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The role of specific warm-up amongst traditional resistance training exercises performances

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"Emancipate yourself from mental slavery, none but ourselves can free our minds."

Bob Marley

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List of Publications

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- **Ribeiro, B.,** Pereira, A., Neves, P.P., Sousa, A.C., Ricardo, F., Marques, M.C., Marinho, D.A., & Neiva, H.P. (2020). The role of specific warm-up during bench press and squat exercises: a novel approach. *International Journal of Environment Research and Public Health*, *17* (18), 6882. doi:10.3390/ijerph17186882. (JCR Impact Factor: 2.849).

Beyond these papers, a presentation was conducted as a preliminary approach to warm-up and strength performance:

- **Ribeiro, B.,** Pereira, A., Marinho, D.A., Marques, M.C., & Neiva, H.P. (2019). The effect of warm-up for maximal strength performance: brief review. *Motricidade, 15*(S1), 132. doi: 10.6063/motricidade.16967.

Abstract

In the last few years, investigations have been conducted to better understand warm-up design for different sports performance, such as running, swimming, and team sports. However, few have focused on warm-up impact during training. For instance, the ideal warm-up load for resistance training is unclear and should be further studied. The current thesis aimed to analyze the effects of different specific warm-ups in resistance training and to verify how different loads affect squat and bench press resistance training, by measuring the mechanical, physiological, and psychophysiological responses. To support this, the following steps were performed: (i) a literature review focusing on the warm-up effects on strength during resistance exercises; (ii) analysis of the effects of specific warm-up in squat and bench press exercises; and (iii) analysis of the effects of three different specific warm-ups in squat and bench press training. The main conclusions drawn were: (i) despite the recent increased interest in this subject, there is limited research on the effects of warm-up in resistance training; (ii) literature suggests that specific warm-up provides the changes needed to prepare the athlete for the upcoming resistance effort, with no benefits from adding a general warm-up; (iii) the specific warm-up with progressive intensity, performed in the same exercise as the main activity, optimizes squat and bench press resistance training; (iv) propulsive velocity and mechanical power during squat resistance training were positively influenced by performing a progressive-intensity warm-up or a specific warm-up with 80% of training load; (v) the time to achieve peak velocity, mechanical power and work in bench press training were optimized after the progressive-intensity warm-up. Our results give clear evidence that higher intensities (i.e., 80% of training load) and only a few repetitions (i.e., 6 repetitions) should be used during specific warm-ups to optimize squat training. However, bench press training should be preceded by more repetitions (i.e., 2 × 6 repetitions) with progressive loads (i.e., 40% and 80% of training load). Furthermore, warming up with few repetitions and low loads may not be enough to maximize squat and bench press performances. These findings can be used by sports professionals to optimize resistance training and performance, and by researchers for their future investigations to further understand the effects of warm-up in strength performance.

Keywords

Pre-exercise; Power; Strength; Training; Velocity; Work.

Resumo

Nos últimos anos têm sido desenvolvidas investigações para entender a estrutura do aquecimento realizado em competição na corrida, natação e em desportos de equipa. Contudo, poucos estudos debruçaram-se acerca do impacto do aquecimento durante o treino. Por exemplo, a carga ideal de aquecimento para o treino da força muscular é ainda desconhecida e deverá ser estudada. A presente Tese pretende analisar os efeitos de diferentes aquecimentos específicos no treino da força e verificar como cargas diferentes podem afetar o desempenho no exercício de supino e de agachamento, analisando as respostas mecânicas, fisiológicas e psicofisiológicas. Para isso, diferentes etapas foram concretizadas: (i) uma revisão da literatura acerca dos efeitos do aquecimento na força durante os exercícios resistidos; (ii) a análise do efeito do aquecimento específico nos exercícios de agachamento e supino; e (iii) a análise dos efeitos de três diferentes aquecimentos específicos no treino de agachamento e de supino. As principais conclusões foram: (i) apesar do recente aumento do interesse neste assunto, há poucas pesquisas sobre os efeitos do aquecimento no treino de força; (ii) a literatura sugere que o aquecimento específico fornece as mudanças necessárias para preparar o atleta para o exercício de força, sem benefícios extra ao adicionar um aquecimento geral prévio; (iii) o aquecimento específico com intensidade progressiva, realizado no mesmo exercício da atividade principal, otimiza o treino de agachamento e de supino; (iv) a velocidade e a potência mecânica durante o treino de agachamento foram influenciadas positivamente pela realização de um aquecimento de intensidade progressiva ou um aquecimento específico com 80% da carga de treino; (v) o tempo para atingir o pico de velocidade, potência mecânica e trabalho no treino de supino foram otimizados após o aquecimento de intensidade progressiva. Estes resultados evidenciam que as intensidades mais elevadas (i.e., 80% da carga de treino) e apenas algumas repetições (i.e., 6 repetições) devem ser usadas durante o aquecimento específico para otimizar o treino de agachamento. No entanto, o treino de supino deve ser precedido por mais repetições (i.e., 2 × 6 repetições) com cargas progressivas (i.e., 40% e 80% da carga de treino). O aquecimento com poucas repetições e cargas baixas pode não ser suficiente para maximizar o desempenho do agachamento e do supino. Estas evidências podem ser utilizadas por profissionais do desporto para otimizar o treino de força e o desempenho, e por investigadores que pretendam entender melhor os efeitos do aquecimento no desempenho da força muscular.

Palavras-chave

Pré-exercício; Força; Velocidade; Treino; Potência

Resumo Alargado

Diversos estudos têm vindo a ser desenvolvidos no âmbito da influência do aquecimento no rendimento desportivo. Contudo, a literatura é ainda escassa no que se refere ao impacto do aquecimento durante o treino para as diferentes modalidades desportivas. Considerando que o treino da força é parte integrante do processo de preparação dos desportistas, torna-se fundamental otimizar cada sessão de treino, maximizando os seus resultados. Neste sentido, o aquecimento poderá ter um papel fundamental para a melhoria do rendimento durante o treino da força e na otimização do rendimento desportivo a longo prazo. Pouco se sabe acerca da carga ideal a ser utilizada durante o aquecimento para o treino da força muscular. A presente tese teve como objetivo analisar o efeito da realização do aquecimento específico no treino da força e verificar como diferentes cargas poderão influenciar a realização de uma sessão tradicional de treino dos exercícios de agachamento e supino. Para isso, foram analisadas as respostas mecânicas, fisiológicas e psicofisiológicas, antes, durante e após a realização do treino. Para fundamentar os objetivos desta tese foram elaborados três artigos científicos, nomeadamente uma revisão sistemática da literatura e dois artigos experimentais.

Na revisão sistemática foram analisados e sintetizados artigos acerca das estratégias de aquecimento e seus efeitos na força muscular no desempenho de exercícios resistidos. Os procedimentos utilizados como estratégia de pesquisa foram de acordo com as recomendações PRISMA. Os critérios de inclusão focaram-se em estudos transversais, com a utilização e experimentação acerca do aquecimento e o seu efeito no desempenho com cargas externas submáximas e máximas, em indivíduos saudáveis. Pesquisou-se por estudos originais em quatro bases de dados (Web of Science, Scopus, PubMed, and ScienceDirect), publicados entre maio de 1973 e dezembro de 2019, sendo que onze estudos foram incluídos. Pudemos verificar que a maior parte dos estudos debruçou-se sobre os efeitos na força máxima e no número de repetições realizadas. Os resultados revelaram, na sua maioria, a inexistência de diferenças significativas entre diferentes estratégias de aquecimento, particularmente comparando o aquecimento geral e específico, na força máxima. Alguns estudos pareceram indicar que a realização de um aquecimento específico cargas externas elevadas (> 70% da força máxima dinâmica: 1RM) pode afetar positivamente a força em exercícios resistidos. De acordo com esta revisão sistemática, podemos admitir que nos últimos anos houve um aumento do interesse por parte da investigação acerca do efeito do aquecimento em exercícios resistidos. Na literatura existente, apesar dos resultados após o aquecimento específico não diferirem do aquecimento geral, parece haver uma tendência para que o aquecimento específico promova as alterações necessárias para preparar o atleta para o esforço seguinte. Os estudos revelaram ainda que o aquecimento deve ser efetuado com elevadas cargas externas e reduzidas repetições, ou com cargas leves e elevada velocidade de execução de forma a criar um efeito de potenciação pós-ativação, sendo expectável que os efeitos agudos verificados possam resultar num aumento da performance muscular a longo prazo.

Tendo por base as evidências obtidas na revisão da literatura, pretendeu-se perceber melhor o efeito do aquecimento específico no desempenho muscular durante a sessão de treino de força muscular. Assim, o primeiro artigo experimental teve como objetivo analisar os efeitos do aquecimento específico nos exercícios de agachamento e supino, através da análise de respostas mecânicas, fisiológicas e psicofisiológicas. Foi formulada a hipótese de que o aquecimento específico poderia otimizar o treino resistido, aumentando a velocidade média propulsiva e a potência mecânica produzida. Dos 34 participantes no estudo, 12 (23.58 ± 2.78 anos de idade; 1.76 ± 0.08m de estatura; 77.50 ± 11.23 kg de massa corporal) foram avaliados no exercício de agachamento e 22 (23.50 ± 2.15 anos de idade, 1.76 ± 0.06m de estatura, 77.23 ± 8.93 kg de massa corporal) foram avaliados no exercício de supino. Após a sessão de familiarização com a correta execução dos exercícios de agachamento e supino, na primeira avaliação determinou-se a carga dinâmica máxima (1RM). Através desse valor foi calculada a carga de treino, correspondente a 80% de 1RM. A série tradicional do treino foi definida como sendo 3 x 6 repetições com 80% 1RM. Esta série foi completada individualmente e de forma aleatória, com e sem a realização de aquecimento, nas duas sessões seguintes. O aquecimento específico foi constituído por 6 repetições com 40% da carga de treino seguido de 6 repetições com 80% da carga de treino. Para a avaliação e monitorização das variáveis mecânicas durante o treino foi utilizado um transdutor de velocidade linear (T-Force System, Ergotech, Murcia, Spain). Foi ainda avaliada a resposta da frequência cardíaca e a perceção subjetiva de esforço através da escala de Borg (6-20). Os resultados revelaram que os participantes realizaram a primeira série de treino no exercício de agachamento e de supino com valores superiores de velocidade média propulsiva, comparando com a não realização de aquecimento. Também o pico da velocidade foi elevado e o tempo despendido para atingir esse pico foi reduzido, quando precedido de aquecimento específico, no exercício de agachamento. Curiosamente a perda de velocidade durante o treino foi moderadamente alta quando o aquecimento foi efetuado. Nos dois exercícios avaliados, não foram encontradas diferenças significativas na potência mecânica ou no trabalho realizado durante o treino. A resposta da frequência cardíaca também não demonstrou diferenças entre as condições após a realização do treino. No entanto, valores mais elevados de perceção de esforço foram obtidos depois do treino de agachamento quando precedido de aquecimento. Com a realização deste estudo foi possível revelar que o aquecimento específico com intensidade progressiva (6 x 40% + 6 x 80% da carga do treino), parece otimizar a produção de força e pode ser usado como preparação para uma sessão de treino nos exercícios de agachamento e supino. De acordo com os resultados, a hipótese de que a velocidade média propulsiva e a potência mecânica durante o treino resistido do agachamento e supino, poderiam ser influenciadas pelo aquecimento específico foi parcialmente confirmada.

Conhecendo-se assim o efeito benéfico do aquecimento específico, tornou-se fundamental procurar perceber os efeitos de diferentes aquecimentos, variando a carga utilizada durante os mesmos. Assim, o estudo experimental que se seguiu foi desenvolvido com o objetivo de analisar os efeitos de diferentes aquecimentos específicos nos exercícios de supino e agachamento, avaliando respostas mecânicas, fisiológicas e psicofisiológicas. Foi elaborada a hipótese de que o aquecimento específico com cargas elevadas poderá otimizar o treino da força, aumentando a velocidade propulsiva e a potência mecânica nos exercícios de agachamento e supino. Dos 40 participantes, 14 (24.43 ± 3.48 anos de idade; 1.76 ± 0.71m de estatura; 77.71 ± 10.35 kg de massa corporal) foram avaliados no exercício de agachamento e 26 (22.19 ± 1.67 anos de idade, 1.77 ± 0.06m de altura, 72.23 ± 8.21 kg de massa corporal) no supino. A primeira sessão foi utilizada para a avaliação da composição corporal e adaptação dos sujeitos aos exercícios propostos. Na segunda sessão procedeu-se à determinação da carga de 1RM no exercício de agachamento e supino usando um teste de carga progressiva. Nas restantes três sessões, procedeu-se à avaliação das variáveis mecânicas durante o treino de força após a realização de um aquecimento específico, variando a carga utilizada. À semelhança do estudo experimental anterior, foi também avaliada a resposta da frequência cardíaca e a perceção subjetiva de esforço através da escala de Borg (6-20). Foram avaliadas três condições de aquecimento diferentes, de forma aleatória, nomeadamente, o aquecimento com carga elevada (6 x 80% da carga de treino), carga baixa (6 x 40% da carga de treino) e um aquecimento progressivo (6 x 40% + 6 x 80% da carga de treino). A sessão de treino consistiu na realização de 3 séries de 6 repetições com 80% 1 RM. Os resultados demonstraram que os participantes foram capazes de atingir maiores valores de velocidade do movimento na segunda e na terceira série do treino de agachamento, com o aquecimento composto

por cargas mais elevadas, comparativamente às cargas mais baixas. Os participantes efetuaram o agachamento a uma velocidade média propulsiva mais elevada e demoraram menos tempo para atingir a máxima velocidade após o aquecimento realizado com maior carga, quando comparado com o aquecimento de baixa carga. No supino, o tempo para atingir o pico da velocidade nas primeira e segunda séries após o aquecimento progressivo foi menor quando comparado com o aquecimento com cargas mais baixas. Não foram detetadas quaisquer diferenças na potência mecânica, contudo, os resultados demonstraram uma tendência para um trabalho superior desenvolvido durante o treino realizado após o aquecimento progressivo. Tal foi evidente no trabalho realizado nas primeiras séries do treino de supino e na totalidade do treino comparativamente ao aquecimento com carga baixa. Não foram encontradas diferenças significativas na frequência cardíaca e na perceção de esforço entre as diferentes condições de aquecimento.

De acordo com os resultados apresentados na presente Tese, pudemos concluir que i) existe uma clara carência de investigação acerca do aquecimento específico para o treino da força, sendo que os estudos existentes manifestam alguma tendência para que o aquecimento específico tenha efeitos positivos; ii) o aquecimento específico, realizado no mesmo exercício que o treino, parece otimizar a produção de força através da possibilidade em realizar maior velocidade propulsiva durante as primeiras repetições do treino e ajudando a atingir maiores velocidades máximas em menor tempo; iii) a velocidade média propulsiva demonstrou uma tendência para ser mais elevada no início da sessão de treino de agachamento, após o aquecimento realizado com cargas progressivas; no entanto, as séries de treino seguintes demonstraram melhores resultados quando precedidas de um aquecimento realizado com 80% da carga de treino; iv) no exercício de supino, o tempo para atingir o pico da velocidade, a potência mecânica produzida e o trabalho, foram otimizados após o aquecimento progressivo (i.e., 40% seguido de 80% da carga de treino); v) de uma forma geral, podemos constatar que o aquecimento de baixa intensidade (i.e., 40% da carga de treino) foi o que apresentou resultados menos significativos quando comparado com as outras condições de aquecimento.

Palavras-chave:

Pré-exercício;Força;Velocidade;Potência;Trabalho.

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List of Abbreviations

1RM	One-repetition maximum
BPM	Beats per minute
CI	Confidence Intervals
ES	Effect sizes
F	Female
HR	Heart rate
HRmax	Maximal heart rate
HRreserve	Reserve heart rate
M	Male
MPP	Mean propulsive power
MPPmin	Mean propulsive power minimal
MPV	Mean propulsive velocity
ND	Not determined
PAP	Postactivation potentiation
PRISMA	Preferred Reporting Items for Systematic reviews and Meta-Analyses
PV	Peak velocity
REPS	Repetitions
RM	Repetitium maximum
RPE	Rating of perceived exertion
SDs	Standard Deviations
SPSS	Statistical Package for Social Sciences
T	Trained
Time to PV	Time to peak velocity
VL	Velocity loss
VO2max	Maximal oxygen uptake
WU	2x6 repetitions with 40% and 80% of the training load
WU80	6x80% of training load
WU40	6x40% of training load

Chapter 1. General Introduction

Warm-up is a common practice in all sports contexts, and it is considered essential by athletes and coaches for reaching optimal performance (Fradkin et al., 2010; MacGoawn et al., 2015). Most benefits from warm-up are related to an increased body temperature that will promote elasticity increase of connective tissue, velocity for the transmission of nerve impulses, decrease in viscosity of the muscle-tendon system, redistribution of blood flow, and improvement of the skeletal muscle oxygen diffusion (Bishop, 2003a, 2003b). These effects most likely result in improved aerobic and anaerobic function and contribute to a decrease in the risk of injuries (Bishop, 2003a, 2003b; McGowan et al., 2015; Neiva et al., 2014; Young & Behm, 2002).

The increased body temperature can be promoted via active and/or passive warm-up, depending on the use of physical activity with consequent energy expenditure (McGowan et al., 2015). The passive warm-up is characterized by stimulating the increase of body temperature through external mechanisms, such as hot showers, saunas, heated clothes, or massages (Nader et al., 2011). The active warm-up represents the athlete's most used strategy to increase body temperature before sport competition events, inducing greater metabolic changes (Bishop, 2003b, McGowan et al., 2015). This type of warm-up adds some effects that are caused by the physical activity itself, such as the increase in the baseline values of oxygen consumption (Atkinson et al., 2005) and in the range of motion that results from the breakdown of actin and myosin cross-bridges (Billington et al., 2014). Moreover, some activities performed at maximal or submaximal intensities can cause post-activation potentiation (PAP) effects and increase motor neuron excitability, influencing post-warm-up performances (Alves et al., 2019; Sale, 2004). Therefore, it is understandable that most coaches and athletes use active warm-up preferentially.

Knowing the mentioned effects of warm-up, previous studies tried to understand the warm-up effects in sports performance (Ferreira et al., 2016; Junior et al., 2014; Ribeiro et al., 2014). Several studies emerged in the last few years comparing the effects of different warm-ups, volume, intensity, time to recovery after warm-up, and specificity of the tasks (McGowan et al., 2015; Neiva et al., 2014; Zois et al., 2011). Nevertheless, there are still many factors that need to be investigated and clarified (Wilson et al., 2013; Zois et al., 2011). Moreover, most of the studies demonstrating the benefits of warm-up focused mainly on individual and team-sports performance and on specific activities such as sprint and jump, identifying some benefits in their performance (Gourgoulis et al., 2003; Pojskić et al., 2015). The warm-up was found to improve running sprint performance (Marinho et al., 2017), swimming performance (Neiva et al., 2015), cycling performance (Burnley et al., 2005), and jumping, (Burkett et al., 2005), highlighting the role of warm-up for performance optimization. Moreover, little is known about its effects in strength performance and resistance training.

