), leg press (Junior et al., 2014; Viveiros et al., 2024), lat pull-down (Viveiros et al., 2024), and biceps curl (Ribeiro et al., 2014). For the bench press exercise, it was found that 2 sets of 2 repetitions at 90% 1RM or 1 set of 5-8 repetitions at 50-60% 1RM were effective in increasing the number of total repetitions compared to 70-75% 1RM (Alves et al., 2021; Junior et al., 2014; Viveiros et al., 2024). In the leg press, it was found that 2 sets of 2 repetitions at 90% 1RM or 1 set of 5 repetitions at 60% 1RM were effective in increasing the number of maximum repetitions (Junior et al., 2014; Viveiros et al., 2024). In the squat, it was observed that a general warm-up of 8 repetitions at 45% 1RM followed by a specific warm-up of 3 repetitions at 90% 1RM was more effective in increasing the number of total repetitions with a relative load of 75% 1RM than no specific warm-up (Souza et al., 2024). These results, which reinforce the positive impact of warm-up strategies with a progressive increase in relative intensity on mechanical performance, guided the prescription of the warm-ups and/or re-warm-ups in Studies 3 and 4 of this doctoral thesis.

Contrary to our initial expectation, the scoping review found no studies analyzing the impact of re-warm-up strategies during resistance training on subsequent mechanical performance. Therefore, the need for further studies on this topic became clear in order to understand its relevance in resistance training (Study 4). Furthermore, it has also become important to understand whether strength coaches and practitioners adopt warm-up and re-warm-up strategies during training sessions, especially in settings such as gyms and fitness centers, given the limited number of studies demonstrating their impact on resistance training performance (Washif et al., 2025). As such, a questionnaire was developed to address this topic and understand how and whether warm-up and re-warm-up strategies are applied in a practical context (Study 2).

Therefore, Study 2 of this doctoral thesis aimed to characterize the warm-up and re-warm-up routines among Portuguese practitioners and coaches involved in resistance training. Several strength trainees and coaches responded to an online questionnaire designed to describe their current warm-up and re-warm-up practices in the context of resistance training and explore their perceptions of the importance, practical application, and perceived effects of these practices. In general, most participants, regardless of sex, reported performing a warm-up before the resistance training sets, demonstrating an adequate understanding of the warm-up practices. In contrast, the re-warm-up practices were reported much less frequently in both men and women. These results were in agreement with the first study of the thesis, suggesting that re-warm-up strategies are little explored in a practical context. The results of Study 2 also indicated that the dual-task role (practitioner and coach) impacted the adherence to re-warm-up. In this case, individuals performing the dual role were more likely to adopt re-warm-up strategies, therefore demonstrating a broader understanding of resistance training methodologies. In addition to these results, an inverse relationship was also observed between age and the use of re-warm-up strategies, with older participants being less likely to employ them. Therefore, based on the observed data, there is a clear need to disseminate more information about the benefits of re-warm-up and to update coaches and practitioners on the latest evidence regarding the impact of re-warm-up practices on subsequent mechanical performance during resistance training.

At this point in the doctoral thesis, it became evident that there was a need to further analyze the impact of different warm-up strategies with progressive intensity, including general and specific components, on subsequent mechanical performance, as well as the effect of different re-warm-up strategies during resistance training. Although the existing literature highlights the use of specific warm-up strategies with progressive intensity and the various benefits arising from their application in resistance training (Ribeiro et al., 2020, 2021), a significant gap was found in the comparison between general and specific warm-up protocols in this context. This research gap reinforced the need for studies comparing these strategies to provide a more comprehensive understanding of how to effectively warm up and/or re-warm up during resistance training sessions. Based on these research needs, Studies 3 and 4 were conducted.