It is known that muscular strength is associated with force-time characteristics, for example, rate of force development and mechanical power, and the improvement of these variables is related to enhanced sport performance and potentiation effects (Suchomel et al., 2016). Coaches and athletes have already realized that stronger athletes outperform their weaker counterparts with regard to both strength-power- and endurance-based sports or events (Aagaard et al., 2011; Haff et al., 2012). Therefore, there has been a growing interest in practices and methods to increase the efficiency of resistance training (Andersen et al., 2010). This way, the intention is not only to increase gains but also to reduce the time spent on resistance training, being able to dedicate more time to recovery or to specific sport skills development. The additional benefits for resistance training can include the ability to take advantage of an efficient warm-up, as verified in other sports and specific tasks (Cormie et al., 2010; Styles et al., 2015). With a proper warm-up, each individual can optimize the activation of the muscle system that is involved in the sport-specific task, improve neural stimulation and inhibit the muscles that impair performance, maximizing resistance training gains (Hughes et al., 2017). Therefore, the influence of warm-up in resistance training and strength performance and, consequently, in performance, cannot be overlooked.

Because warm-up can be important for optimizing athletes' performance and muscle strength is one of the most important physical factors in performing any type of movement (Ferreira et al., 2016; Külkamp et al., 2009), there is a need to further understand the main outcomes regarding the effects of warm-up on resistance training and strength performance (Study 1). Most of the research on this subject studied the influence of general and/or specific warm-up in maximal dynamic strength (e.g. 1RM load) and the number of repetitions with submaximal loads (e.g. % 1RM load). The general warm-up is characterized by the stimulation of the main muscle groups and/or entire body, increasing body and muscle temperature, and stimulating the cardiovascular and pulmonary system for the ensuing activity (Abbud et al., 2013). It can be performed with other activities different from the main one. The specific warm-up stimulates the muscle groups that will be used in the training session through the use of similar movements, but usually with a reduced load to prepare the neuromuscular system (Batista, 2003; Di Alencar & Matias, 2010; Rosa & Montandon, 2008). According to the literature, the specific warm-up can cause additional benefits in the working muscles, such as increased blood flow and greater recruitment of motor units, according to the specificity of the requested movement (Bishop, 2003b; Di Alencar & Matias, 2010; Fermino et al., 2008; Rubini, et al., 2007). For instance, Alves et al. (2019) verified that the subjects who performed a specific warm-up completed a higher number of repetitions in first and second sets of resistance training (11.5 ± 3.1 and 6.5 ± 1.9, respectively) than those who did not perform any warm-up (10.4 ± 2.7 and 5.5 ± 1.8), suggesting that specific warm-up can be used during resistance training to promote total work and potentially increase long-term results. Moreover, others reported no significant differences between the use of general warm-up and specific warm-up in maximal strength in upper and/or lower limbs (Abbud, et al., 2013; Barroso et al., 2013; Brandenburg, 2005; Foganholi et al., 2012; Gil et. al., 2015; Junior et. al, 2014; Nader, et al., 2009; Ribeiro, et al., 2014).

According to the above-mentioned evidence, considerable attention from the investigation should be dedicated to the understanding of the effect of specific warm-ups on resistance training (Barroso et al., 2013; McGowan et al., 2015). Thus, it seems relevant to analyze the effect of a specific warm-up, in squat and bench press exercises, considering that these are the most commonly used exercises in strength-related studies and resistance training contexts. Despite previous studies which suggest that a specific warm-up is needed to obtain maximal strength performance, several controversial results and methodological flaws still exist (Fradkin et al., 2010; Silva et al., 2018; Tillin & Bishop, 2009). For example, existing literature evaluated mostly the effect of specific warm-up on the number of repetitions and/or the maximal dynamic load (e.g., Abad et al., 2011; Ribeiro et al., 2014; Wilcox et al., 2006). This is conditioned by the daily variation of 1RM performance, and there could be a high risk of injury when performing high loads without a proper warm-up. One of the factors that can hinder a correct warm-up prescription or resistance training is the determination of 1RM, which could be inappropriate for precise assessment of the real effort performed by athletes (González-Badillo et al., 2011). A valid and accurate assessment of individual strength is important for determining an individual's functional capacity and monitoring training responses in any population (Brown & Weir 2001; Garber et al., 2011). The velocity of movement is a reliable variable that can be assessed in a real resistance training set with submaximal external loads, and it can be used to determine maximal dynamic individual strength (González-Badillo et al., 2011; González-Badillo and Sánchez-Medina, 2010).

Furthermore, the traditional method to determine 1RM load requires a progressive increase in the external loads. This way, the first repetitions during the 1RM assessment can disguise the influence of previous warm-up activities, and also, the rising fatigue can compromise the results. This probably contributed to contradictory findings regarding the effect of specific warm-up. However, new evaluation procedures can be used to evaluate resistance training performance without these constraints. The load-velocity relationship has emerged as a method for objectively monitoring resistance training and dynamic strength performance (González-Badillo et al., 2011; González-Badillo and Sánchez-Medina, 2010; Jovanović and Flanagan, 2014). Therefore, the effects of specific warm-up activities in resistance training could be further understood using as primary outcomes the mechanical responses, such as the velocity of movement, power, and work (Study 2).

Considering that performance of strength exercise can be improved with a previous specific strength warm-up, the optimal load to be used during warm-up remains uncertain. Abbad et al. (2011) presented an improvement of 2.8% in 1RM load after a specific warm-up of 1 set, 8 repetitions with 50% 1RM followed by 1 set of 3 repetitions with 70% of 1RM. It appears that warm-up with high external loads (2 sets of 2 repetitions with 90% of 1RM load) may positively affect the number of repetitions with 70% of 1RM in leg press and bench press exercises (Junior et al., 2014). In fact, studies suggested that a warm-up with high external loads (> 70% 1 repetition maximum - 1RM- load) or post-activation potentiation (PAP) activities might result in higher force production in the upper and lower limbs and potentially increase long-term results (Abad et. al. 2011; Alves et al., 2019; Wilcox et al. 2006). However, others were unable to find a potentiating effect with a set of 5 repetitions with a 5RM load on following strength performance (Hrysomallis et al., 2001), or found that varying the external loads during warm-up seemed not to cause any advantage to an explosive bench press movement (Brandenburg et al., 2005). The use of higher loads can be related to fatigue increase, which may remove the potential for performance improvement if the resting phase is not sufficient (Hamada et al., 2003).

It seemed that, when the specific warm-up was performed at loads close to the maximum, the results tended to demonstrate that the ability to produce strength could be positively affected (Alves et al., 2019; Evans et al., 2001; Junior et al., 2014; Wilcox et al., 2006). Still, there are no clear conclusions about different warm-up loads (Abbud, et al., 2013; Barroso et al., 2013; Brandenburg, 2005; Foganholi et al., 2012; Gil et. al., 2015; Nader, et al., 2009; Ribeiro, et al., 2014). The efficiency of this process seems to depend on the balance between fatigue onset and muscle potentiation (Tillin et al., 2009), which is caused by several factors such as training experience (Kilduff et al., 2007), the rest period between warm-up sets, and the main activity (Kilduff et al., 2008). Intensity, as a determinant of exercise load (González-Badillo et al., 2017), is fundamental for designing an appropriate specific warm-up without impairing performance during subsequent strength training and should be studied. Clear conclusions are difficult to present, as different research approaches compare different warm-up strategies and intensities. Hence, it is of the utmost importance to further understand the effects of different loads used during warm-up in subsequent resistance training performance (Study 3).

Knowing the importance of warm-up for optimizing the effects of resistance training and strength performance and at the same time avoid the early effects of muscle fatigue, it is important to observe the effects and influence of using different specific warm-up strategies to increase the efficacy of training. The current thesis aimed to analyze the effects of different specific warm-ups in resistance training and to verify the effects of different loads in squat and bench press resistance training, by measuring the mechanical responses (primary outcomes) and physiological and psychophysiological responses (secondary outcomes). It was hypothesized that a specific warm-up would optimize resistance training, by increasing propulsive velocity and mechanical power produced in bench press and squat exercises.

According to the main purpose, this thesis is developed according to the following sequence:

- Chapter 2 presents a systematic review based on the early studies regarding the effects of different warm-up strategies on resistance training and strength performance (Study 1).

- Chapter 3 shows the experimental studies developed to accomplish the main purpose of this thesis:

    - Study 2 aims to verify the effects of the specific warm-up and of no warm-up in squat and bench press exercises, measuring the mechanical responses (propulsive velocity, mechanical power and work), and the secondary outcomes, including physiological (heart rates) and psychophysiological (ratings of perceived exertion: RPE), during a typical training set.

- Study 3 was developed to analyse the effects of different specific warm-ups on bench press and squat exercises, evaluating mechanical responses (propulsive velocity, mechanical power and work) and physiological (heart rate) and psychophysiological (ratings of perceived exertion: RPE) variables during a typical resistance training set.

Following the presentation of the studies, a general discussion of the results is provided (Chapter 4), followed by the main conclusions and limitations of the thesis (Chapter 5). Some suggestions for future research are also presented (Chapter 6).

Chapter 2. Literature Review

Study 1

The effect of warm-up in resistance training and strength performance: a systematic review.

Abstract

The warm-up is fundamental to optimize physical activity and exercise performance. However, little is known about the effect of warm-up in resistance training and strength performance. We performed a systematic review to synthesize and analyze the effects of different warm-up strategies in maximal and submaximal strength during resistance exercises. A search for studies was performed on four databases (Web of Science, Scopus, PubMed, and ScienceDirect) for original research published between May 1973 and December 2019. Eleven articles were selected, according to the inclusion criteria. Most of the studies evaluated the effects of warm-up on maximal strength and the number of repetitions until failure. The results were not consensual regarding the use of general warm-up followed by a specific warm-up. Moreover, while some studies showed that specific warm-up did not lead to different results than without warm-up, others found that performing only the specific warm-up was the best way to obtain maximal strength performance. It seemed that the maximal strength and the number of repetitions could be positively affected when a specific warm-up is performed at loads close to the maximum. Further studies are needed to deepen the knowledge about the preparation procedures for optimizing resistance exercise performances.

Keywords: General warm-up; Performance; Pre-exercise; Specific warm-up; Strength.

Introduction

The warm-up is usually used to progressively adapt physically and mentally the body for the main exercise, optimizing performance and reducing the risk of injuries (Gray, & Nimmo, 2001; McCrary, Ackermann, & Halaki, 2015; Neiva, Marques, Barbosa, Izquierdo, & Marinho, 2014; Parr, Prince, & Cleather, 2017; Silva, Neiva, Marques, Izquierdo, & Marinho, 2018; Simão, et al., 2004). Most of the benefits resulting from warm-up are related to the increased body temperature and are widely accepted to be beneficial to performance (Bishop, 2003; Albuquerque, Maschio, Gruber, Souza, & Hernandez, 2011; McGowan, Pyne, Thompson, & Rattray, 2015; Neiva, Marques, Barbosa, Izquierdo, & Marinho, 2014). For this, the warm-up practices usually include bouts of exercise of different intensities and specific technical practices for the following activity (Kilduff, Finn, Barker, Cook, & West, 2013). Although there is increasing interest in research on the effectiveness of warm-up, there is still some controversy regarding the advantages it gives specifically to resistance training and strength performance.

The positive influence of warm-up on sports performance is clear but there is a need for specific investigations about the variables that compose it, as well as their effect on the manifestation of specific strength (Gil, Neiva, Sousa, Marques, & Marinho, 2019). The number of variables involved in the warm-up process is high, and it is a complex task to design an effective warm-up model across all sports and exercise types. There is a need for specific knowledge about all the parameters that predominantly influence their effectiveness. Therefore, the warm-up must be designed for specific needs in sport. Everyone involved in physical activity and exercise, individual and team sports, requires the use of muscle to produce movement. Thus, muscular performance at maximal or submaximal efforts can be considered essential to succeed in each exercise performance. The role of muscle strength performance is widely recognized in the scientific and sport context (Wilcox, Larson, Brochu, & Falgenbaum, 2006; Abad, Prado, Ugrinowitsch, Tricoli, & Barroso., 2011). Enhancing strength performance and optimizing resistance training (strength training exercises where muscles exert a force against an external load) should be a priority for athletes and sports scientists. Indeed, warm-ups could be fundamental for this performance optimization.

Scientific research has demonstrated the efficacy of warm-up strategies for individual and/or team sports, but there is little information about the effect of warm-up in strength performance (Gil et al., 2019; Alves et al., 2019). As a result, sports professionals continue to design their routines based on experience and not so much on scientific evidence. To the best of our knowledge, no detailed systematic review has comprehensively examined the literature regarding the effects of warm-up activity on resistance training and maximal strength performance. Analyzing studies that have evaluated the effect of warm-up strategies on strength performance would provide coaches and sports scientists with valuable knowledge and strategies to optimize resistance training programs. Therefore, the purpose of this systematic review was to synthesize and analyse research findings on the effects of warm-up strategies on strength performance during resistance exercises.

Methods

This study intended to summarize the findings and conclusions reported in the literature on the effect of warm-up, between general and specific in strength performance in adults. An extensive literature search was developed to identify the articles published on this subject. Supported on inclusion and exclusion criteria, some articles were excluded for future studies and others are part of this systematic review.

Search Strategy

A systematic review was conducted according to PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) guidelines (Methley, Campbell, Chew-Graham, McNally, & Cheraghi-Sohi 2014). The search was performed using the Boolean search method, which limited the search results with operators including AND/OR to only those documents containing relevant key terms.

Original research articles published between May 1973 and December 2019 were identified, in which warm-up and strength performance was reported. The search was conducted in four databases (Web of Science, Scopus, PubMed, and ScienceDirect) using the keywords: ("warm-up" OR "no warm-up") AND ("1 repetition maximum:1RM, or repetition") AND ("general warm-up") AND ("specific warm-up") AND ("resistance training OR strength training") AND ("strength OR power), with multiple combinations and without any year our language restrictions. Review articles (qualitative review, systematic review, and meta-analysis) were not considered. Also, those articles focusing only on stretching and flexibility warm-ups were excluded.

Inclusion and Exclusion Procedures

The included studies focused on i) cross-sectional interventions; ii) strength performance outcomes during resistance exercises (i.e. exercises against external loads, maximal and submaximal strength loads, number of repetitions); iii) healthy subjects without any training restrictions; iv) subjects with a minimum of 18 years of age. The studies were selected for further analysis if they assessed at least one type of active warm-up (i.e. involving physical activity). The evidence extracted from the selected studies was based on research design, aim, subjects, procedures/outcomes, and findings.

Quality Assessment

The analysis of the methodological quality of the studies included in the systematic review was carried out by two independent reviewers, according to the methods recommended by The Cochrane Collaboration (Higgins & Green, 2011). The authors resolved the disagreements by consensus (a third author was consulted to resolve the disagreements, whenever necessary). Each included study was assessed using the following domains: random sequence generation (selection bias), allocation concealment (selection bias), blinding of participants and personal (performance bias), blinding of outcome assessor (detection bias), incomplete outcome data (attrition bias), selective outcome reporting (reporting bias), and other sources of bias (Higgins & Green, 2011). In each domain, the criterion was adjudged as “low risk”, “high risk”, or “unclear risk”. If the judgement was unclear due to lack of information, insufficient detail, or uncertainty concerning the potential for bias, an “unclear risk” was given. The quality assessment was not used to article screening and selection, but to inform the reader about the risk of bias in each study. Review Manager software (RevMan, The Nordic Cochrane Centre, Copenhagen, Denmark) Version 5.4 was used to create risk-of-bias graphs.

Results

Our search identified relevant articles but some of them did not meet the inclusion criteria. These studies were excluded based on the fact of being focused on another main subject, such as running performance, anthropometric characteristics, flexibility, stretching warm-up, or using participants of other chronological ages including children or seniors. Consequently, a total of eleven studies were considered for further analysis. From these, the earliest one was published in 2003 and the most recent in September 2019. The studies focusing on warm-up strategies and the relation with 1RM strength are presented in Figure 1.

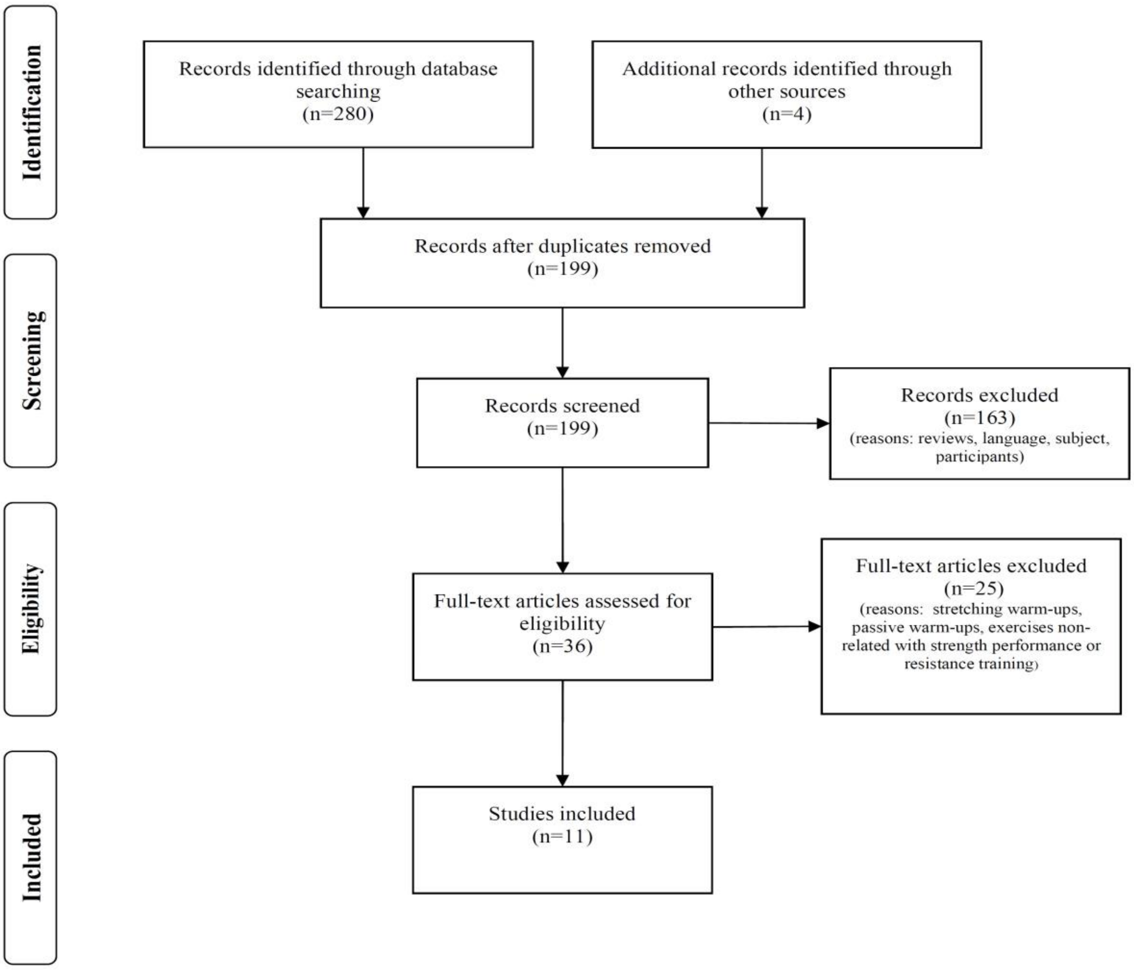

Figure 1. PRISMA (preferred reporting items for systematic reviews and meta-analysis) study flow diagram.

The Table 1 summarizes the studies that investigated the results of the general and specific warm-up (Alves et al., 2019, Barroso, Batista, Tricoli, Roschel, & Ugrinowitsch, 2013; Abbud, Tabet, & Dias, 2013; Abad, et al., 2011; Gil, Roschel & Barroso, 2015; Junior, et al., 2014; Ribeiro, et al., 2014; Foganholi, & Guariglia, 2012; Nader, et al., 2009; Wilcox, et al., 2006; Brandenburg, 2005). The selected studies presented a mean score of 8.65 points for quality standards.

Table 1 - Description of the studies presented about the general and specific warm-up. The variables presented refer to the authors, subjects, volume, intensity, the transition (min), evaluation test, and performance results.

Study	Subjects	Warm-up	Transition	Evaluation	Main results
Abad et al (2011)	13 T (M)	Wu1 – 20min stationary cycling (60% of HRmax) + Wu2. Wu2 - 8 reps (50 % 1RM load) + 3 reps (70% 1RM load) leg press.	3min	1RM Leg Press	1RM: Wu1>Wu2
Abbud et al (2013)	10 T (F)	Wu1 – No warm-up Wu2 - 10 reps (40% 1RM load) + 5 reps (60% 1RM load), bench press	ND	Bench press, number of repetitions (70%1RM load)	No significant differences between protocols.
Alves et al. (2019)	14 T (M)	Wu1 – Wu2 + 3reps (90% 1RM load), bench press. Wu2 – 8 reps (50% 1RM load), bench press.	10min (Wu1) 4min (Wu2)	3x 75% 1RM load, maximal reps, bench press	Wu1 > Wu2 in the first and second sets
Barroso et al (2013)	16 T (M)	Wu1 - 5 min cycling (40% VO_2max) + Wu5 Wu2 -5 min cycling (70% VO_2max) + Wu5 Wu3 -15 min cycling (40% VO_2max) + Wu5 Wu4 - 15 min cycling (70% VO_2max) + Wu5 Wu5 - 8 reps (50% 1RM load) + 3 reps (70% 1RM load) leg press.	3min	1RM Leg Press	Wu3 > Wu1, Wu2, Wu4, Wu5 Wu4 < Wu1, Wu2, Wu3, Wu5
Brandenburg et al (2005)	9 T (M)	Wu1 – 1x5 reps (100% of 5RM load) bench-press Wu2 - 1x5 reps (75% of 5RM load) bench-press Wu3 - 1x5 reps (50% of 5RM load) bench-press Wu4 – No warm-up	4min	Bench press throw 3 reps ~45% 1RM load	No significant differences between protocols.
Foganholi et al (2012)	6 T (M)	Wu1 – 10 reps (50% 1RM load) bench press Wu2 - 2min walking (5km/h) + 5 min running (8km/h) Wu3 - active static stretching 10sec, 3reps (pectoral, deltoid and triceps)	ND	Bench Press 1RM	No significant differences between protocols.

<: lower than; >: higher than; F: female; HR: heart rate; Hrmax: maximal heart rate; HRreserve: reserve heart rate; M: male; ND: not determined; Reps: repetitions; RM: repetitium maximum; T: trained; VO_2max: maximal oxygen uptake Wu: warm-up;

Table 2 (continued) - Description of the studies presented about the general and specific warm-up. The variables presented refer to the authors, subjects, volume, intensity, the transition (min), evaluation test, and performance results.

Study	Subjects	Warm-up	Transition	Evaluation	Main results
Gil et al (2015)	12 T (M)	Wu1 - Running 5min (9km/h) + 5min flexibility exercises + Wu2 Wu2 - 8reps (50% 1RM load) + 3reps (80% 1RM load). Leg press and bench press.	3min	1RM bench press 1RM leg press	No significant differences between protocols.
Junior et al (2014)	14 T (M)	Wu1 - 5min walking 50% VO_2max. Wu2 - 5 min cycling 50% VO_2max. Wu3 - 15 reps (40% 1RM load). Bench press or leg press unilateral. Wu4 - 2 x 2 (90% 1RM load). Bench press or leg press unilateral. Wu5 – No warm-up Wu2 was only assessed before unilateral leg press evaluation	1min	70%1RM load, maximal reps in bench press or in unilateral leg press	Bench press: Wu4 >Wu1, Wu3, Wu5 Wu5>Wu3 Wu1>Wu3 Leg press unilateral: Wu4> Wu1, Wu2, Wu3, Wu5 Wu2>Wu1
Nader et al (2009)	9 T (M)	Wu1 - aerobic 10min treadmill (70%HRreserve) Wu2 - 15 reps (50% 8RM load) bench-press	90s	Bench press 3x8RM load	No significant differences between protocols.
Ribeiro et al (2014)	15 T (M)	Wu1 - Rest 10min on a chair. Wu2 - 10 reps (50% of 80%1RM load), bench press, squat, arm curl. Wu3 - cycling 10min (40 km/h) Wu4 – Wu3 + Wu2	30s	4 x 80% 1RM load, maximal reps in bench press, squat, arm curl.	No significant differences between protocols.
Wilcox et al (2006)	12 T (M)	Wu1 - 5min low-intensity stationary cycling and 3 upper body static stretches. Wu2 – Wu1+Medicine ball chest passes Wu3 – Wu1+Plyometric push ups	30s	1RM Bench Press	1RM: Wu2 and Wu3 > Wu1

<: lower than; >: higher than; F: female; HR: heart rate; Hrmax: maximal heart rate; HRreserve: reserve heart rate; M: male; ND: not determined; Reps: repetitions; RM: repetitium maximum; T: trained; VO_2max: maximal oxygen uptake Wu: warm-up.

It can be observed that most of the selected studies did not find statistically significant differences between different warm-up strategies concerning general warm-up and specific warm-up in maximal strength in upper and/or lower limbs in the exercises leg-press and bench press, respectively (Junior et. al, 2014; Foganholi et al., 2012; Abbud, et al., 2013, Ribeiro, et al., 2014; Gil et. al., 2015; Nader, et al., 2009; Barroso et al., 2013; Brandenburg, 2005). Among these studies, different warm-ups that were assessed did not affect the performance in the resistance training exercises, strength, number of repetitions, fatigue index, or effort and also suggest there is no performance advantage when explosive upper-body movement is preceded by resistance exercise of varying loads.

Otherwise, Alves et al., (2019), Abad et. al. (2011), and Wilcox et al. (2006) showed statistically significant differences when the control group was compared with the experimental groups (general or specific warm-up), suggesting that a warm-up with high external loads (> 70% 1RM) or post-activation potentiation (PAP) may produce higher force production in the upper and lower limbs and potentially increase long-term results. The findings suggested that an acute bout of low-volume and explosive-force body movements performed with 1–5 repetitions at 80–90% before a lRM attempt might enhance strength performance (Alves et al., 2019).

Risk of Bias in the Included Articles

In general, it was possible to notice the lack of information about the risk of bias in several key criteria in many articles. A high percentage of unclear risk of bias was found in the following key criteria: allocation concealment (91%); blinding of participants and personnel (100%); and blinding of outcome assessment (100%). Moreover, 9% of the studies revealed a high risk of bias in the random sequence generation and the allocation concealment. The remaining key criteria (incomplete outcome, selective reporting, and other bias) obtained 100% of low risk of bias. (Figure 2 and Figure 3).

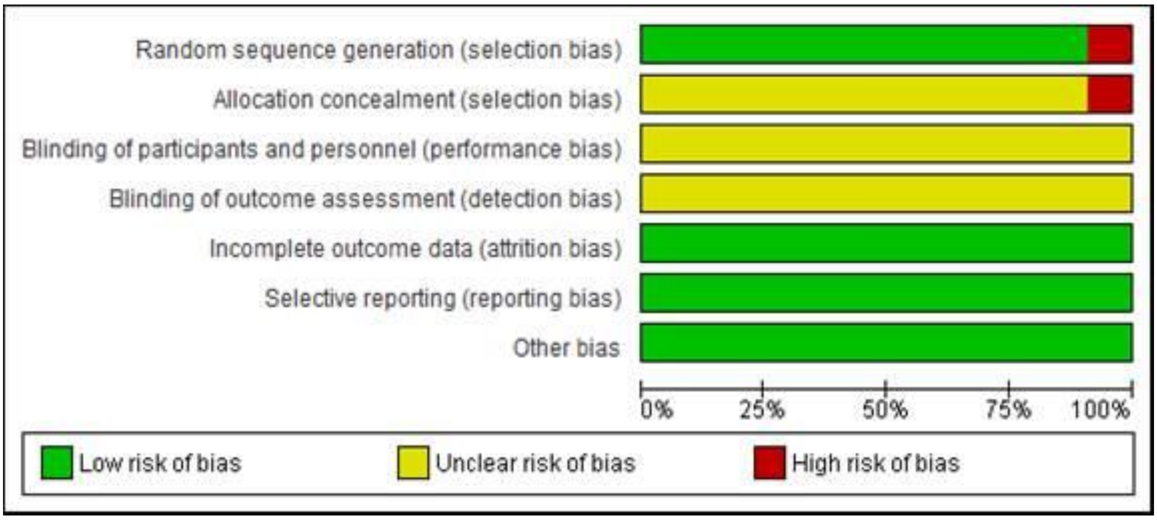

Figure 2 - Risk-of-bias item presented as percentages across all included studies.

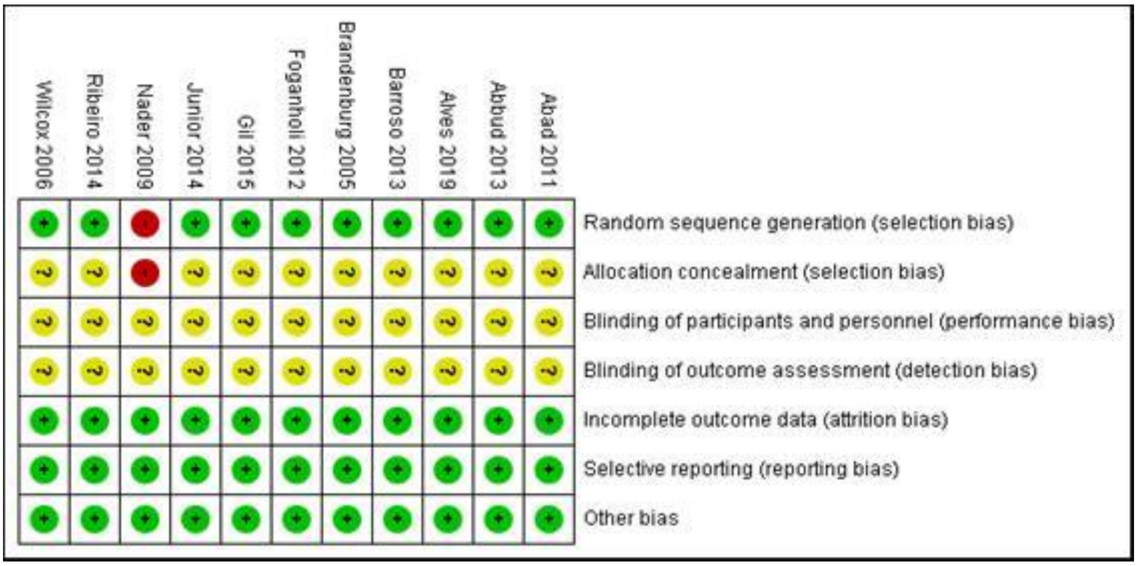

Figure 3 - Judgments about each risk-of-bias item for each included study. + indicates low risk, ? indicates unclear risk, – indicates high risk.

Discussion

The current review aimed to summarize the scientific findings of the use of different warm-ups in resistance exercises, and then further understand the influence of general and specific warm-ups. The selected studies were recent, with a clear increased interest in this thematic after 2005. This increase could be explained by the greater interest of athletes and coaches. Their belief that warm-up is essential to maximize performance, inspired researchers to deepen the knowledge about warm-up effects and recommended activities (McGowan, et al., 2015).

Warm-up before training or competition still is one of the most interesting topics in the sports research area in the last years (Alves et al., 2019). It can be stated that high-level athletes presented an individual adaptation to each warm-up design, special in different sports like cycling, running, or vertical jump (Abad et al., 2011; Ribeiro et al., 2014; Gil et al., 2015). Increased muscle and core body temperature is the major contributing factor to influence performance (Nader et al., 2009; Barroso et al., 2013) thus, the active warm-up is the most preferred method with better physiologic increases in post-activation (Gil et al., 2019; Alves et al., 2019). Moreover, the combination of different variables and their relationship and the lack of a standard warm-up difficult the analysis of the results and the definition of the better method strategy. Regarding resistance exercise performance, we verified that different strategies were used to improve maximal strength performance (Wilcox et al., 2006; Abad et al., 2011; Foganholi et al., 2012; Gil et al., 2015). The key role of warm-up in strength performance is an asset to optimize training for all technical and research community.

Scientific research showed ambiguous results according to the warm-up procedures, in resistance exercise performance. Therefore, it is relevant to examine the effects of general and/or specific warm-up in strength exercises. In the present review, the different warm-ups evaluated showed some differences between studies. Some of them reported the benefits of general or specific warm-up when compared to no warm-up condition (Alves et al., 2019, Abad et. al., 2011; Wilcox et al., 2006). Between different conditions of warm-up, it seems that the resistance training was not influenced or affected by the type of warm-up (Junior et. al, 2014; Foganholi et al., 2012; Abbud, et al., 2013, Ribeiro, et al., 2014; Gil et. al., 2015; Nader, et al., 2009; Barroso et al., 2013; Brandenburg, 2005). The maximum number of repetitions at 70% 1RM after a session with and without warm-up did not show differences. The responses of the number of repetitions to a single set in the exercise of the upper limbs were not affected by the previous warm-up (Abbud, et al. 2013).

The warm-ups usually named post-activation potentiation protocols increased performance, by increasing the total number of repetitions and total work performed during bench press resistant training (Alves et al., 2019). It was found that the participants improved, with a warm-up with external loads, close to the maximum/or high loads. This effect appears to be a performance enhancer of the following exercise. Nevertheless, caution should exist regarding the interval between warm-up and main exercise It should understand how much rest is needed to benefit from this optimization without impairment caused by fatigue from the previous stimulus. The studies included in the current review did not focus on this issue, but we should highlight that the main improvements were found with resting times between 3 and 10 min. This time interval was already recommended to be used after a post-activation potentiation stimulus in other activities (Wilson et al., 2013). Moreover, the load used during warm-up should not cause too much fatigue and compromise the subsequent performance, such as exemplified in other sports (Gil, et al., 2019). So, an effective strategy to improve strength performance seems to be a near-maximal stimulation before the resistance exercise performance. For instance, it showed to contribute to a greater number of repetitions in strength exercise without fatigue compared to the treadmill and bicycle warm-up exercise (Ribeiro, et al. 2014, Gil, et al., 2015). Maybe the increase of the activation of the precursors the phosphorylation of the actin-myosin light chains and the greater excitability of the motoneurons during near-maximum strength warm-up led to better performances (Gil, et al., 2019). These could be the mechanisms of improvement explaining other stimulations of warm-up. According to Wilcox et al. (2006) and Abad et al. (2011), low-volume explosive movements as a plyometric push-up or medicine ball chest before a 1RM attempt may enhance bench-press performance in athletic men.

Nader, et al. (2009) and Foganholi, et al. (2012) analyzed different warm-ups strategies (aerobic versus horizontal bench press exercise) and found no differences in 1RM bench press assessment and perception of effort during evaluations. This might indicate that specific warm-up or general warm-up result in the same bench press maximal performance. In the other hand, it seems that long-duration and low-intensity general warm-up could be appropriated to improve 1RM performance in leg-press (Barroso, et al., 2013; Junior, et al. 2014). This could highlight the need for different warm-ups, according to each different resistance exercise.

Specific warm-up seems to improve the performance when applied before the exercises (Brandenburg, 2005) comparing to no warm-up. Nevertheless, the use of different submaximal loads during the specific warm-up did not reveal different results. Explosive upper-body performance preceded by a specific warm-up with different intensities, 100%, 75%, or 50% of 5RM loads, did not differently affect the athletic performance before a single explosive movement in the upper limbs (Brandenburg, 2005). Still, further studies are required to better understand the influence of different loads during specific resistance exercise warm-up.

According to the present review, general warm-up followed by a specific warm-up performed with low volume might enhance strength performance, with optimized 1RM values. It seems that performing high-force, low-velocity movements, or low-force, high-velocity movements during the warm-up period is the better strategy for resistance exercises. Our findings suggest that explosive exercises significantly increase maximal muscle strength. Literature suggests that this happens because of enhanced neural stimulation and improved the excitability of the fast-twitch units, which are known to play a significant role in maximal strength performance (for detail, Alves et al., 2019). Moreover, if the temperature conditions vary, a general warm-up before specific warm-up could induce significant neuromuscular adjustments that increased muscle force production capacity during dynamic tasks (Abad et al., 2011)

It must be emphasized that researchers have started to study the effects of warm-up on strength performance, but numerous doubts remain about the better warm-up design that should be used to optimize resistance exercise performance. The present results suggested that the number of repetitions, the specific exercises, and intensities of warm-ups for upper and lower limbs can influence the results. However, further studies should be developed to understand the influence of the recovery period between warm-up and the main resistance exercise. Among the literature, some limitations should be addressed. Most of the studies used a small number of participants and the methodological procedures were not clear. Moreover, more variables should be analyzed to better understand the effects of warm-up, such as velocity, power, work, technical aspects, and metabolic responses. Most of the studies only analyzed maximal values of strength and/or the number of repetitions performed in a specific resistance exercise. Researchers should include more exercises, analyze training sets and entire training sessions to further improve the knowledge on the warm-up issue. Methodological procedures should be improved. For instance, the non-existence of a control group contributes to the difficulty of comparing such studies. We verified that there are no longitudinal studies, which evaluate the changes over time caused by the warm-up in strength development.

Conclusion

The interest in the effect of warm-up in resistance exercise performance has increased in the last few years. Specific warm-up showed effects that did not differ from a general warm-up, which highlights that specific warm-up seems to provide the changes that are needed to prepare the athlete for the upcoming resistance effort. The studies have shown that this warm-up should be performed with high external loads and few repetitions, or with low loads and high velocity of movement in order to create a post-activation potentiation effect. This potentiation seems to be beneficial to optimize the performance of 1RM, increase the number of maximal repetitions, and increased total work in resistance exercising with external loads. It is expectable that these acute effects would result in increased muscular performance over long-term periods, but further investigation is needed. These recent trends could be useful tools for coaches and athletes as training strategies to optimize training results and thus to maximize performance.

Chapter 3. Experimental Studies

Study 2

Specific warm-up enhances movement velocity during bench press and squat resistance training.