Study 3 aimed to compare the effects of two different warm-up strategies on mechanical, physiological, and psychophysiological performance during a resistance training session of 3 sets of 8 repetitions at 80% 1RM in the bench press or squat (Neves et al., 2024). Specifically, it was compared the effects of a specific warm-up with progressive intensity (i.e., 6 repetitions at 40% of the training load followed by 6 repetitions at 80% the of the training load) and a general warm-up (8 minutes of treadmill running at 50-55% of heart rate reserve [HR_{res}] followed by 2 minutes at 70% HR_{res}) followed by the specific warm-up described previously on variables such as barbell lifting velocity and power, heart rate, blood lactate, and perceived exertion. The squat and bench press were chosen because they are widely used by practitioners worldwide and are the most common exercises in resistance training research (Kompf & Arandjelović, 2017; Pereira et al., 2024; Ribeiro et al., 2020; Trybulski et al., 2022). Overall, the results of Study 3 revealed no significant differences between the two warm-up strategies in terms of barbell lifting velocity and power, blood lactate, and perceived exertion in either the bench press or squat exercises. The only difference observed was a greater increase in heart rate after the specific warm-up, preceded by the general warm-up, in bench press training, therefore suggesting greater cardiovascular activation without a direct impact on mechanical performance. Therefore, these results revealed that both warm-up strategies with progressive intensities can be used in resistance training contexts without compromising subsequent mechanical performance. In the same line, Ribeiro et al. (2020) also found no differences in mechanical performance between a specific warm-up strategy involving 6 repetitions at 80% of the training load and another strategy involving 6 repetitions at 40% of the training load followed by 6 repetitions at 80% of the training load during squat and bench press training. Therefore, taken together, these results suggest that including a general cardiovascular warm-up before a specific warm-up of progressive intensity does not negatively impact subsequent strength performance, whether in the bench press or squat. The choice of one of the warm-up strategies should be made based on individual needs, available training time, and personal preferences of each athlete (Afonso et al., 2024; Sople & Wilcox, 2025).

In Study 4, we aimed to compare the effects of re-warm-up and no re-warm-up on mechanical, physiological, and psychophysiological performance during resistance training (3 sets of 8 repetitions at 80% 1RM) with the squat and bench press exercises performed in the same session (Neves et al., 2025). The mechanical responses to re-warm-up observed during resistance training varied according to the exercise sequence. On the one hand, it was found that re-warming up after the bench press (6 repetitions at 40% of the training load followed by 6 repetitions at 80% of the training load) produced greater increases in barbell lifting velocity in the squat compared with the training sequence without re-warming up between the two exercises. On the other hand, performing a re-warm-up after the squat did not improve mechanical performance in the bench press compared to the sequence without the re-warm-up. However, it is important to note that the velocity loss and effort index were greater in the third training set of the bench press in the condition without the re-warm-up, thus reflecting a higher mechanical effort. This initial evidence in the literature suggests that re-warm-up before the squat enhances subsequent mechanical performance in the lower limbs, while the benefits of re-warm-up appear to be less evident in the bench press. This result may be due to the recruitment of larger muscle groups during the squat (Contreras et al., 2016), which may benefit from pre-activation to maximize their mechanical performance. Unlike the squat, the bench press involves smaller muscle groups (Rodríguez-Rosell et al., 2018; Sanchis-Moysi et al., 2010), which may benefit from muscle activation performed in previous exercises such as the squat. Finally, it is also noteworthy that no significant differences in physiological and psychophysiological responses were observed between the strategies with and without re-warm-up, either in the bench press-squat sequence or in the squat-bench press sequence. Therefore, in summary, these results indicate that the effects of re-warm-up are primarily reflected in mechanical performance parameters, such as barbell lifting velocity, with more pronounced improvements for the lower limbs.