Abstract

Warm-up is commonly used to optimize physical performance but literature still scarce about the effect during resistance training. The purpose of this study was to investigate the effect of specific warm-up on squat and bench press resistance training. Thirty-four resistance-trained males (23.53±2.35 years) participated in the current study. Among these, 12 were evaluated in the squat and 22 in the bench press. After determining the maximal strength load (1RM), each participant performed a training set (3x6 repetitions) with 80% 1RM (training load) after completing a specific warm-up and without warming up, in random order. The warm-up comprised 2x6 repetitions with 40% and 80% of the training load, respectively. Mean propulsive velocity, velocity loss, peak velocity, mechanical power, work, heart rate and ratings of perceived exertion were assessed. The results showed that after the warm-up, the participants were able to perform the squat and bench press at a higher mean propulsive velocity in the first set (squat:0.68 ± 0.05 vs. 0.64 ± 0.06 m.s^{-1}, p = 0.009, ES = 0.91; bench press:0.52 ± 0.06 vs. 0.47 ± 0.08 m.s-1, p = 0.02, ES = 0.56). The warm-up positively influenced the peak velocity (1.32 ± 0.12 vs. 1.20 ± 0.11 m.s^{-1}, p = 0.001, ES = 1.23) and the time to reach peak velocity (593.75 ± 117.01 vs. 653.58 ± 156.53 ms, p = 0.009, ES=0.91) during the squat set. The specific warm-up seems to optimize muscle force production by enabling a higher movement velocity during the first training repetitions and to allow greater peak velocities in less time.

Key words: Power; Pre-exercise; Strength; Velocity; Work

Introduction

Warming-up before physical exercise is usually recommended in all sports and physical activities (McGowan et al., 2015; Silva et al., 2018). It has been suggested it affects performance through several mechanisms, such as increased motor neuron excitability, reduced muscle stiffness, increased metabolic efficiency, allowing easier and more efficient movement (Bishop, 2003a; Bishop, 2003b; McGowan et al., 2015). The research increased in the last few years and supported the positive effects of warm-ups in individual and team sports and in specific activities such as sprinting and jumping (Silva et al., 2018; Gourgoulis et al., 2003; Pojskić et al., 2015). Still, little is known about the effect of warming-up in strength-specific activities, such as resistance training performance (McGowan et al., 2015).

Muscular performance at maximal or submaximal efforts can be considered essential to succeed in each exercise performance (Kraemer and Ratamess, 2004; Suchomel et al., 2016). Enhancing strength performance and optimizing resistance training should be a priority for athletes and sports scientists. Therefore, warm-ups could be fundamental for this performance optimization. Usually, before any resistance training set, the preparatory activities included a general warm-up, brief period of submaximal aerobic activity such as running or cycling, followed by specific warm-up exercises, such as the main activity (McGowan et al., 2015; Gil et al., 2019). However, several studies verified that including a general component followed by a specific warm-up brings no extra benefits (Gallo and Mello, 2017; Ribeiro et al., 2014; Wilcox et al., 2006).

Although there is a trend toward the positive influence of using only the specific warm-up (Wilcox et al., 2006; Junior et al., 2014; Ribeiro et al., 2020), some contradictory findings still exist. Wilcox et al. (2006) found improved one-repetition maximum (1RM) performance in bench-press after plyometric push-ups and medicine-ball chest throws compared to a general warm-up comprising 5 min of low-intensity stationary cycling at low intensity and upper body static stretches. Moreover, when specific warm-ups were performed at loads close to maximum, results demonstrated that the ability to produce strength could be positively affected (Junior et al., 2014, Ribeiro et al., 2020). On the contrary, others found no significant effects between specific warm-up compared to no warm-up in maximal dynamic strength performance (Abad et al., 2011) and causing fatigue in submaximal resistance training repetition performance (Ribeiro et al., 2014). Research has tried to elucidate the effects of warm-ups on strength through 1RM performance and the number of repetitions until failure (Ribeiro et al., 2014; Wilcox et al., 2006; Abad et al., 2011). This disregarded the daily variation of 1RM performance and other confounding factors, such as a progressive increase of loads during 1RM assessment. This aspect, together with the fatigue caused by 1RM protocol, can compromise the influence of previous warm-up activities and affect the outcomes. These facts probably contributed to contradictory findings regarding the effect of specific warm-up.

The load-velocity relationship has emerged as a method for objectively monitoring resistance training and dynamic strength performance (González-Badillo et al., 2011; González-Badillo and Sánchez-Medina, 2010; Jovanović and Flanagan, 2014). The evaluation of the resistance performance through mechanical variables such as the velocity of movement, a variable that is more constant and reliable, and that can be tested in a real resistance training set with submaximal external loads (González-Badillo et al., 2011; González-Badillo and Sánchez-Medina, 2010), would allow overcoming some issues found by previous research in this topic. Therefore, the purpose of this study was to analyze the effects of a specific warm-up on bench press and squat exercises. The primary outcomes were the mechanical responses during a typical training set (propulsive velocity, mechanical power, and work). The secondary outcomes included physiological (heart rates) and psychophysiological (ratings of perceived exertion: RPE) responses to a training session. It was hypothesized that a specific warm-up would optimize resistance training by increasing propulsive velocity and mechanical power produced in bench press and squat exercises.

Methods

Study Design

A crossover research design was used to analyze the effects of warming-up on mechanical responses, mean propulsive velocity (MPV) and propulsive mechanical power (MPP), physiological (heart rate) and psychophysiological variables (ratings of perceived exertion: RPE). The first session was used for body composition assessment and familiarization with testing protocols. Body mass and height (Seca Instruments, Ltd, Hamburg, Germany) were measured and then each participant carried out some practice sets with light loads (only barbell load) in bench press or squat, while the researcher emphasized the proper technique. The second session was used to determine the individual load-velocity relationships and to establish the maximal dynamic load (1RM) of each participant in squat or bench press exercise. The third and fourth sessions were used to evaluate performance during a resistance training session with or without warming up. This resistance training was performed randomly after warming-up or without warming-up, ensuring a rest greater than 48 hours between conditions.

All sessions were performed using a Smith machine (Multipower Fitness Line, Peroga, Murcia, Spain). The bar velocity was measured by using a linear transducer sampling at 1000 Hz (T-Force System, Ergotech, Murcia, Spain) connected to a 16-bit analog to digital converter (Biopac MP100 Systems, Santa Barbara, CA, USA). The T-force System was interfaced with a personal computer to automatically calculate the relevant kinematic variables parameters for every repetition (González-Badillo et al., 2011; Sánchez-Medina and González-Badillo, 2011).

Subjects

Thirty-four men aged 19-29 years volunteered to participate in the current study. Among these, 12 (23.58 ± 2.78 years; 1.76 ± 0.08m height; 77.50 ± 11.23 kg body mass) were evaluated in the squat exercise and 22 (23.50 ± 2.15 years, 1.76 ± 0.06m height, 77.23 ± 8.93 kg body mass) in the bench-press exercise. The subjects were physically active, engaged in physical activity regularly with experience in resistance training in the previous two years. All participants were asked to report any previous illness, injury, or other physical issues that would hinder their performance. The eligibility criteria were being injury-free, aged between 18 and 35 years old and having previous experience with the back squat and bench press exercise. The exclusion criteria was the evidence of an orthopaedic or medical problem or another self-reported issue that would endanger their health. The participants were informed about the study procedures and a written informed consent was signed. The investigation was conducted in accordance with the Declaration of Helsinki and approved by the University Research Ethics Committee.

Isoinertial Strength Assessment

In the squat exercise, each subject started from the upright position with the knees and hips fully extended, stance approximately shoulder-width apart and the barbell resting across the back at the level of the acromion. The eccentric phase was performed in a continuous motion until the top of the thighs was below 90º and the concentric phase was made at the maximum velocity to initial position (Sánchez-Medina and González-Badillo, 2011; Sánchez-Medina et al., 2017). Trained spotters were present on both sides of the barbell when high loads were lifted to ensure safety.

In the bench press exercise, each participant lay in supine position on a flat bench, with their feet resting on the floor and the hands placed slightly wider than shoulder-width on the barbell. They were instructed to lower the bar to the chest just above the nipples in a controlled way and, after approximately 1.0 seconds of pause, to start the concentric phase of the movement as fast as possible. The momentary pause at the chest between the eccentric and concentric actions occured to minimize the contribution of the rebound effect and allow for more reproducible, consistent measurements (Pallarés et al., 2014). The subjects were not allowed to bounce the bar off their chest nor to raise their shoulders or trunk off the bench (Sánchez-Medina and González-Badillo, 2011).

The initial load was set at 20 and 30 kg for all participants in the bench press and squat exercises, respectively, and was gradually increased by 10 kg increments. The test ended for each participant when they attained concentric MPV of 0.4 ms-1 in the bench press and 0.6 ms-1 in the squat, correspondent to 85% 1RM in both (González-Badillo and Sánchez-Medina, 2010; Sánchez-Medina et al., 2017). Inter-set recoveries ranged from 3 minutes (light) to 5 minutes (heavy loads). The 1RM was calculated from the MPV attained during the progressive loading test as follows: (100 x load)/(-5.961 x MPV^2) - (50.71 x MPV) + 117 for the squat (Sánchez-Medina et al., 2017), and (100 x load)/(8.4326 x MPV^2) - (73.501 x MPV) + 112.33 for the bench press exercise (González-Badillo and Sánchez-Medina, 2010).

Resistance Training Assessment

The warm-up condition comprised six repetitions with 40% of the training load followed by six repetitions with 80% of the training load (1 min interval). In the control condition (no warm-up), the subjects were required to remain seated for 5 min before the resistance training performance. The resistance training session consisted of three sets of six repetitions with 80% 1RM load, with 3 min of inter-set recovery. These sets and loads were chosen because of their common use in resistance training in different competitive sports, and their effects on muscular development and performance improvement (Kraemer and Ratamess, 2004; Adams, 2002; Sousa et al., 2018). All the participants reported no fatigue at the start of each session. If there was some fatigue, they would be dismissed and evaluated the following day.

The subjects were required to always execute the concentric phase at the maximal intended velocity. All velocity measures corresponded to the propulsive phase of each repetition (González-Badillo et al., 2011; González-Badillo and Sánchez-Medina, 2010). For the analysis, it was considered the best MPV (mean velocity value from the start of the concentric phase until the acceleration of the bar is lower than gravity) over each set, the relative magnitude of MPV loss (VL) within the set and within the training (calculated as the percent loss in MPV from the fastest to the slowest repetition) (Sánchez-Medina and González-Badillo, 2011), the peak velocity (PV: maximum instantaneous velocity value reached during the concentric phase at a given load) (García-Ramos et al., 2018), and the time to achieve PV in each repetition. Moreover, considering the propulsive velocity and the load, other mechanical variables were analyzed from the software output, such as the maximal value of MPP in each set, the minimal MPP value (MPPmin), the work produced in each set and the entire training (total).

Physiological and Psychophysiological Variables

Heart rate values were assessed at rest (baseline), 1 min after the warm-up and immediately after training (1 min). Additionally, the rating of perceived exertion (RPE) values were recorded using a 16-points Borg scale (6-20 rates) (Borg, 1998) immediately after the warm-up and following the resistance training.

Statistical Analysis

Standard statistical procedures were selected to calculate means, standard deviations (SDs), and 95% confidence intervals. The normality of all distributions was verified with the Shapiro–Wilk test, and the parametric statistical analysis was adopted. To compare the two trials, the Student's paired t-tests were used and the level of statistical significance was set at $p \leq 0.05$. The Cohen's d (effect size: ES) for within-subjects' comparisons was calculated, and magnitude values were considered small (0.20), moderate (0.60), large (1.20) and very large (2.00) (Hopkins et al., 2009). The statistical treatment was performed using the Statistical Package for Social Sciences (IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY: IBM Corp).

Results

The mean values, differences, and ES for MPV, PV, VL and time to PV in the first set, second set, third set, and total squat training are reported in Table 1. The participants were able to perform the squat exercise at higher MPV in the first set after the warm-up. Moreover, the PV and time to reach PV in the first set were also higher when the warm-up was completed before the squat resistance training. Curiously, the VL in the third training set was moderately higher when the warm-up was performed. Despite there being no differences between conditions in velocity and time-related variables in the remaining sets, in Figure 1 it can be observed a tendency for higher MPV values in all repetitions after the warm-up.

Table 1 - Mean values ± standard deviations for velocity and time-related variables in each set or training (total) in squat. Differences and *p*-values are also presented.

	No warm-up	Warm-up	Difference (± 95% CI)	*p*- value	ES
MPV [set 1] ($m.s^{-1}$)	0.64 ± 0.06	0.68 ± 0.05	0.04 (± 0.03)	0.009**	0.91
MPV [set 2] ($m.s^{-1}$)	0.67 ± 0.07	0.67 ± 0.07	0.01 (± 0.02)	0.52	0.19
MPV [set 3] ($m.s^{-1}$)	0.64 ± 0.07	0.66 ± 0.08	0.02 (± 0.03)	0.20	0.40
MPVmin [set 1] ($m.s^{1}$)	0.55 ± 0.07	0.56 ± 0.09	0.01 (± 0.04)	0.54	0.18
MPVmin [set 2] ($m.s^{1}$)	0.55 ± 0.08	0.57 ± 0.09	0.01 (± 0.03)	0.39	0.26
MPVmin [set 3] ($m.s^{1}$)	0.54 ± 0.07	0.53 ± 0.09	-0.01 (± 0.05)	0.60	0.16
PV [total] ($m.s^{-1}$)	1.20 ± 0.11	1.32 ± 0.12	0.12 (± 0.06)	0.001**	1.23
Time to PV [set1](ms)	653.58 ± 156.53	593.75 ± 117.01	-59.83 (± 41.70)	0.009**	0.91
Time to PV [set2](ms)	615.17 ± 139.4	608.42 ± 118.55	-6.75 (± 47.63)	0.76	0.09
Time to PV [set3](ms)	631.17 ± 155.25	608.92 ± 123.89	-22.25 (± 49.01)	0.34	0.29
VL [set 1] (%)	14.41 ± 3.91	17.57 ± 9.77	3.17 (± 6.12)	0.28	0.33
VL [set 2] (%)	17.15 ± 5.30	16.61 ± 5.93	-0.55 (± 4.22)	0.78	0.08
VL [set 3] (%)	15.60 ± 5.30	19.94 ± 7.34	4.34 (± 4.47)	0.06	0.62
VL [total] (%)	23.00 ± 3.44	26.47 ± 9.24	3.47 (± 5.19)	0.16	0.43

MPV, mean propulsive velocity; MPVmin, minimal mean propulsive velocity; PV, peak velocity; Time to PV, time to peak velocity; VL, velocity loss; 95%CI, confidence intervals; ES, effect sizes. Statistically significant differences ** $p \leq 0.01$.

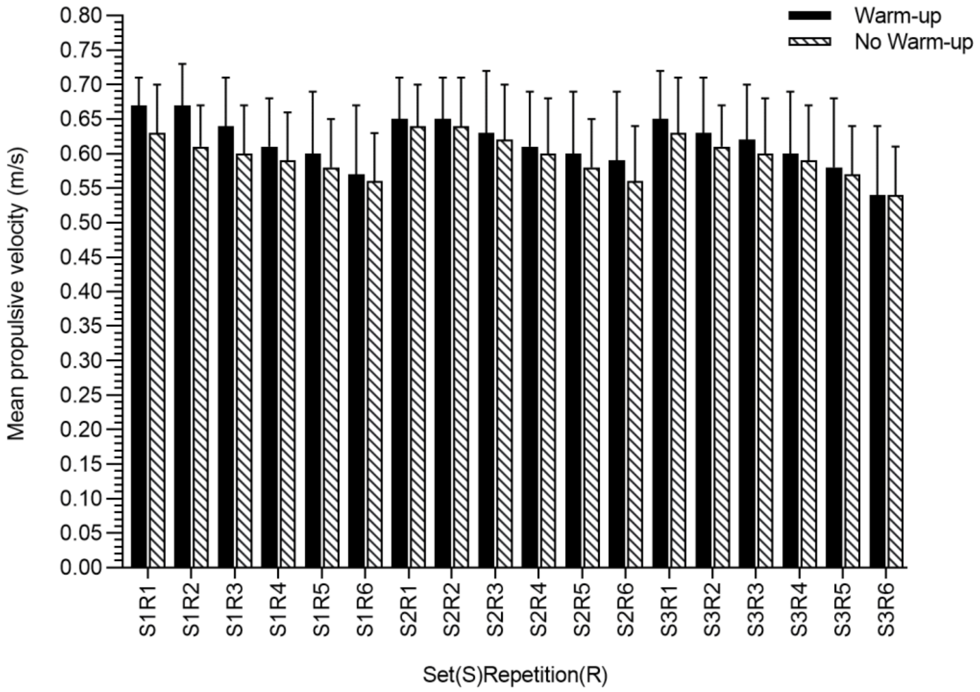

Figure 1 - Mean propulsive velocity values in each repetition performed during the squat exercise, after warm-up or no warm-up.

Table 2 presents the results recorded regarding the mechanical power and work produced during the squat performance. No differences were found in these variables between doing and not doing the warm-up before squat resistance training.

Table 2 - Mean values ± standard deviations for power and work developed in each set and total training of squat. Differences and *p*-values are also presented.

	No warm-up	Warm-up	Difference (± 95% CI)	*p*-value	ES
MPP [set 1] (W)	492.48 ± 77.31	521.25 ± 106.85	28.77 (± 31.52)	0.07	0.58
MPP [set 2] (W)	505.22 ± 87.92	514.57 ± 94.76	9.37 (± 20.15)	0.33	0.29
MPP [set 3] (W)	488.75 ± 102.61	498.01 ± 94.77	9.26 (± 31.58)	0.53	0.19
MPPmin[set 1](W)	416.95 ± 76.72	425.40 ± 89.28	8.45 (± 35.93)	0.62	0.15
MPPmin[set 2](W)	411.43 ± 70.49	421.79 ± 84.62	10.34 (± 24.51)	0.37	0.27
MPPmin[set 3](W)	409.29 ± 100.19	397.68 ± 94.39	-11.61 (± 44.08)	0.57	0.17
Work [set 1] (j)	2338.85 ± 552.93	2394.62 ± 559.22	55.77 (± 126.29)	0.35	0.28
Work [set 2] (j)	2356.21 ± 540.60	2381.62 ± 506.41	25.41 (± 147.63)	0.71	0.11
Work [set 3] (j)	2321.40 ± 584.77	2360.48 ± 511.27	39.08 (± 141.42)	0.56	0.18
Work [total] (j)	7016.46 ± 1666.28	7136.71 ± 570.68	120.25 (± 394.78)	0.52	0.19

MPP, mean propulsive power; MPPmin, minimal mean propulsive power; 95%CI, confidence intervals; ES, effect sizes.

When analyzing the velocity and time-related variables in bench press exercise (Table 3), it can be found that the participants were faster in the first set after warming-up (MPV). However, no other variable was found to be highly influenced by warm-up performance.

Table 3 - Mean values ± standard deviations for velocity and time-related variables in each set or training (total) in bench press. Differences and *p*-values are also presented.

	No warm-up	Warm-up	Difference (± 95% CI)	*p*-value	ES
MPV [set 1] ($m.s^{-1}$)	0.47 ± 0.08	0.52 ± 0.06	0.05 (± 0.04)	0.02*	0.56
MPV [set 2] ($m.s^{-1}$)	0.48 ± 0.08	0.48 ± 0.09	0.01 (± 0.05)	0.82	0.05
MPV [set 3] ($m.s^{-1}$)	0.48 ± 0.07	0.49 ± 0.07	0.01 (± 0.04)	0.56	0.13
MPVmin [set 1] ($m.s^{1}$)	0.34 ± 0.09	0.37 ± 0.10	0.03 (± 0.06)	0.28	0.23
MPVmin [set 2] ($m.s^{1}$)	0.32 ± 0.08	0.33 ± 0.10	0.00 (± 0.04)	0.76	0.07
MPVmin [set 3] ($m.s^{1}$)	0.32 ± 0.07	0.31 ± 0.10	0.02 (± 0.05)	0.91	0.03
PV ($m.s^{-1}$)	0.80 ± 0.13	0.81 ± 0.11	0.01 (± 0.09)	0.74	0.07
Time to PV [set1](ms)	657.23 ± 283.01	545.86 ± 540.52	-111.36 (± 181.16)	0.22	0.27
Time to PV [set2](ms)	647.68 ± 287.01	545.68 ± 278.91	-102.00 (± 196.37)	0.29	0.23
Time to PV [set3](ms)	639.55 ± 285.38	586.32 ± 270.58	-53.23 (± 172.75)	0.53	0.14
VL [set 1] (%)	28.20 ± 14.16	30.11 ± 13.33	1.92 (± 7.55)	0.60	0.11
VL [set 2] (%)	33.70 ± 12.51	33.38 ± 14.84	-0.32 (± 6.31)	0.92	0.02
VL [set 3] (%)	33.23 ± 13.64	36.40 ± 15.32	3.17 (± 6.62)	0.33	0.21
VL [total] (%)	42.00 ± 12.95	45.00 ± 15.77	3.00 (± 7.01)	0.38	0.19

MPV, mean propulsive velocity; MPVmin, minimal mean propulsive velocity; PV, peak velocity; Time to PV, time to peak velocity; VL, velocity loss; 95%CI, confidence intervals; ES, effect sizes. Statistically significant differences * $p \leq 0.05$.

In Figure 2, it can be verified that each repetition of the first set performed in the bench press was faster after warming-up. Then, in the following repetitions, the no warm-up condition resulted in similar or higher MPV values.

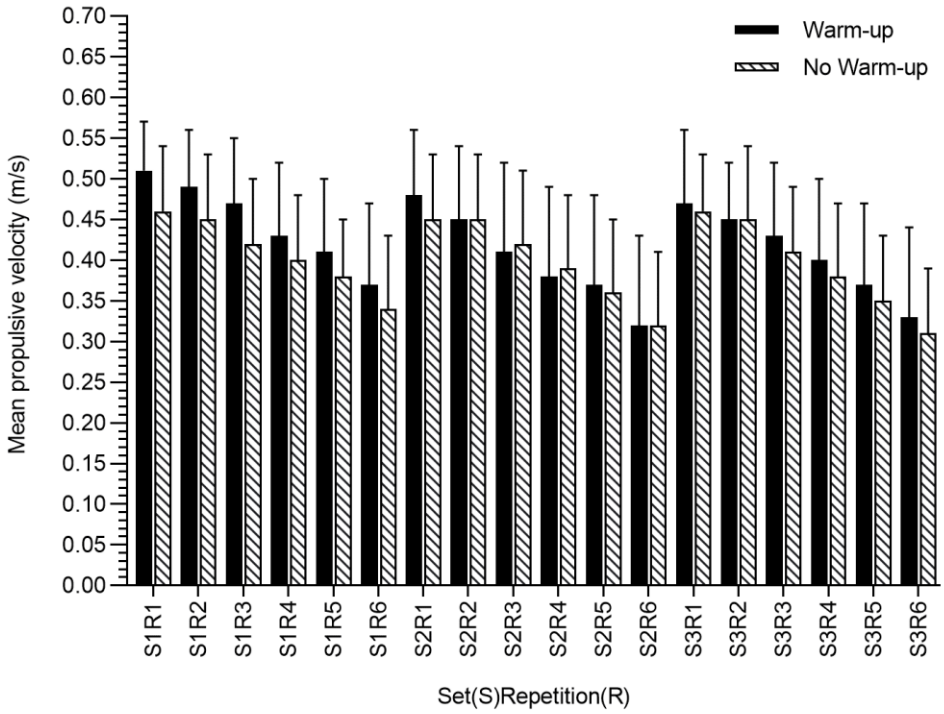

Figure 2 - Mean propulsive velocity values in each repetition performed during the bench press exercise, after warm-up or no warm-up.

As well as the squat exercise, the mechanical power and work produced during the bench press presented no differences between the assessed conditions (Table 4).

Table 4. Mean values ± standard deviations for power and work developed in each set and total training of bench press. Differences and *p*-values are also presented.

	No warm-up	Warm-up	Difference (± 95% CI)	*p*-value	ES
MPP [set 1] (W)	280.73 ± 78.86	330.91 ± 93.95	50.18 (± 55.18)	0.07	0.40
MPP [set 2] (W)	285.73 ± 91.81	311.41 ± 107.10	25.45 (± 63.61)	0.41	0.18
MPP [set 3] (W)	281.95 ± 90.70	312.91 ± 102.20	30.95 (± 60.80)	0.30	0.23
MPPmin[set 1](W)	201.41 ± 78.95	232.95 ± 88.69	31.55 (± 57.30)	0.27	0.24
MPPmin[set 2](W)	186.68 ± 81.73	212.68 ± 101.26	26.00 (± 60.82)	0.38	0.19
MPPmin[set 3](W)	186.23 ± 74.52	197.86 ± 68.30	11.64 (± 44.66)	0.59	0.12
Work [set 1] (j)	1586.36 ± 511.64	1718.77 ± 424.33	132.41 (± 323.22)	0.40	0.18
Work [set 2] (j)	1571.23 ± 488.62	1685.27 ± 433.04	114.05 (± 316.45)	0.46	0.16
Work [set 3] (j)	1587.18 ± 480.92	1671.77 ± 392.52	84.59 (± 306.09)	0.57	0.12
Work [total] (j)	4744.59 ± 1474.24	5075.64 ± 1242.21	331.05 (± 941.82)	0.47	0.16

MPP, mean propulsive power; MPPmin, minimal mean propulsive power; 95%CI, confidence intervals; ES, effect sizes.

The warm-up caused the heart rate to increase in the squat (no warm-up: 78 ± 7bpm vs. warm-up: 139 ± 14bpm, $p < 0.001$, ES = 3.98) and the bench press (77 ± 12bpm vs. 110 ± 15 bpm, $p < 0.001$, ES = 1.81). Immediately after performing the three sets of resistance training, no differences were found in heart rate values in the squat exercise (144 ± 12 bpm vs. 146 ± 12bpm, $p = 0.45$, ES = 0.19) and in the bench press (132 ± 21 bpm vs. 126 ± 20 bpm, $p = 0.13$, ES = 0.28). The perceived effort after the squat training was different between conditions (15.36 ± 1.15 vs. 15.93 ± 1.64, $p = 0.05$, ES = 0.56), while no differences occurred regarding the bench press training (14.17 ± 1.34 vs. 14.55 ± 1.64, $p = 0.27$, ES = 0.21).

Discussion

The main purpose of the current study was to analyze the effects of a specific warm-up on squat and bench press resistance performance. The hypothesis that the propulsive velocity and mechanical power during squat and bench press resistance training would be influenced by performing a specific warm-up was partially confirmed by the current results. The main results revealed that participants were able to attain higher MPV in the first set in bench press and squat exercises, higher PV and lower time to PV in the squat exercise after warming-up. No significant differences were found in the produced power and performed work in each set and the entire training. These results showed that warming up influences the squat and bench press exercise performance during a typical resistance training session, specifically in the first repetitions and in the bar highest movement velocity. Nevertheless, these positive effects seem not to influence resistance training overall, obtaining similar values of total developed work.

It is usually recommended to perform a specific warm-up including exercises that are similar to the main activity, performed with lower but progressive intensities (Gil et al., 2019; Slawinski et al., 2010). The specific warm-up should not only increase body temperature but also facilitate the neuromuscular readiness to perform the following exercise (Bishop, 2003a; Bishop, 2003b; Gil et al., 2019). In fact, previous findings suggested that a specific warm-up is needed to obtain maximal strength performance, such as 1RM or multiple RM (Junior et al., 2014; Abad et al., 2011). However, several controversial results still exist, and some methodological issues could be pointed out (e.g. procedures to determine 1RM and the associated risk) about the efficiency of a specific warm-up in resistance training and strength performance. To the best of our knowledge, this was the first study that investigated the effects of a specific warm-up in one entire typical resistance training rather than maximal dynamic strength performances and analysis of the mechanical responses such as movement velocity.

The participants in this study were able to perform the squat and bench press at higher velocities after performing a specific warm-up with progressive loads. The higher MPV values were recorded in the first set of both exercises after the warm-up. Moreover, in the squat exercise, the PV of the overall training and the time to achieve PV in the first set were the best. This meant that they were able to develop larger forces in a shorter period of time, and this is known to be highly related to improved performance in several sports, specifically jumping, sprinting, cycling and weightlifting performance (Slawinski et al., 2010; McLellan et al., 2011; Stone et al., 2014). Our results corroborate some previous studies that reported improved strength performance after a specific warm-up. An acute bout of low volume, explosive upper body movements during 30 s showed an enhancement in 1RM bench press performance (Wilcox et al., 2006). In agreement, others suggested that a warm-up including submaximal loads resulted in optimized performances during subsequent exercise (Arabatzi et al., 2014; Gołaś et al., 2016). The specific warm-up could provide a post-activation potentiation effect and augment the muscle force-generating capacity (Gil et al., 2019; Hodgson et al., 2005). Thus, a specific warm-up with progressive loads might be responsible for the improvement of type II muscle fiber activity and velocity performance enhancement (Hodgson et al., 2005).

In the squat and bench press exercise, there was a decrease throughout the second and third sets, due to the onset of fatigue. This was more evident when a warm-up was performed. Without a warm-up, there was an increase or at least maintenance of the values of MPV and MPP, and a decrease in the time to achieve PV in the squat and bench press exercises. These outcomes reflected the need for a previous warm-up, providing evidence that after a first resistance set, the participants were able to improve their strength performance and even to eliminate the differences of the warm-up condition. Those values were also confirmed by the moderate effect size obtained in the VL of total training. VL is usually used as an indicator of fatigue, meaning that the higher the speed loss, the greater mechanical, metabolic and hormonal stress (Sánchez-Medina and González-Badillo, 2017). In the current study, it is interesting to note that the VL seemed to be higher when the warm-up was performed. The higher VL during the warm-up can be related to the fact that higher MPV was found in the first set and no differences were found in the minimal value of MPV throughout the resistance training. This was found to be true on the squat, but in the bench press the VL was similar between the assessed conditions. Hence, we found that the best performance obtained after a progressive warm-up resulted in a tendency for greater VL.

Despite there being no significant differences in the mechanical power and work developed throughout the training, the results showed a trend toward higher values after warming-up, in both sets and overall training. Overall, it seems that without warming-up, the participants were not adequately prepared for physical activity, specifically in this resistance training. The resting state of muscle fibers may have hampered the rate of muscle strength development (Tod et al., 2015). The results showed that the movement velocity during the squat and bench press must be stimulated by an external resistance to obtain the greatest benefits and optimize the results. Curiously, the benefits of warming-up were clearer in the squat exercise. This might be due to the higher stimulation that occurred during the warm-up in this exercise and/or because of the exercise different characteristics. This is in accordance with the higher values of perceived exertion in the squat training after warming-up. In the squat exercise, there is a greater amount of involved muscle mass and it is more influenced by the stretch-shortening cycle that takes place when transitioning from the eccentric to the concentric phase of the movement (Sánchez-Medina and González-Badillo, 2011).

Some limitations should be addressed to the current study. The outcomes are limited to the analyzed muscle groups and extrapolation as to other resistance training exercises remains speculative. Also, we should interpret the results knowing that the participants were all healthy young adult males and, although experienced, they were not competitors. Future studies should be developed to further understand different warm-ups (general and/or specific), using the new methods and procedures of measuring resistance and strength performance such as those used in the current study. Even knowing the current study limitations, the current findings are still relevant for coaches and researchers to increase the knowledge about warm-up exercises and its effects on resistance training and strength performance.

Conclusion

In summary, the current study suggests that a specific warm-up with progressive-intensity submaximal loads should be performed before a squat or bench press typical resistance training. The specific warm-up seems to optimize muscle force production by enabling a higher movement velocity during the first repetitions of the training and to attain higher peak velocities in less time. Despite there being a tendency for higher power and work values throughout all the three performed sets, the overall mechanical work and produced power were not different between warm-up and no warm-up, revealing that the effect of the warm-up is lost during training. Muscle strength is very important to support competitive tasks and daily activities. In this sense, the warm-up can determine the success or not of the athlete in achieving his goals. A specific warm-up, performed in the same exercise as the main activity, with progressive intensity (40% followed by 80% of the training load) seems to enhance force production and should be used before a squat or a bench resistance training. These findings could provide new insights for researchers, coaches, sports professionals, and practitioners to improve training efficiency and optimize performance.

Study 3

The role of specific warm-up during bench press and squat exercises: a novel approach.

Abstract

The current study aimed to verify the effects of three specific warm-ups on squat and bench press resistance training. Forty resistance-trained males (19-30 years) performed 3x6 repetitions with 80% of maximal dynamic strength (designated as training load) after one of the following warm-ups (48h between), i) 2x6 repetitions with 40% and 80% of the training load (WU), iii) 6x80% of training load (WU80), or iii) 6x40% of the training load (WU40). Mean propulsive velocity (MPV), velocity loss (VL), peak velocity (PV), time to achieve PV, power, work, heart rates, and ratings of perceived exertion were analysed. In squat, higher MPV were found in WU80 compared with WU40 (2nd set: 0.69 ± 0.09 *vs.* 0.67 ± 0.06 $m.s^{-1}$, $p = 0.02$, ES = 0.80; 3rd set: 0.68 ± 0.09 *vs.* 0.66 ± 0.07 $m.s^{-1}$; $p = 0.05$, ES = 0.51). In bench press, time to PV was lower in the WU compared with WU40 (1st set: 574.77 ± 233.46 *vs.* 694.50±211.71 ms, $p < 0.01$, ES = 0.69; 2nd set: 533.19 ± 272.22 *vs.* 662.31 ± 257.51 ms, $p = 0.04$, ES = 0.43) and total work was higher (4749.90 ± 1312.99 *vs.* 4631.80 ± 1355.01 j, $p = 0.01$, ES = 0.54). The results showed that force outputs were mainly optimized by the WU80 in squat training and by WU in bench press training. Moreover, warming-up with few repetitions and low loads could not be enough to optimize squat and bench press performances.

Key words: Pre-exercise; Strength; Velocity; Power; Work

Introduction

Warm-up has been identified as essential to maximize the athlete's performance in different sports and physical activities (McGowan et al., 2015). The activities performed before the main competition event or training session seemed to increase body temperature and this way causing the athlete to benefit from decreased stiffness, increased nerve conduction rate, and increased metabolic efficiency (Bishop, 2003a; Bishop, 2003b). Based on this, over the years, the benefits of warm-up were taken for granted and it became usual practice, sometimes without enough scientific evidence to support it. Warm-up has shown improved individual (e.g. cycling, running, swimming) and team-sports (football, rugby) (Gourgoulis et al., 2003; Silva et al., 2018) but some contradictory results highlighted that specific warm-up designs (type, intensity, volume) should be further understood. Moreover, few is known regarding the effect of different warm-ups in some other specific activities, such as resistance training (Junior et al., 2014; Alves et al., 2019). Each athlete is used to warm-up before any resistance training, in other to obtain higher performance levels in every single session (Ribeiro et al., 2014; Alves et al., 2019). However, improper use of volume and/or intensity of the tasks during warm-up can compromise the following performance, as shown in other sports (Neiva et al., 2015).

Previous research found an increase of 3% of upper body power during medicine ball throw after specific warm-up in the bench press with the maximal external load that each subject can move properly for 5 repetitions, contrary to higher or lower loads (Evans et al., 2001). The number of repetitions performed until fatigue in bench press and leg extension seemed to be largely influenced by the specific warm-up intensity (Junior et al., 2014). When the specific warm-up was performed at loads close to the maximum (90% of maximal dynamic [1RM] load), the results demonstrated that the ability to produce maximal dynamic strength could be positively affected (Junior et al., 2014). It seems that there is a tendency to use high external loads before power exercises, using the underlying mechanisms resulting from post-activation potentiation, but few are known about the intensities before resistance training sessions (Gil et al., 2019). In fact, the post-activation potentiation has been suggested to optimize maximal strength (Gil et al., 2019; Conrado et al., 2018), but only recently it was applied to multiple resistance training sets (Alves et al., 2019). It was found that adding 3 repetitions performed with 90% 1RM load to a specific warm-up of 8 repetitions with 50% 1RM, caused an increase of work and number of repetitions performed during 3 sets until failure with 75% 1RM in bench press (Alves et al., 2019).

The authors suggested that this acute optimization of training could potentially increase results over the long term.

Strength performance can be improved using a specific warm-up (Junior et al., 2014; Abad et al., 2011); nevertheless, the optimal load to be used remains uncertain. The efficiency of warm-up practices depends on the balance between fatigue onset and muscle potentiation (Kilduff et al., 2008). This balance is provided by several factors such as training experience (Kilduff et al., 2007), the rest period between warm-up sets, and the main activity (Kilduff et al., 2008), volume and intensity performed (Sale, 2002). To our knowledge, the few existing studies on the influence of specific warm-up loads in resistance exercise should be deepened, by analyzing other variables. Most of the studies used the determination of 1RM load or multiple submaximal repetitions as dependent variables, disregarding the daily variation of 1RM performance (Junior et al., 2014; Barroso et al., 2013; Brandenburg, 2005). Furthermore, it is needed a progressive increase of external loads to evaluate 1RM load and this increases the confounding factors, perhaps reducing the effects of prior warm-up and increasing the fatigue effect over the assessment. This compromises any results and do not allow the researchers to better understand the effects of different warm-ups on force and power production. The novelty of the current study would be the evaluation of the resistance exercise performance using mechanical variables such as the velocity of movement, that can be tested in a real resistance training set with submaximal external loads (González-Badillo et al., 2011; González-Badillo & Sánchez-Medina, 2010). Linear position technology has been used to measure velocity, displacement, power, force variables to determine and monitor performance in resistance exercises (González-Badillo et al., 2011; González-Badillo & Sánchez-Medina, 2010; Jovanović & Flanagan, 2014). Therefore, controlling the movement velocity at which a given resistance exercise is executed is critical to ensure that training is as effective as possible and will allow a reliable analysis of the effect of previous warm-up procedures.

Knowing the importance of warm-up for strength optimization and the need to avoid the effects of muscle fatigue, it is important to observe the effects and the influence of using different specific warm-up designs to increase the efficiency of resistance training exercises performance. For instance, during resistance training, an appropriate warm-up would increase force development against the same training external load, improving the training efficiency, training intensity, and therefore, long-term adaptations to develop higher force values and/or higher velocities (González-Badillo et al., 2011; Pareja-Blanco et al., 2017). Therefore, the purpose of this study was to analyze the effects of different specific warm-ups on bench press and squat exercises, evaluating mechanical responses (propulsive velocity and mechanical power), physiological (heart rate), and psychophysiological (ratings of perceived exertion: RPE) variables during a typical resistance training set. It was hypothesized that a specific warm-up with increasing intensities would optimize resistance training, by increasing propulsive velocity and mechanical power produced in bench press and squat exercises.