Considering that responses to conditioning activities (e.g., warm-ups) on subsequent physical performance vary substantially among athletes (Koźlenia & Domaradzki, 2024; Poulos et al., 2018; Sañudo et al., 2020), Study 5 aimed to i) analyze the interindividual responses in barbell lifting velocity during the first resistance training set preceded by a re-warm-up, and ii) compare the differences between responders and non-responders in terms of anthropometry, training experience, muscle strength, and acute physiological and psychophysiological changes during training. This study consisted of a secondary analysis of the data obtained in Study 4 (Neves et al., 2025), where participants were classified as responders or non-responders based on the improvements observed in mean propulsive velocity in the first training set after the re-warm-up. Overall, the results indicated that 45.5% of participants responded positively to the bench press re-warm-up, increasing the barbell lifting velocity in the first training set, while 68.2% responded positively to the squat re-warm-up. These results may be attributed to the greater muscle volume recruited during the squat compared to the bench press, which enables higher training volumes and workloads to be handled before reaching muscular fatigue (Mangine et al., 2015; Romagnoli & Piacentini, 2022; Shimano et al., 2006). Therefore, consistent with the results observed in Study 4, re-warming up appears to have a greater impact on mechanical performance during the squat than the bench press. Regarding the differences between responders and non-responders, the results found in Study 4 aligned with the literature on the impact of prior conditioning activities on subsequent physical performance (Chiu et al., 2003; Koźlenia & Domaradzki, 2024; Poulos et al., 2018; Sañudo et al., 2020), demonstrating that responders presented higher 1RM values and superior anthropometric characteristics (e.g., taller and heavier) than non-responders. Taken together, these results suggest that taller, heavier athletes with higher 1RM values are more likely to benefit from re-warm-up strategies on subsequent mechanical performance.

By identifying the physical profiles of those who were most likely to benefit from re-warm-up in subsequent strength performance, Study 5 provided important suggestions for individualizing re-warm-up routines during resistance training. In practical terms, taller, heavier athletes with higher 1RM values appear to be more prepared for the neuromuscular recruitment induced by re-warm-up sets with low to moderate relative loads (i.e., 6 repetitions at 40% of the training load followed by 6 repetitions at 80% of the training load) in subsequent strength exercises. However, it is important to note that the intervention was limited to two strength exercises and a single re-warm-up strategy. Therefore, it will be important to expand the diversity of strength exercises and test different relative loads, volumes, and rest intervals in future research. Improving the methodological approach will enable strength and conditioning coaches to prescribe evidence-based re-warm-up regimens that maximize individual mechanical performance.

This doctoral thesis recognizes several limitations that require attention, among which the following stand out:

i. Recruiting a larger and more heterogeneous sample (e.g., with men and women) would allow for greater generalizability of the results and more robust conclusions on some of the variables analyzed, therefore reducing the risk of biased results.
ii. The nature of the interventions (i.e., crossover design) does not allow inferences about the long-term impact of different warm-up and re-warm-up protocols on mechanical, physiological, and psychophysiological performance.
iii. The prescription of only a specific warm-up and re-warm-up of progressive intensity (2 sets of 6 repetitions at 40% and 80% of the training load) does not

allow us to understand whether other volumes and relative intensities induce different results.

iv. The inclusion of only two strength exercises (bench press and squat) limits the generalizability of the results to other strength exercises, particularly those that exercise the posterior muscles of the body (e.g., back and hamstrings).

v. The analysis of variables related to muscle damage, such as creatine kinase, testosterone, and cortisol, would allow for a more detailed analysis of the physiological impact of different warm-up and re-warm-up strategies and how these influence responses at the group and individual level.

vi. The lack of literature on the effects of different re-warm-up strategies during resistance training on mechanical, physiological, and psychophysiological performance did not allow for corroborating or refuting the evidence observed in this doctoral thesis.