Materials and Methods

Experimental Approach to the Problem

The current study tried to further understand the importance of warm-up intensities for resistance training exercises performance, and then to realize the optimal warm-up load that should be used pre-training. The effects of warm-up load in resistance training performance were evaluated by analyzing the bar movement velocity using a recent validated device (González-Badillo & Sánchez-Medina, 2010; González-Badillo et al., 2017; Sánchez-Medina et al., 2017). Knowing that by increasing the movement velocity against a load will result in greater performance, this will probably influence the acute and long-term training effects (González-Badillo et al., 2011; Jovanović & Flanagan, 2014; González-Badillo et al., 2017). One of the novelties of the current study is the assessment of the resistance performance using mechanical variables such as the velocity of the movement, which could be the best reference to measure the real effort by the athlete with submaximal external loads (González-Badillo et al., 2011; González-Badillo et al., 2010).

A crossover research design was used to analyze the effects of warm-up on mechanical responses, mean propulsive velocity (MPV) and propulsive mechanical power (MPP), physiological (heart rate) and psychophysiological variables (ratings of perceived exertion: RPE). After the adaptation session, four evaluation sessions were performed on four different days (48hours between). The first evaluation was to determine the 1RM load of each participant in squat or bench press exercise. Then, each participant performed a resistance training (3 sets of 6 repetitions at 80%1RM loads) in the following three sessions. These resistance exercises were chosen because of their relevance in resistance training, and thus commonly used by conditioning specialists and coaches for sports training. Moreover, the intensity of 80% 1RM is widely used in traditional resistance training and it is in the optimal range of relative intensities (30-

80% 1RM) that were suggested to improve long term muscular performance (Garnacho-Castaño et al., 2018; Sánchez-Medina et al., 2014). This resistance training was performed randomly after three different warm-ups: the progressive-intensity (WU) included 2sets of 6 repetitions with 40% and 80% of the training load; the warm-up that included 1 set of 6 repetitions 80% of training load (WU80) and the other that included 1 set of 6 repetitions 40% of training load (WU40).

Subjects

Forty men aged 19-30 years old volunteered to participate in the current study. From these, fourteen (24.43 ± 3.48 years; 1.76 ± 0.71m of height; 77.71 ± 10.35 kg of body mass) were evaluated in squat exercise and twenty-six (22.19 ± 1.67 years, 1.77 ± 0.06m of height, 72.23 ± 8.21 kg of body mass) were assessed in bench-press exercise. Subjects were physically active, engaged in physical activity regularly with an experience of resistance training for the last two years. Everyone was asked to report any previous illness, injury, or other physical issues that would hinder their performance. The eligibility criteria were being healthy and injury-free, aged between 18 and 35 years old, and have previous experience with the back squat and bench press exercises. Criteria of exclusion were the evidence of an orthopedic or medical problem or another self-reported issue that would endanger their health. The participants were informed about the study procedures and written informed consent was signed. The investigation was conducted in accordance with the Declaration of Helsinki and was approved by the University of Beira Interior Research Ethics Committee.

Procedures

The first session was used for body composition evaluation (Seca Instruments, Ltd, Hamburg, Germany) and adaptation with testing conditions where the subjects performed some repetitions with lower loads in bench press or squat, according to some orientations about correct technique. The second session was used to determine the individual load-velocity relationships and estimated 1RM strength in the squat or bench press exercise using a progressive loading test. Then, the last three sessions were used to evaluate performance during a resistance training session with different specific intensities warm-ups. All procedures were performed using a Smith machine (Multipower Fitness Line, Peroga, Murcia, Spain), like other studies (e.g. Pareja-Blanco et al., 2017, Sanchez-Medina & González-Badillo, 2011, Sanchez-Medina et al., 2017). The smith machine allows only a vertical displacement of the barbell along a fixed pathway and a very low friction force between the barbell and the support rails, acting identical to free-weights (Sanchez-Medina & González-Badillo, 2011). Moreover, the bar velocity was measured by using a linear transducer sampling at 1000 Hz (T-Force System, Ergotech, Murcia, Spain) connected to a 16-bit analog to digital converter (Biopac MP100 Systems, Santa Barbara, CA, USA). The T-force System was interfaced with a personal computer to automatically calculate the relevant kinematic variables parameters for every repetition (González-Badillo et al., 2011; González-Badillo & Sanchez-Medina, 2010; Sanchez-Medina & González-Badillo, 2011).

In the squat exercise, each subject started from the upright position with the knees and hips fully extended, stance approximately shoulder-width apart and the barbell resting across the back at the level of the acromion. The eccentric phase was performed in a continuous motion until the top of the thighs was below the horizontal and the concentric phase was made at the maximum velocity to initial position (González-Badillo et al., 2011; Sanchez-Medina & González-Badillo, 2011). Trained spotters were present on both sides of the barbell when high loads were lifted to ensure safety. In the bench press exercise, each participant lay supine on a flat bench, with their feet resting on the floor and hands placed on the barbell slightly wider than shoulder-width. They were instructed to lower the bar to the chest, just above the nipples, in a controlled manner and after approximately 1.0 seconds of pause, they started the concentric phase of the movement as fast as possible. The momentary pause at the chest between the eccentric and concentric actions to minimize the contribution of the rebound effect and allow for more reproducible, consistent measurements (Pallarés et al., 2014). The subjects were not allowed to bounce the bar of their chest or raise the shoulders or trunk off the bench (González-Badillo & Sanchez-Medina, 2010).

To determine individual 1RM load, the initial load was set at 20 and 30 kg for all participants in the bench press and squat exercises, respectively, and was gradually increased by 10 kg increments. The test ended for each participant when the attained concentric MPV of 0.4 ms^{-1} in the bench press and 0.6 ms^{-1} in the squat, correspondent to 85% 1RM in both (González-Badillo & Sanchez-Medina, 2010; Sanchez-Medina & González-Badillo, 2011). Three attempts were executed for light (< 50% 1RM), 2 for medium (50-80% 1RM) and only 1 for the heaviest (> 80% 1RM) loads. Inter-set recoveries were 3 min for the light and medium loads and 5 min for the heaviest loads; (González-Badillo & Sanchez-Medina, 2010; Sanchez-Medina & González-Badillo, 2011). The 1RM was calculated from the MPV attained during the progressive loading test, as follows: $(100 \times load)/(-5.961 \times MPV^2) - (50.71 \times MPV) + 117$ for the squat

(Sanchez-Medina & González-Badillo, 2011), and (100 x load)/(8.4326 x MPV^2) - (73.501 x MPV) + 112.33 for the bench press exercise (González-Badillo & Sanchez-Medina, 2010).

Three different warm-up conditions were randomly implemented. The WU comprised 6 repetitions with 40% of the training load followed by 6 repetitions with 80% of the training load (1min inter-set interval). The warm-up with high intensity included 1 set of 6 repetitions 80% of the training load (WU80) and the warm-up with low intensity comprised 1 set of 6 repetitions 40% of the training load (WU40). The effect of performing warm-up was assessed during a bench press or squat resistance training session, performed 3 min after warm-up. The resistance training consisted of 3 sets of 6 repetitions with 80% 1RM load, with 3min of inter-set recovery. The number of sets and loads intensities were selected because of their common use in resistance training in diverse competitive sports, and their effects on muscular development and performance improvement (Adams, 2002; Kraemer & Ratamess, 2004). During the execution of exercises, there was a continuous orientation to maintain the execution technique. All the subjects reported no fatigue at the start of each session.

All velocity measures identified in this study corresponded to the propulsive phase of each repetition (González-Badillo et al., 2011; González-Badillo & Sanchez-Medina, 2010; González-Badillo et al., 2017). The maximal value and minimum value of MPV (mean velocity value from the start of the concentric phase until the acceleration of the bar is lower than gravity) over each set, the relative magnitude of MPV loss (VL) within the set and within the training (calculated as the percent loss in MPV from the fastest to the slowest repetition) (González-Badillo et al., 2017), the peak velocity (PV: maximum instantaneous velocity value reached during the concentric phase at a given load) (García-Ramos et al., 2018), and the time to achieve PV in each repetition was considered for further analysis. Moreover, considering the propulsive velocity and the load, other mechanical variables were analyzed from the software output, such as the maximal and minimal value of MPP in each set, the work produced in each set, and in the entire training.

The heart rate values were assessed at rest (baseline), 1min after the warm-up and immediately after training (1min). Additionally, the rating of perceived exertion (RPE) values were recorded using a 16-points Borg scale (6-20 rates) (Borg, 1998) immediately after warm-up and after the resistance training.

Statistical Analysis

Standard statistical procedures were selected to calculate means, standard deviations (SDs), and 95% confidence intervals. The normality of all distributions was verified with the Shapiro–Wilk test, and parametric statistical analysis was adopted. The effect of the warm-up procedures was analyzed by an ANOVA for repeated measures, with sphericity checked using Mauchly's test. Posthoc paired t-tests were run to additional investigate the effect of each condition. The effect size was calculated to estimate the variance between conditions (partial eta squared: η_p^2) and Cohen's dz (ES) for within-subjects' comparisons were calculated using the Excel spreadsheet by Lakens (Lakens 2013). For partial eta squared (η_p^2), the cut-off values were interpreted as 0.01 for small, 0.09 for moderate and 0.25 for large and ES values of 0.20, 0.60, 1.20 and 2.00 were considered small, moderate, large, and very large magnitudes, respectively (Hopkins et al., 2009). The statistical treatment was performed using the Statistical Package for Social Sciences (IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY: IBM Corp).

Results

The mean values, differences, and ES for MPV in the first, second, and third sets in the squat exercise are presented in Table 1. There were small effects in MPV in the first set of the resistance training between warm-up conditions (F = 1.31, p = 0.29, η_p^2 = 0.09). However, MPV showed to be moderately affected by warm-up conditions in the second (F = 2.78, p = 0.08, η_p^2 = 0.18) and third sets (F = 2.28, p = 0.12, η_p^2 = 0.15). In these sets, the participants were able to perform the squat exercise at higher MPV values after the WU80, comparing to WU40. The minimal value of MPV in WU40 showed lower values when compared with the other warm-ups during the second set (F = 25.23, p < 0.001, η_p^2 = 0.66). No significant differences were found between conditions in the VL during the first (F = 0.29, p = 7.48, η_p^2 = 0.02), second (F = 2.59, p = 0.09, η_p^2 = 0.17) and third sets (F = 0.51, p = 0.61, η_p^2 = 0.04). Curiously, the values were moderately higher in the WU40 during the second set. In figure 1 it can be observed a tendency for higher MPV values during second and third set after WU80 and the lower values after WU40 during second set.

Table 1 - Mean values ± standard deviation of the maximal value of mean propulsive velocity (MPV), minimal MPV values and velocity loss (VL) in each set and total training (total) in squat. Differences and confidence intervals (95%CI), effect sizes (ES) and *p*-values are also presented.

				WU vs. WU80		WU vs. WU40		WU80 vs. WU40	
	WU	WU80	WU40	Difference (± 95 % CI)	*p* – value (ES)	Difference (± 95 % CI)	*p* - value (ES)	Difference (± 95 % CI)	*p* - value (ES)
MPV [set 1] (m.s⁻¹)	0.71 ± 0.08	0.69 ± 0.07	0.68 ± 0.06	0.02 (± 0.02)	0.10 (0.48)	0.03 (± 0.04)	0.21 (0.40)	0.01 (± 0.03)	0.71 (0.15)
MPV [set 2] (m.s⁻¹)	0.69 ± 0.09	0.71 ± 0.05	0.67 ± 0.06	-0.01 (± 0.04)	0.46 (0.27)	0.02 (± 0.04)	0.15 (0.34)	0.04 (± 0.03)	0.02* (0.80)
MPV [set 3] (m.s⁻¹)	0.68 ± 0.09	0.69 ± 0.07	0.66 ± 0.07	-0.02 (± 0.05)	0.41 (0.13)	0.02 (± 0.01)	0.08 (0.58)	0.03 (± 0.04)	0.05* (0.51)
MPVmin [set 1] (m.s⁻¹)	0.58 ± 0.10	0.58 ± 0.10	0.58 ± 0.08	0.01 (± 0.06)	0.88 (<0.01)	0.01 (± 0.04)	0.79 (<0.01)	0.00 (± 0.05)	0.98 (<0.01)
MPVmin [set 2] (m.s⁻¹)	0.58 ± 0.09	0.59 ± 0.07	0.54 ± 0.11	-0.01 (± 0.05)	0.69 (0.12)	0.04 (± 0.04)	0.01** (0.70)	0.05 (± 0.05)	0.04* (0.60)
MPVmin [set 3] (m.s⁻¹)	0.54 ± 0.09	0.57 ± 0.09	0.55 ± 0.09	-0.03 (± 0.06)	0.31 (0.34)	-0.01 (± 0.04)	0.58 (0.16)	0.02 (± 0.06)	0.62 (0.18)
VL [set 1] (%)	17.56 ± 9.14	16.31 ±10.35	15.11 ± 7.44	1.26 (± 8.47)	0.75 (0.09)	2.45 (± 6.06)	0.40 (0.23)	1.19 (± 5.85)	0.67 (0.12)
VL [set 2] (%)	16.35 ± 5.63	16.32 ± 6.07	20.57 ±10.89	0.03 (± 3.16)	0.99 (0.01)	-4.22 (± 4.75)	0.08 (0.51)	-4.25 (± 5.66)	0.13 (0.43)
VL [set 3] (%)	19.99 ± 7.11	18.44 ± 9.94	16.86 ± 8.57	1.55 (± 6.21)	0.60 (0.14)	3.14 (± 5.45)	0.24 (0.33)	1.59 (± 8.21)	0.68 (0.11)
VL [total] (%)	26.59 ± 8.58	26.83± 10.58	26.09±10.40	-0.24 (± 5.40)	0.93 (0.03)	0.50 (± 5.53)	0.85 (0.05)	0.74 (± 8.33)	0.85 (0.05)

** *p*≤0.01; * *p*≤0.05.

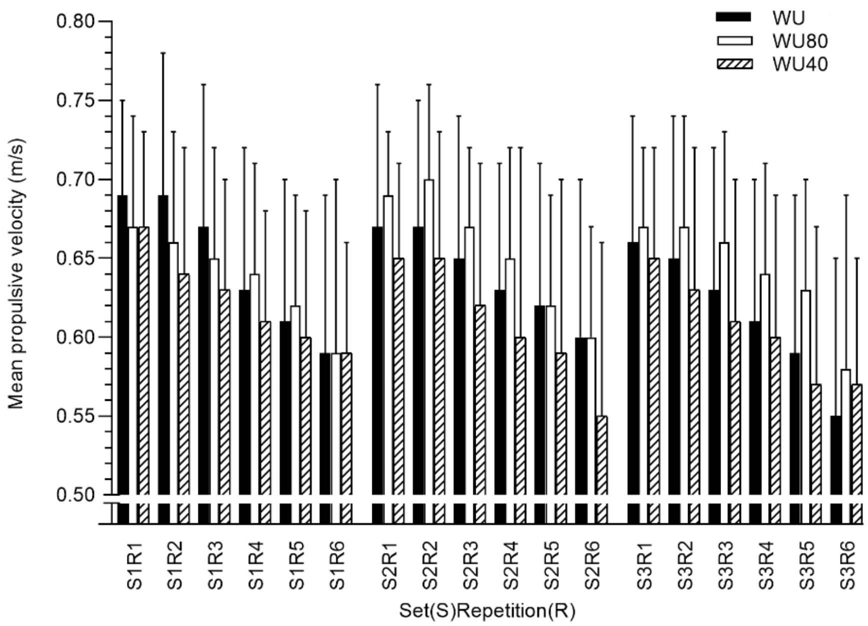

Figure 1 - Mean propulsive velocity values in each repetition performed during the squat exercise, after WU, WU80 and WU40.

The mean values, differences, and ES for PV and time spent to achieve PV in the first, second, and third sets in the squat exercise are presented in Table 2. The participants were able to attain PV in less time in the second set after WU80 when compared to WU40 ($F = 3.09$, $p = 0.06$, $\eta_p^2 = 0.19$).

Table 2 - Mean values ± standard deviation of the peak velocity (PV) and time to reach peak velocity (time to PV) in each set and total training (total) in squat. Differences and confidence intervals (95%CI), effect sizes (ES) and *p*-values are also presented.

				WU vs. WU80		WU vs. WU40		WU80 vs. WU40	
	WU	WU80	WU40	Difference (± 95 % CI)	*p* – value (ES)	Difference (± 95 % CI)	*p* - value (ES)	Difference (± 95 % CI)	*p* - value (ES)
PV [total] ($m.s^{-1}$)	1.33 ± 0.11	1.32 ± 0.07	1.30 ± 0.08	0.01 (± 0.05)	0.76 (0.11)	0.03 (± 0.05)	0.16 (0.38)	0.03 (± 0.04)	0.20 (0.29)
Time to PV [set1](ms)	586.21 ± 109.87	589.93 ±133.11	638.00 ± 163.28	-3.71 (± 60.23)	0.90 (0.04)	-51.79 (± 53.18)	0.06 (0.56)	-48.07 (± 50.85)	0.06 (0.55)
Time to PV [set2](ms)	601.64 ± 110.91	565.86 ±106.87	623.50 ± 136.80	35.79 (± 54.94)	0.18 (0.38)	-21.86 (± 45.19)	0.32 (0.28)	-57.64 (± 51.25)	0.03* (0.65)
Time to PV [set3](ms)	606.93 ± 114.53	582.57 ±129.29	619.36 ± 191.00	24.36 (± 48.06)	0.29 (0.29)	-12.43 (± 69.26)	0.71 (0.10)	-36.79 (± 76.09)	0.32 (0.28)

* $p \leq 0.05$.

Table 3 presents the results of the mechanical power and work produced during the squat performance. Despite no differences were found between conditions in MPP, in the first ($F = 0.81$, $p = 0.46$, $\eta_p^2 = 0.06$), second ($F = 1.73$, $p = 0.20$, $\eta_p^2 = 0.12$) and third set ($F = 2.16$, $p = 0.14$, $\eta_p^2 = 0.14$), moderate effects were found with lower values in WU40 condition. Large effects were found in the minimal values of MPP in the second set ($F = 7.73$, $p = 0.02$, $\eta_p^2 = 0.37$), with higher values recorder in WU80 and progressive compared with WU40. No differences were found in the work produced during the squat resistance training ($F = 0.92$, $p = 0.41$, $\eta_p^2 = 0.07$).

Table 3 - Mean values ± standard deviation of the maximal value of the mean propulsive power (MPP), the minimal value (MPPmin), and work developed in each set and total training (total) in squat. Differences and confidence intervals (95%CI), effect sizes (ES) and *p*-values are also presented.

	WU	WU80	WU40	WU vs. WU80 Difference (± 95 % CI)	p – value (ES)	WU vs. WU40 Difference (± 95 % CI)	p - value (ES)	WU80 vs. WU40 Difference (± 95 % CI)	p - value ES
MPP [set 1] (W)	528.78 ± 107.18	519.29 ± 90.75)	510.86 ± 101.92	9.49 (± 25.06)	0.43 (0.22)	17.92 (± 33.82)	0.27 (0.31)	8.43 (± 31.71)	0.58 (0.15)
MPP [set 2] (W)	521.09 ± 98.87	532.53 ± 102.09)	501.25 ± 83.04	-11.44 (± 41.70)	0.56 (0.16)	19.84 (±3 1.58)	0.20 (0.36)	31.28 (± 36.39)	0.09 (0.50)
MPP [set 3] (W)	501.46 ± 96.06	523.07± 107.75	492.48 ± 91.46	-21.61 (± 42.53)	0.29 (0.29)	8.99 (± 17.00)	0.27 (0.31)	30.59 (± 33.19)	0.07 (0.53)
MPPmin [set1] (W)	430.41 ± 85.19	428.86 ± 99.11	424.17 ± 94.14	1.56 (± 42.27)	0.94 (0.02)	6.24 (± 34.24)	0.70 (0.11)	4.69 (± 33.51)	0.77 (0.08)
MPPmin [set 2] (W)	425.78 ± 82.25	440.29 ± 90.33	391.97 ± 91.33	-14.51 (± 51.24)	0.45 (0.21)	33.81 (± 33.38)	0.02* (0.74)	48.32 (± 54.31)	0.03* (0.65)
MPPmin [set 3] (W)	398.86 ± 88.74	422.53 ± 111.28)	406.07 ± 99.94	-23.66 (± 43.26)	0.29 (0.32)	-7.21 (± 24.25)	0.53 (0.17)	16.46 (± 46.57)	0.46 (0.20)
Work [set 1] (J)	2405.81 ± 532.92	2322.21 ± 493.88	2385.81 ± 549.18	83.59 (± 107.05)	0.12 (0.45)	19.99 (± 159.89)	0.79 (0.07)	-63.60 (± 163.90)	0.42 (0.22)
Work [set 2] (J)	2388.63 ± 488.98	2342.16 ± 506.69	2377.38 ± 490.31	46.47 (± 87.76)	0.27 (0.31)	11.25 (± 96.19)	0.80 (0.07)	-35.22 (± 94.29)	0.43 (0.22)
Work [set 3] (J)	2361.30 ± 502.87	2319.56 ± 504.58	2368.65 ± 493.40	41.74 (± 77.47)	0.27 (0.31)	-7.35 (± 116.55)	0.89 (0.04)	-49.09 (± 133.67)	0.44 (0.21)
Work [total] (J)	7155.73 ± 1517.62	6983.94 ± 1489.85	7131.84 ± 1509.67	171.79 (± 200.29)	0.09 (0.50)	23.89 (± 338.94)	0.88 (0.04)	-147.90 (±328.57)	0.35 (0.26)

* $p \leq 0.05$.

In bench press, no differences were found between conditions in MPV and VL (Table 4 and figure 2). However, there were differences in time to PV in first ($F = 2.44$, $p = 0.10$, $\eta_p^2 = 0.09$) and second set ($F = 3.11$, $p = 0.05$, $\eta_p^2 = 0.11$) after WU warm-up when compared with WU40 (Table 5).

Table 4 - Mean values ± standard deviation of the maximal value of mean propulsive velocity (MPV), minimal MPV value, and velocity loss (VL) in each set or training (total) in bench-press. Differences and confidence intervals (95%CI), effect sizes (ES) and *p*-values are also presented.

	WU	WU80	WU40	WU vs. WU80		WU vs. WU40		WU80 vs. WU40	
				Difference (± 95 % CI)	p – value (ES)	Difference (± 95 % CI)	p - value (ES)	Difference (± 95 % CI)	p - value ES
MPV [set 1] (m.s-1)	0.53 ± 0.07	0.52 ± 0.11	0.50 ± 0.10	0.01 (± 0.05)	0.74 (0.09)	0.02 (± 0.04)	0.15 (0.35)	0.02 (± 0.04)	0.44 (0.19)
MPV [set 2] (m.s-1)	0.48 ±0.09	0.48 ± 0.10	0.48 ±0.08	0.00 (± 0.06)	0.97 (<0.01)	0.00 (± 0.03)	0.98 (<0.01)	0.00 (± 0.04)	0.94 (<0.01)
MPV [set 3] (m.s-1)	0.50 ±0.08	0.47 ± 0.11	0.47 ± 0.10	0.03 (± 0.05)	0.18 (0.26)	0.03 (± 0.03)	0.09 (0.40)	0.00 (± 0.04)	0.89 (<0.01)
MPVmin [set 1] (m.s-1)	0.37 ± 0.11	0.36 ± 0.11	0.36 ± 0.09	0.01 (± 0.06)	0.74 (0.07)	0.01 (± 0.04)	0.73 (0.09)	0.00 (± 0.04)	0.94 (<0.01)
MPVmin [set 2] (m.s-1)	0.33 ± 0.11	0.32 ± 0.13	0.33 ± 0.11	0.01 (± 0.08)	0.85 (0.05)	0.00 (± 0.04)	0.91 (<0.01)	-0.01 (±0.05)	0.70 (0.08)
MPVmin [set 3] (m.s-1)	0.32 ± 0.12	0.31 ± 0.12	0.31 ± 0.11	0.01 (± 0.06)	0.61 (0.07)	0.01 (± 0.05)	0.53 (0.09)	0.00 (±0.05)	0.99 (<0.01)
VL [set 1] (%)	30.65 ± 13.83	30.96 ± 12.23	28.19 ± 9.32	-0.31 (± 6.33)	0.92 (0.02)	2.46 (± 6.74)	0.46 (0.15)	2.77 (± 5.17)	0.28 (0.22)
VL [set 2] (%)	33.42 ± 14.35	35.69 ± 16.73	32.81 ± 13.43	-2.27 (± 9.87)	0.64 (0.09)	0.62 (± 6.05)	0.84 (0.04)	2.89 (± 6.81)	0.39 (0.17)
VL [set 3] (%)	35.96 ± 15.76	35.35 ± 13.66	35.54 ± 14.48	0.62 (± 7.23)	0.86 (0.03)	1.42 (± 7.90)	0.71 (0.02)	0.81 (±7.06)	0.82 (0.01)
VL [total] (%)	44.86 ± 12.98	43.81 ± 13.80	45.12 ± 13.11	1.04 (± 6.79)	0.76 (0.06)	-0.27 (± 5.78)	0.92 (0.02)	-1.31 (± 5.34)	0.62 (0.10)

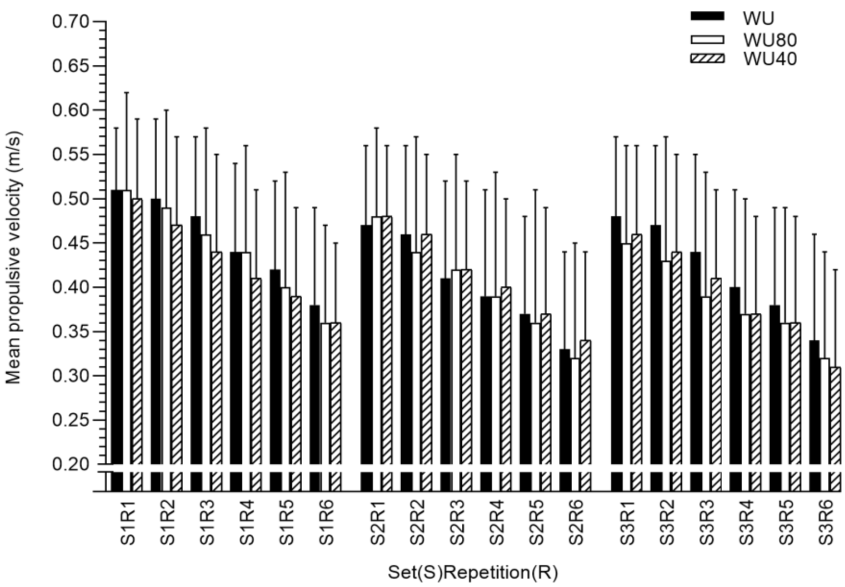

Figure 2 - Mean propulsive velocity values in each repetition performed during the bench press exercise, after WU, WU80 and WU40.

Table 5 - Mean values ± standard deviation of the peak velocity (PV) and time to reach peak velocity (time to PV) in each set or training (total) in bench-press. Differences and confidence intervals (95%CI), effect sizes (ES) and *p*-values are also presented.

	WU	WU80	WU40	WU vs. WU80		WU vs. WU40		WU80 vs. WU40	
				Difference (± 95 % CI)	p – value (ES)	Difference (± 95 % CI)	p – value (ES)	Difference (± 95 % CI)	p - value (ES)
PV [total] (m.s-1)	0.82 ±0.11	0.80 ± 0.15	0.82 ± 0.12	0.02 (± 0.05)	0.43 (0.17)	0.00 (± 0.04)	0.95 (<0.01)	-0.02 (± 0.05)	0.45 (0.17)
Time to PV [set1] (ms)	574.77 ± 233.46	588.62 ± 334.46	694.50 ± 211.71	-13.85 (± 137.71)	0.84 (0.04)	-119.73 (± 70.36)	<0.01** (0.69)	-105.89 (±144.22)	0.14 (0.30)
Time to PV [set2] (ms)	533.19 ± 272.22	549.58 ± 293.34	662.31 ± 257.51	-16.39 (± 96.37)	0.73 (0.07)	-129.12 (±120.81)	0.04* (0.43)	-112.73 (±128.65)	0.08 (0.35)
Time to PV [set3] (ms)	583.19 ± 272.04	609.19 ± 334.18	575.61 ± 303.09	-26.00 (± 119.23)	0.66 (0.09)	7.58 (±130.52)	0.91 (0.02)	33.58 (±171.65)	0.69 (0.08)

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

Table 6 presents the results recorded regarding the mechanical power and work produced during the bench exercise. Despite no differences were found between conditions in MPP, it can be observed significant results in work, with progressive warm-up showed higher values when compared to 40% of training load warm-up in first (F = 3.00, p = 0.06, η_p^2 = 0.11) and second set (F = 2.31, p = 0.11, η_p^2 = 0.08). The total work also presented significant results between these two conditions (F= 2.56, p = 0.09, η_p^2 = 0.09).

Immediately after performing the three sets of resistance training, no differences were found in heart rate values in bench press exercise (F = 1.74, p = 0.19, η_p^2 = 0.06) and in the squat (F = 0.97, p = 0.39, η_p^2 = 0.07). In the perceived effort after the bench press training, no differences were found between conditions (F = 0.39, p = 0.68, η_p^2 =0.01), and no differences existed regarding the squat training (F = 2.17, p = 0.14, η_p^2 = 0.14).

Table 6 - Mean values ± standard deviation of the maximal value of the mean propulsive power (MPP), the minimal value (MPPmin), and work developed in each set and total training (total) in bench-press. Differences and confidence intervals (95%CI), effect sizes (ES) and *p*-values are also presented.

	WU	WU80	WU40	WU vs. WU80		WU vs. WU40		WU80 vs. WU40	
				Difference (± 95 % CI)	p - value (ES)	Difference (± 95 % CI)	p - value (ES)	Difference (± 95 % CI)	p - value ES
MPP [set 1] (W)	309.30 ± 89.35	303.68 ± 87.97	292.25 ± 77.90	5.61 (± 30.05)	0.70 (0.08)	17.04 (± 20.09)	0.09 (0.34)	11.43 (± 25.60)	0.37 (0.18)
MPP [set 2] (W)	288.13 ± 103.95	283.09 ± 82.62	286.45 ± 93.54	5.04 (± 29.87)	0.73 (0.07)	1.68 (± 18.47)	0.85 (0.04)	-3.35 (± 22.28)	0.76 (0.06)
MPP [set 3] (W)	293.65 ± 97.98	279.92 ± 86.21	277.43 ± 98.77	13.74 (± 47.49)	0.56 (0.12)	16.22 (± 18.07)	0.08 (0.36)	2.48 (± 48.18)	0.92 (0.02)
MPPmin[set1] (W)	213.86 ± 79.99	211.38 ± 83.48	209.95 ± 66.28	2.48 (± 33.78)	0.88 (0.03)	3.91 (± 25.34)	0.75 (0.06)	1.43 (± 26.28)	0.91 (0.02)
MPPmin[set2] (W)	195.27 ± 94.72	184.76 ± 81.72	194.44 ± 85.96	10.51 (± 42.15)	0.61 (0.10)	0.83 (± 24.40)	0.95 (0.01)	-9.68 (± 30.93)	0.53 (0.13)
MPPmin[set3] (W)	184.26 ± 58.27	179.75 ± 79.56	183.65 ± 94.00	4.50 (± 32.70)	0.78 (0.06)	0.61 (± 29.79)	0.97 (0.01)	-3.89 (± 32.57)	0.81 (0.05)
Work [set 1] (J)	1600.42 ± 448.60	1587.83 ± 427.57	1555.32 ± 440.22	12.59 (± 44.22)	0.56 (0.12)	45.10 (± 34.99)	0.01** (0.52)	32.51 (± 37.61)	0.09 (0.35)
Work [set 2] (J)	1580.15 ± 453.53	1550.15 ± 421.00	1542.10 ± 461.30	30.00 (± 43.32)	0.16 (0.28)	38.05 (± 30.84)	0.02* (0.49)	8.04 (± 40.15)	0.68 (0.08)
Work [set 3] (J)	1569.33 ± 418.91	1534.35 ± 417.90	1534.38 ± 456.36	34.98 (± 57.36)	0.22 (0.25)	34.95 (± 41.02)	0.09 (0.35)	-0.03 (± 45.16)	0.99 (<0.01)
Work [total] (J)	4749.90 ± 1312.99	4672.32 ±1261.93	4631.80±135 5.01	77.59 (± 125.19)	0.21 (0.25)	118.11 (± 87.65)	0.01** (0.54)	40.52 (± 111.54)	0.46 (0.15)

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

Discussion

The main purpose of the present study was to analyze the effects of a specific warm-up with different loads on squat and bench press performances, using some novel procedures to measure force outputs. Thus, we compared the force outputs during a typical resistance training set by measuring mechanical variables, such as movement velocity and power, and physiological and psychophysiological variables. The participants were able to reach higher MPV in the second and third sets of squat exercise in WU80 compared to WU40. Nevertheless, in the bench press, the time to PV was lower after the warm-up with progressive intensity. No differences were found in MPP but there was a tendency for higher work performed after the progressive warm-up. This was highlighted by the higher work values obtained in the bench-press exercise during the first, second set and overall training compared with WU40. The hypothesis that the propulsive velocity and mechanical power during squat resistance training would be influenced by performing a progressive specific warm-up or 80% of training load, was confirmed by the presented results. However, in the bench press, the time to PV, the mechanical power and work seem to be optimized with a progressive warm-up. The results revealed that each specific warm-up caused different responses according to the following exercise, specifically during the squat and bench press exercise training.

It is known the importance of MPV to monitor resistance training variables such as the intensity and the volume, but also it can be considered as the steadiest variable for muscle strength assessment in isoinertial conditions (González-Badillo et al., 2011; González-Badillo & Sánchez-Medina, 2010; González-Badillo et al., 2017). Therefore, the effects of warm-up in the velocity of the movement performed during resistance training should be fundamental to further understand the warm-up design, procedures, and to optimize resistance training and then long-term performance. In fact, sports require the athletes to move, launch, shut, run, at high-speed rates that should be improved by resistance training (Gourgoulis et al., 2003; Pojskić et al., 2015), and warm-up can play an essential role in training optimization. It has been established that specific warm-up is beneficial to 1RM and the number of repetitions performed with submaximal loads (Junior et al., 2014; Evans et al., 2001) but, until now, few are known regarding the quantity and load of the specific warm-up and the influence during resistance training, analyzing mechanical variables that showed to influence resistance training performance.

The MPV showed a tendency to be higher at the beginning of the squat training session, after WU. Yet, in the second and third sets, WU80 was the condition with better results. In the bench press, these differences did not exist, perhaps due to the lower quantity of muscles involved and the inferior complexity of the movement (Evans et al., 2001). It is expectable that, with greater complexity and quantity of muscle involved, the squat exercise could require a more specific warm-up. This led to differences in the first set of squat, with the progressive warm-up resulting in better results. Moreover, this is evidenced by outputs in the second set, in which the WU80 caused higher MPV values and less time to PV. It seemed that after performing just one set of warm-up with 80% of training load (64%1RM), less fatigue was accumulated comparing with the two sets performed during WU and thus resulting in greater results in the following training sets. Nevertheless, in the bench press, the WU was the most effective, resulting in less time to PV in the first sets and a tendency for higher MPV values.

The results of this study corroborate with some investigations that reported improved strength performance and increased work and number of repetitions after a warm-up with high loads (Alves et al., 2019). The specific warm-up can enhance force production after a maximum or near-maximal muscle stimulation (Junior et al., 2014) and some authors attributed this situation to increased phosphorylation of the myosin regulatory light chain, especially in type II muscle fibers (Xenofondos et al., 2010). Moreover, a proper warm-up promotes an increase in body temperature, increased velocity nerve transmission impulses and oxygen availability in the muscular system, decreased connective tissue stiffness and viscosity of the musculoskeletal system, allowing the body to stay more available for the activity to be performed (McGowan et al., 2015; Bishop, 2003b; Albuquerque et al., 2011). In this case, the faster velocities attained and the lower time to achieve maximal velocities could signify better neuromuscular capacity or acute potentiation (González-Badillo et al., 2017), resulting from a more appropriate stimulus. This was verified in WU and WU80, which were the warm-ups performed with higher loads.

The VL and metabolic stress depend considerably on the number of repetitions performed and the functional and structural adaptations in the muscle according to the intensity effort (Pareja-Blanco et al., 2017). In the current study, the training VL was similar between warm-ups in both exercises. Nevertheless, the minimal MPV and MPP values were verified after WU40, which supports the lower performances in this condition. The reduction in movement velocity during resistance exercise may be indicative of fatigue (Pareja-Blanco et al., 2017; Sanchez-Medina & González-Badillo, 2011). On the one hand, the lower values of MPV after WU40 are representative of worse neuromuscular capacity, and, on the other hand, the lower values of minimal MPV and MPP showed decreased strength performance and/or higher levels of fatigue in this warm-up condition. Moreover, regarding the work produced during training, the greatest effects were found after WU condition, particularly in bench press exercise, with higher values compared with WU40. The work produced during the resistance training depends on the mass, vertical displacement of the bar, and number of repetitions performed during the session. Considering that the external load and number of repetitions were the same between analyzed warm-up conditions, greater work could be caused by some minor changes in acceleration and/or in the displacement of the bar during exercise.

Some limitations should be addressed to the current study. We should be aware that only bench press and squat exercises were analyzed, and cautions should exist when generalizing our findings to other resistance training exercises. Nevertheless, the squat and bench press are some of the most used exercises in strength-related studies and most resistance training contexts. A larger sample would benefit more clear conclusions in some of the analyzed variables and future studies could also monitor and control the nutritional intake of participants throughout the study as well as other variables (e.g. hormonal responses and core temperature). Despite these limitations, the results are interesting for all coaches and athletes, and researchers. Most of the research investigating warm-up on muscle force output generally focuses on maximal dynamic strength, the maximal number of repetitions, disregarding the confounding effect of the procedures (i.e. the influence of previous repetitions on maximal performance output, adding effects to the warm-up independent variable). Linear position technology, commonly used to measure force outputs and monitor athletic performance, allowed us to measure and analyze the changes in resistance training caused by different specific warm-ups.

Conclusion

The current study took a novel approach to warm-up research by examining the effects of warm-up in resistance training using some recent procedures to measure performance. In summary, an increase in force outputs during squat training was found after specific warm-up, comprising only six repetitions with 80% of the training load. This was clear during the second and third training set. In the bench press, a progressive-intensity warm-up of two sets of 6 repetitions with 40% and 80% of training load was the most effective, resulting in less time to attain maximal velocities and augmented work. In general, the warm-up with 40% of the training load was the one with worse performances in both exercises.