Chapter 5. Overall Conclusions

The studies presented in this thesis provided a comprehensive analysis of the effects of different warm-up and re-warm-up strategies on mechanical variables in resistance training. The five studies contributed to addressing gaps identified in the literature, highlighting both the acute effects of these strategies on physical performance and their practical application by strength and conditioning professionals:

i. Previous studies demonstrated the benefits of specific warm-up routines using progressive intensities in variables such as barbell lifting velocity and power in resistance exercises. However, they also revealed a notable scarcity of studies investigating the effects of re-warm-up within a resistance training session.

ii. Although warm-up is widely recognized and commonly implemented, re-warm-up remains underutilized in professional practice. Factors such as professional role, age and technical knowledge influence the adoption of this strategy, indicating the need for educational initiatives to promote its evidence-based implementation.

iii. While different warm-up strategies (i.e., specific vs. general plus specific) did not lead to significant changes in mechanical and psychophysiological variables, applying a re-warm-up between exercises resulted in acute performance improvements, especially in the back squat. These effects could be justified by the maintenance of neuromuscular activation and the mitigation of fatigue induced by inactivity between sets or exercises, even though no changes were observed in physiological or perceptual markers.

iv. The effectiveness of re-warm-up is not uniform across individuals and is influenced by personal characteristics, such as strength level, stature and body mass. These findings emphasize the importance of personalizing preparatory strategies based on individual profiles, contributing to more effective and targeted approaches in resistance training.

Chapter 6. Suggestions for Future Research

The findings obtained in this thesis represent a step forward on the path to better understanding of how warm-up and re-warm-up strategies influence mechanical performance in resistance training. There is still a long way to go before we can define re-warm-up protocols that maximize neuromuscular potentiation and minimize the interindividual variability observed. In this sense, the following future research directions are suggested below:

i. Given the limited research on re-warm-up strategies in resistance training, further investigation is warranted. Future studies should examine additional variables (e.g., creatine kinase, testosterone, cortisol, and muscular temperature) and employ larger and more diverse participants to enhance the robustness and generalizability of the findings.

ii. Include participants of both sexes (male and female), stratified across defined age ranges (e.g., 18–30, 31–50, and 51+ years) and experience levels (recreational: < 1 year of RT; intermediate: 1–3 years; advanced/competitive: > 3 years or national-level athletes). Ensure balanced subgroup sizes (e.g., ≥ 15 individuals each) to permit robust sex, age and training-status comparisons.

iii. Compare general, specific and hybrid warm-up protocols with different resistance training exercises, training loads, intensities, volumes, transition times and rest intervals.

iv. Evaluate and compare the efficacy of re-warm-up in multi-joint (e.g., deadlift, lat pulldown, row) and single-joint exercises (e.g., biceps curl, leg extension).

v. Conduct longitudinal studies to monitor chronic adaptations in strength, power, and hypertrophy following different warm-up and re-warm-up strategies.

vi. Validate warm-up and re-warm-up protocols in real-world gym and competition settings, assessing adherence and performance outcomes over a full season.

Chapter 7. References

Chapter 1. General Introduction

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Appendix

Supplementary Content Questionnaire (Study 2)

Warm-Up and/or Re-Warm-Up in Gym/Fitness Center Context

If you are a strength and conditioning coach or athlete, you are invited to participate in this questionnaire. Its main objective is to characterize the warm-up and re-warm-up strategies currently used in resistance training by coaches/athletes. This questionnaire is part of a scientific investigation conducted by Pedro Neves, a Ph.D. student in Sports Sciences at the University of Beira Interior (UBI). The present study aims to gather information on the importance, structure, load, and context of warm-up/re-warm-up application. The questionnaire is anonymous, and the collected data will be used exclusively for research purposes.

We appreciate your participation in advance!

Estimated completion time: Less than 10 minutes.

For any additional clarification, you may contact us via email at:
pedroneves93@hotmail.com

Informed Consent for Participation in Research Studies

By completing this questionnaire, I understand that:

1. Participation in this study is voluntary, and I may withdraw at any time.
2. No advantages, disadvantages, costs, or risks are expected during participation.
3. The collected data will be deleted after the study's completion and presentation.
4. The results may be published, but anonymity will be preserved.