Some practical applications can be drawn. Despite some different responses according to each exercise, progressive-intensity specific warm-up and WU80 should be used to maximize performance during resistance training. In specific, our outcomes allowed us to disclose that higher intensities (i.e. 80% of training load) and only a few repetitions (i.e. 6 repetitions) should be used during specific warm-ups to optimize squat training. However, the bench press exercise should be preceded by some more repetitions (i.e. 2 x 6repetitions) with progressive loads (i.e. 40% and 80% of training load). The present findings can be applied before the bench press and squat resistance training but also when assessing maximal dynamic strength. Knowing that the movement velocity can be used to determine maximal dynamic strength and to monitor resistance training performance, our outcomes can provide new insights and recommendations for sports professionals and researchers to improve training efficiency and optimize performance.

Chapter 4. General Discussion

The purpose of the current investigation was to analyze the specific warm-up effects in squat and bench press resistance training. Thus, we compared the mean propulsive velocity, propulsive mechanical power and work in squat and bench press exercises between different specific warm-ups, during a traditional resistance training session. Moreover, secondary outcomes were analyzed, such as physiological and psychophysiological variables. Our findings suggested that the specific warm-up with progressive intensity, performed in the same exercise as the main activity, positively influences squat or bench press resistance training, maximizing muscle force production by enabling a higher movement velocity during the first repetitions. Our data also showed that a specific warm-up with 80% of training load should be performed before a squat exercise, but in bench-press it seemed beneficial to choose a progressive warm-up type (i.e., 40% followed by 80% of training load). Nevertheless, a warm-up with 40% training load did not seem enough to stimulate and prepare the athlete for a squat or bench press resistance training session. These outcomes clearly showed that specific warm-up is essential to resistance training and strength performance, and that higher intensities should be used to optimize the upcoming resistance training effort.

The lack of research on warm-up in strength performance, and specifically during resistance training, was the initial reason behind our investigation. Resistance training causes some functional and structural adaptations, such as muscle architecture and cross-sectional area, and muscle activation, leading to neuromuscular adaptations and strength gains (Behm, 1995; Sale, 1987; Trezise & Blazevich, 2019) Given that muscular strength underpins a vast number of attributes related to improving performance across a wide range of sport skills and to reducing the risk of injury (Gray & Nimmo, 2001; McCrary et al., 2015; Neiva et al., 2014; Parr et al., 2017; Silva et al., 2018; Simão, et al., 2004), practitioners should incorporate resistance training as a method of preparing to maximize performance. Therefore, we should also understand how to optimize resistance training, contributing to an efficient training and long-term maximized strength performance. One way to do this is to understand preparatory activities that precede any resistance training, and to learn how to design and apply a proper warm-up that would result in an optimized training session.

Warm-up has been documented as fundamental for maximizing the athlete's performance in different sports and physical activities (Neiva et al., 2014; Silva et al., 2018). Over time, the benefits of warm-up, such as increased body temperature, increased nerve conduction rate, and metabolic efficiency (Bishop, 2003a; Bishop, 2003b), were considered indispensable before any exercise. The recent scientific evidence suggests that warm-up improves individual sports (e.g., cycling, running, swimming) and team sports (e.g., football, rugby) (Gourgoulis et al., 2003; Pojskić et al., 2015; Silva et al., 2018). Yet some contradictory outcomes revealed that specific tasks during warm-up should be better understood, arousing the interest of athletes and coaches in research findings as they search for the ideal warm-up practices so that higher performances could be achieved (McCray et al., 2015; Silva et al., 2018).

The initial work of this thesis was to conduct a review that comprised the published studies about the effects of warm-up in resistance training and strength performance (Study 1). In the last few years, the research on warm-up has increased. However, we observed that the knowledge about the influence of warm-up in strength performance and in resistance training was limited. Warm-up is usually performed to gradually adapt the body physically and mentally for the main exercise, improving performance and reducing the risk of injuries (McCrary et al., 2015; Neiva et al., 2014; Parr et al., 2017; Silva et al., 2018). In the case of strength performance, findings were not consensual among studies, perhaps because of the different warm-ups that were used. Some of them described the positive effects of general or specific warm-up when compared to no warm-up protocol (Abad et al., 2011; Alves et al., 2019, Wilcox et al., 2006). It seemed that the resistance training was not affected by different protocols of warm-up, either in maximal dynamic strength (i.e., 1 repetition maximum – 1RM – load) or in the maximal number of repetitions performed with submaximal loads (% 1RM load) in upper and lower limbs (Abbud, et al. 2013; Brandenburg, 2005; Foganholi et al., 2012; Gil et. al., 2015; Nader, et al., 2009; Ribeiro, et al., 2014).

An issue found during the review analysis was that literature is scarce regarding the effect of specific warm-up on activities such as resistance training and that, in most cases, specific warm-up presented similar results as general warm-up (Foganholi et al., 2012; Nader et al., 2009; Ribeiro et al., 2014). This highlighted that specific warm-up seems to promote the effects required to stimulate the athlete for the main activity. When focusing only on the effects of specific warm-up, the literature tended to show that specific warm-up should be executed with high external loads and few repetitions of movement, or with low loads and high velocity, in order to reach a post-activation potentiation effect (Alves et al., 2019). This effect seems to be positive to improve 1RM loads, increasing the number of maximal repetitions and total work in resistance training with external loads (Alves et al., 2019). However, some inconclusive results still exist (e.g., Abbud et al., 2013; Brandenburg, 2005). More studies are needed to understand the effect of different specific types of warm-up in resistance exercises. Interestingly, it was also found that no studies were developed to understand the long-term adaptations in strength with the use of different warm-ups. We believe that the warm-up can influence resistance training efficiency, by maximizing each training session performance. A proper exercise technique associated with an optimized training load could be essential to achieving the neuromuscular and strength adaptations, which may be important for increased sports performance (Howe et al., 2017).

The efficiency of the warm-up depends on the balance between fatigue onset and muscle potentiation before the main activity (Tillin & Bishop, 2009). Although there are some general recommendations for coaches and athletes, little is known about the warm-up loads to be used before resistance training. Therefore, it seemed relevant to analyze the effect of specific warm-up on squat and bench press resistance exercise (Studies 2 and 3). The evaluation of resistance performance through mechanical variables, such as the velocity of movement, is highly relevant. This variable is constant and reliable and can be tested in a real resistance training set with submaximal external loads (González-Badillo., et al 2011; González-Badillo & Sánchez-Medina, 2010).

To the best of our knowledge, our experimental studies (Studies 2 and 3) were one of the first to investigate the effects of specific warm-up in one entire typical resistance training session, rather than acute maximal or submaximal dynamic strength performances. The first experimental study (Study 2) aimed to compare the effects of specific warm-up and no warm-up in squat and bench press resistance training, and therefore to verify the importance of specific warm-up before resistance training. After determining the maximal dynamic strength load, each participant was required to perform a traditional training set comprising 3 x 6 repetitions with 80% 1RM, after completing a specific warm-up or no warm-up. The training load was used as a reference to determine the load used during warm-up. So, traditionally, training is preceded by a progressive intensity warm-up (e.g., McGowan et, 2015, Neiva et al., 2014, Silva et al., 2018). Based on this, we designed a progressive intensity specific warm-up with 40% and 80% of training load, which corresponded to 32% and 64% 1RM load, respectively. Our results corroborated previous studies that reported improved strength performance after a specific warm-up (Arabatzi et al., 2014; Gołaś et al., 2016; Wilcox et al., 2006). Wilcox et al. (2006) showed that a specific warm-up with low volumes and with explosive movements can improve strength performance. Moreover, warm-up with submaximal loads optimised results in main activities such as jumping, throwing, and pushing (Arabatzi et al., 2014; Gołaś et al., 2016).

According to other researchers, the specific warm-up could promote a post-activation effect, contributing to development of strength performance (Alves et al., 2019; Gil et al., 2019; Hodgson et al., 2005). The PAP effect, after a warm-up with close to maximal or at maximal loads, was recommended to benefit power activities by an acute structural and physiological change that optimizes the effectiveness of muscle contractions (Hodgson et al., 2005; Tillin & Bishop, 2009). Conrado de Freitas et al., (2018) found a higher number of repetitions during 4 sets of squat exercise with 70% of 1RM when compared with a specific warm-up with 2 repetitions with 90% 1RM with no warm-up. However, benefits were mainly owing to the differences observed in the first set of the training session. The fact that the loads used in the specific warm-up were maximum may have contributed to the occurrence of fatigue in the following sets. The beneficial effects were confirmed by our outcomes. In Study 2, the participants recorded higher values of mean propulsive velocity (MPV) in the first set of both exercises, squat and bench press, after specific warm-up. Furthermore, in the squat exercise, the peak velocity (PV) and the time needed to achieve PV in the first set were the variables that showed the higher effects of warm-up. Moreover, the perceived effort after training was higher when the participants performed the warm-up and this could be caused by the higher MPV, higher PV, and lower time to PV in squat exercise after warm-up.

The results of our first experimental study reported the need for a previous specific warm-up, showing that participants were able to improve their strength performance right at the beginning of the training session. Despite significant results were found in the velocity-related variables, mechanical power and work produced throughout training showed a trend towards higher values after warm-up, in both sets and in overall training. Thus, the warm-up comprising 6 repetitions with 40% of training load followed by 6 repetitions with 80% of training load optimized force production and should be used before a squat or a bench resistance training. Considering that the movement velocity during resistance training can be used to determine maximal dynamic strength, the present findings can also be important and should be used before traditional 1RM determination. Knowing that the literature showed no extra gains by adding a general warm-up, it would be interesting to compare different loads of specific warm-ups, using novel methods and procedures to monitor resistance and strength performance such as those used in the present study.

Based on previous outcomes, a second experimental study (Study 3) was designed to verify the effects of different specific warm-ups, with different intensities and volumes, in bench press and squat exercises. This way, three different warm-up conditions were randomly implemented. The progressive intensity warm-up used was the same as in the first experimental study (Study 2). The warm-up with high intensity included 1 set of 6 repetitions with 80% of the training load (WU80) and the warm-up with low intensity comprised 1 set of 6 repetitions with 40% of the training load (WU40). The outcomes showed that each specific warm-up caused different responses depending on the main activity, specifically during the squat and bench press resistance training. Our results supported previous investigations that reported improved strength performance and work after a warm-up with high loads (Alves et al., 2019; Conrado de Freitas et al., 2018). The specific warm-up can enhance force production after a maximum or near-maximal muscle stimulation (Junior et al., 2014), and some authors attributed this situation to an increased phosphorylation of the myosin regulatory light chain, especially in type II muscle fibers (Xenofondos et al., 2010). The high velocities reached and the shorter time to achieve maximal velocities in our study might signify better neuromuscular capacity or acute potentiation (González-Badillo et al., 2017), resulting from a more proper stimulus. This was verified after the progressive warm-up and WU80, which were the warm-ups performed with higher loads.

The highest voluntary velocity of movement makes it possible to obtain the greatest benefits that resistance can provide (González-Badillo & Sánchez-Medina, 2010). Thus, during resistance training, the athletes must perform the concentric phase as fast as possible, that is, at higher MPV values. Thus, the specific warm-up was shown to be fundamental to reach maximal values of MPV and, therefore, optimizing training gains. This was particularly evident when higher loads were used during the specific warm-up. In addition to the effects associated with PAP phenomenon, mentioned above, the higher load during warm-up could stimulate body temperature and the transmission of nerve impulses and decrease connective tissue stiffness, enabling the musculoskeletal system to stay more available for the exercise to be performed (Albuquerque et al., 2011; Bishop, 2003a; McGowan et al., 2015). In the physiological responses that were observed, there was a trend towards higher heart rate values during the implementation of the more intensive warm-up. This could mean a more appropriate physiological response to external load in this case. However, the results were not clear and future investigation should be performed, including some additional physiological variables.

In the same study, Study 3, the velocity loss (VL) was similar between warm-up conditions in both exercises. VL is considered an indicator of fatigue, which means that a greater loss of velocity represents increased mechanical, metabolic, and hormonal stress (González-Badillo, Sánchez-Medina, Pareja-Blanco, & Rodríguez-Rosell, 2017). A probable explanation for the lack of statistical differences in this variable may be due to the higher maximum value of the MPV found in the protocols with higher loads. This way, it was expected that the velocity loss would be greater. Yet the minimal MPV values were observed after WU40. We can attribute the lower movement velocities during resistance exercise to the occurrence of fatigue (Pareja-Blanco et al., 2017; Sanchez-Medina et al., 2011). The lower values of MPV after WU40 are demonstrative of inferior neuromuscular performance and the lower minimal values of MPV and MPP showed decreased strength performance and/or higher levels of fatigue in this warm-up condition. Regarding the work performed during training, the greatest effects were found after progressive warm-up, especially in bench press exercise, with higher values compared with WU40. It is known that work produced depends on the mass, the vertical displacement of the bar, and the number of repetitions performed. In our study, the external load and number of repetitions were the same between conditions, so greater work could be caused by some minor changes in acceleration and/or in the displacement of the bar during exercise.

In the squat training session, our outcomes showed that progressive intensity warm-up resulted in better MPV values in the first set, but it was the WU80 that resulted in better performances in the following training sets. In the bench press training, the better outcomes were found after the WU. These differences could be due to the greater complexity and quantity of muscles involved in squat exercise, which needed more stimulation but, at the same time, could accumulate greater fatigue for the upcoming training sets. According to the results, progressive intensity specific warm-up and WU80 could be used to optimize performance during resistance training. Specifically, higher intensities (i.e., 80% of training load) and only a few repetitions (i.e., 6 repetitions) should be used during specific warm-ups to optimize squat training. Nevertheless, the bench press exercise should be preceded by more repetitions (i.e., 2 × 6 repetitions) with progressive loads (i.e., 40% and 80% of training load). It was also clear that a specific warm-up with few repetitions and low loads would not be enough to optimize squat and bench press performances.

The importance of this investigation lies in the fact that warm-ups are typically performed based on previous experience, and not evidence-based. Moreover, there is a lack of investigations about warm-up in resistance exercises performance that could be applied in a real context, and the existing ones have some methodological issues and limitations. The current study took a novel approach to warm-up research by examining the effects of warm-up in resistance training using some recent procedures to measure performance. To the best of our knowledge, our experimental studies were the first to investigate the effects of specific warm-up in one entire typical resistance training rather than in maximal dynamic strength performances, and to analyze the mechanical responses (i.e., movement velocity-related variables). It is likely that our outcomes will impact the ability to provide efficient information for professionals, researchers, and people who intend to practice any kind of physical activity. Moreover, this can serve as a pilot study for the development of new research on this subject that uses state-of-the-art technology and procedures.

Some limitations in the current thesis should be addressed:

- We should be aware that only a few resistance exercises were analyzed (bench press and squat exercises), and caution should be taken when generalizing our findings;
- Although the participants were all healthy young adult males, and experienced, they were not competitive athletes;
- A larger sample would benefit from more clear conclusions regarding some of the analyzed variables;
- It was not possible to study the secondary physiological outcomes to better understand mechanical responses (i.e., lactate, hormones, electromyography, body temperature, and others);
- Only a few physiological variables were assessed as secondary outcomes to better understand performance changes;
- There was no control of nutritional intake of participants throughout the experimental studies;
- Only males were evaluated, and we should be aware of this when discussing the main findings of the studies.

Chapter 5. Overall Conclusions

The main findings of this work report the importance of the specific warm-up in resistance training, specifically for squat and bench press exercise. Regarding the specific purposes, the conclusions of the present thesis were:

i. There is a lack of research on specific warm-up in resistance training and strength performance, despite the growing interest in this topic;
ii. The literature suggests that specific warm-up provides the changes needed to prepare the athlete for the upcoming resistance effort, with no benefits from adding a general warm-up;
iii. The specific warm-up, performed in the same exercise as the main activity, seems to optimize muscle force production by enabling a higher movement velocity during the first repetitions of the training, and by helping to attain higher peak velocities, and in less time;
iv. The mean propulsive velocity showed a tendency to be higher at the beginning of the squat training session, after progressive warm-up; however, in the second and third sets, specific warm-up with 80% of training load was the condition with better results. It seemed that after performing just one set of warm-up with 80% of training load, less fatigue was accumulated compared with the two sets performed during progressive warm-up, thus resulting in better results in the following training sets;
v. In bench press exercise, the time to achieve peak velocity, mechanical power and work were optimized after the one set of progressive-intensity warm-up (40% *plus* 80% training load);
vi. The warm-up with 40% of the training load was the one with the worst performances in both exercises, when compared to progressive warm-up and with 80% of the training load.

Chapter 6. Suggestions for future investigations

Coaches, athletes, and researchers have long understood the importance of warm-up before competition but have only recently tried to understand the influence in training, i.e., during resistance training. Therefore, there is a lot to understand about this subject, and a few directions for possible future investigations are recommended below:

- To replicate these studies but with different exercises, in order to understand the warm-up effects on different resistance exercises;
- To apply the specific warm-up before several resistance exercises and understand the influence in a real resistance training context (i.e., with more than one exercise);
- Since the results of our studies that used higher warm-up loads had better results, it would be interesting to replicate these studies but with different loads;
- To apply different protocols based on new methods and procedures for measuring resistance and strength performance, such as those used in the current study;
- In order to control a greater number of variables, future studies could also monitor and control the nutritional intake of participants throughout the study, as well as other variables (e.g. blood lactate concentration, hormonal responses, and body temperature);
- Further investigations should focus on a larger sample can bring more conclusive results;
- It could be interesting to further understand the influence of the recovery time after warm-up, so that fatigue can be reduced, and advantage can still be derived from warm-up benefits;
- It would be interesting to verify the possible implications of the effects on resistance training, in long-term specific warm-up programs.

Chapter 7. References

Chapter 1. General Introduction

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Chapter 3, Study 2

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Appendix I

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Appendix I

The effect of warm-up for maximal strength performance: brief review

Introduction

Warm-up is used with the purpose to progressively adapt physically and psychologically for the main activity. The main aim is to increase the performance and to decrease the risk of injuries (Neiva et al, 2014; Silva et al, 2018). To the best of our knowledge, no detailed studies have comprehensively examined the literature regarding the effects of different warm-up designs on 1RM performance. Therefore, the purpose of this study was to analyse the effects of different strategies of specific warm-ups on 1RM performance, thus contributing for increased knowledge to coaches and researchers on the warm-up design for resistance training.

Methods

Databases (Web of Science, Scopus, PubMed, and ScienceDirect) were searched for original research articles published until 2017 (key-words: “warm-up”, “1RM”, “general warm-up”, “specific warm-up” and” no-warm-up”). A total of 18 studies were considered for further analysis.

Results

The results found that general warm-up followed by a specific exercise when compared with only a specific warm-up, does not reveal consensual results. There were studies that revealed significant positive results when the subjects use only the specific warm-up (e.g. Ribeiro et al, 2014; Gil et al., 2015) and only one study revealed the opposite (Endlich et al., 2009). Some studies suggest that when the specific warm-up is performed at loads close to the maximum, the ability to produce strength can be positively affected (Junior et al, 2014). However, other studiesverified the efficacy of the specific warm-up and no significant results were found (Abbud et al, 2013).

Conclusions

The results about the influence of warm-up on strength performance showed ambiguous results, perhaps caused by the different procedures and methods of evaluation. It seems that specific warm-up is the one that most affect strength performance, revealing its importance for resistance training. However, it was shown that some specific tasks, such as stretching and light loads, can negatively affect the strength performance.