Email: ____

I. Demographic Data

Age (years): ___________________

Sex:

☐ Male

☐ Female

☐ Other

Location: _________________________

Academic Qualifications:

☐High School

☐ Bachelor's Degree

☐ Master's Degree

☐ Ph.D.

☐ Other

Field of Academic Qualifications:

☐ Sports Sciences/Sports

☐ Other: _________________________

Role:

☐ Coach

☐ Athlete

☐ Both

Years of experience as a coach/athlete: ____________________

Sport(s) you practice: ______________________________

II. Warm-up Characterization

How important do you consider warm-up is for your training?

☐ Very Important

☐ Important

☐ Slightly Important

☐ Not Important

Do you usually perform a warm-up before resistance training?

☐ Yes

☐ No

If yes, how do you structure your warm-up? (if not, leave blank)

☐ Only general warm-up (non-sport-specific exercises, such as light jogging, joint mobility, or dynamic stretching)

☐ Only specific warm-up (exercises directly related to strength training, such as sets with reduced load or movements similar to the main workout)

☐ Both (general + specific)

What are the main objectives of your warm-up? (you can select more than one option)

☐ Increase body temperature

☐ Improve mobility and flexibility

☐ Activate specific muscle groups

☐ Prevent injuries

☐ Enhance training performance

☐ Other

What is the average duration of your warm-up?

☐ Less than 5 minutes

☐ 5-10 minutes

☐ 10-15 minutes

☐ More than 15 minutes

What is the intensity of your warm-up?

☐ Low (up to ~40% 1RM | up to ~50% HRmax | Very light perceived effort)

☐ Moderate (~40-70% 1RM | ~50-70% HRmax | Moderate perceived effort)

☐ High (above 70% 1RM | above 70% HRmax | High perceived effort)

If possible, specify the intensity of your warm-up (% of 1RM, HRmax, RPE,etc.):

____

What types of exercises do you include in your warm-up? (you can select more than one option):

☐ Cardiorespiratory (running, cycling, etc.)

☐ Joint mobility

☐ Dynamic stretching

☐ Specific training exercises

☐ Muscle activation with light loads

☐ Other

Is there a gap between the warm-up and the start of the main workout?

☐ Yes

☐ No

If yes, what is the average duration of this gap?

☐ Less than 2 minutes

☐ 2-5 minutes

☐ More than 5 minutes

Do you perform a warm-up for all types of strength training?

☐ Yes

☐ No

If not, in what situations do you choose not to warm up?
____

III. Re-warm-up

Do you usually perform a re-warm-up between sets or exercises?

☐ Yes

☐ No

If yes, in what situations do you consider re-warming up necessary?

☐ High-intensity training (≥85% 1RM | ≥90% HRmax | Maximum or near-maximum effort)

☐ Training with long rest intervals (>2 min between sets | >5 min between exercises)

☐ When there is a long break in training (>10 min without activity)

☐ After changes in exercises or equipment (exercises with very different movement patterns)

☐ Other

How do you perform the re-warm-up? (you can select more than one option)

☐ Bodyweight movements

☐ Specific training exercises

☐ Sets with reduced load

☐ Dynamic stretching

☐ Other

If not, what is the main reason for not performing a re-warm-up?

☐ I consider it unnecessary

☐ Lack of time during training

☐ I don't see an impact on performance

☐ It has never been a practice I've adopted

☐ Other

In what situations would you consider including a re-warm-up?

☐ Training with long pauses between sets (>2 min between sets | >5 min between exercises)

☐ Increasing load during training (progression to ≥85% 1RM | Near-maximum effort)

☐ When necessary to avoid performance loss (long breaks >10 min | Maintaining muscle activation)

☐ I do not consider it necessary in any situation

☐ Other

IV. Example of a Typical Warm-up

Describe a typical warm-up you use, divided into:
Initial Part (general activation)
Main Part (specific exercises)
Final Part (transition to the main workout)
Other: