REVIEW ARTICLE

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

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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: pre-exercise; general warm-up; specific warm-up; strength; performance.

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 et al., 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

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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 on strength performance (Gil et al., 2019; Conrado de Freitas et al., 2018). 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.

METHOD

This study intended to summarize the findings and conclusions reported in the literature on the effect of warm-up, between general and specific, on 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 judgment 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 for 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.

Table 1 summarizes the studies that investigated the results of the general and specific warm-up (Conrado de Freitas et al., 2018, Barroso, Batista, Tricoli, Roschel, & Ugrinowitsch,

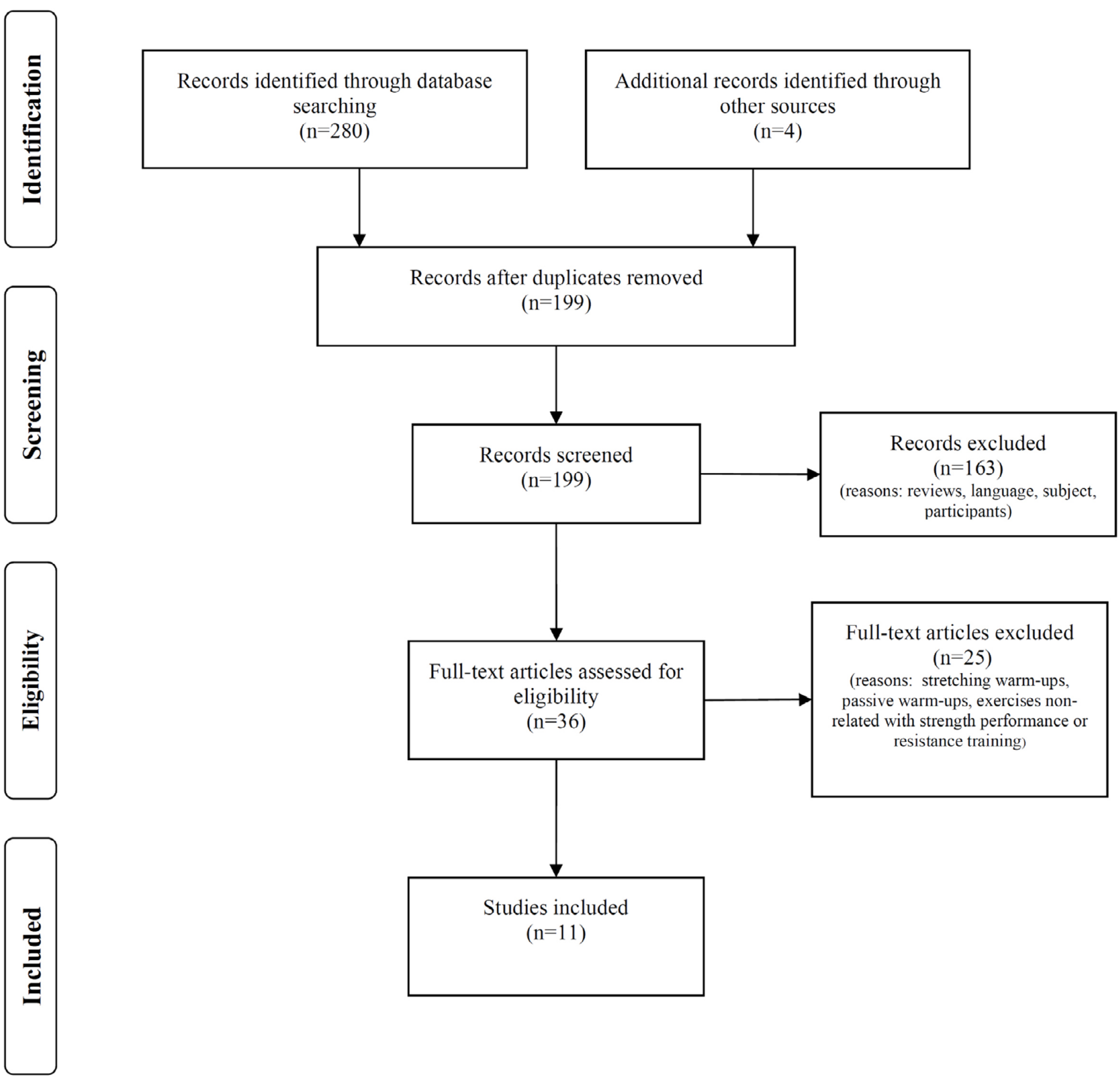

Figure 1. Preferred reporting items for systematic reviews and meta-analysis study flow diagram.

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 – 20 min stationary cycling (60% of HRmax)+ Wu2. Wu2 – 8 reps (50 % 1RM load)+ 3 reps (70% 1RM load) leg press.	3 min	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.
Conrado de Freitas et al. (2018)	14 T (M)	Wu1 – Wu2+ 3res (90% 1RM load), bench press. Wu2 – 8 reps (50% 1RM load), bench press.	10 min (Wu1) 4 min (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.	3 min	1RM leg press	Wu3> Wu1, Wu2, Wu4, Wu5 Wu4< Wu1, Wu2, Wu3, Wu5
Brandenburg et al (2005)	9 T (M)	Wu1 – 1x 5 reps (100% of 5RM load) bench-press Wu2 – 1x 5 reps (75% of 5RM load) bench-press Wu3 – 1x 5 reps (50% of 5RM load) bench-press Wu4 – No warm-up	4 min	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 – 2 min walking (5km/h)+ 5 min running (8km/h) Wu3 – active static stretching 10 sec, 3 reps (pectoral, deltoid and triceps)	ND	Bench press 1RM	No significant differences between protocols.
Gil et al (2016)	12 T (M)	Wu1 – running 5 min (9km/h)+ 5 min flexibility exercises+ Wu2 Wu2 – 8reps (50% 1RM load)+ 3reps (80% 1RM load). Leg press and bench press.	3 min	1RM bench press 1RM leg press	No significant differences between protocols.
Junior et al (2014)	14 T (M)	Wu1 – 5 min walking 50% VO_2max. Wu2 – 5 min cycling 50% VO_2max. Wu3 – 15 reps (40% 1RM load). Bench press or leg press unilateral. Wu4 – 2x 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 10 min treadmill (70% HRreserve) Wu2 – 15 reps (50% 8RM load) bench-press	90s	Bench press 3x 8RM 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 10 min (40 km/h) Wu4 – Wu3+ Wu2	30s	4x 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

F: female; HR: heart rate; Hrmax: maximal heart rate; HRreserve: reserve heart rate; M: male; ND: not determined; Reps: repetitions; RM: repetition maximum; T: trained; VO2max: maximal oxygen uptake; Wu: warm-up.

2013; Abbud, Tabet, & Dias, 2013; Abad et al., 2011; Gil, Roschel, & Barroso, 2016; 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.

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., 2016; 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, Conrado de Freitas et al. (2018), 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 1RM attempt might enhance strength performance (Conrado de Freitas et al., 2018).

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).

DISCUSSION

The current review aimed to summarize the scientific findings of using 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 (Conrado de Freitas et al., 2018). 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., 2016). 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; Conrado de Freitas et al., 2018). 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

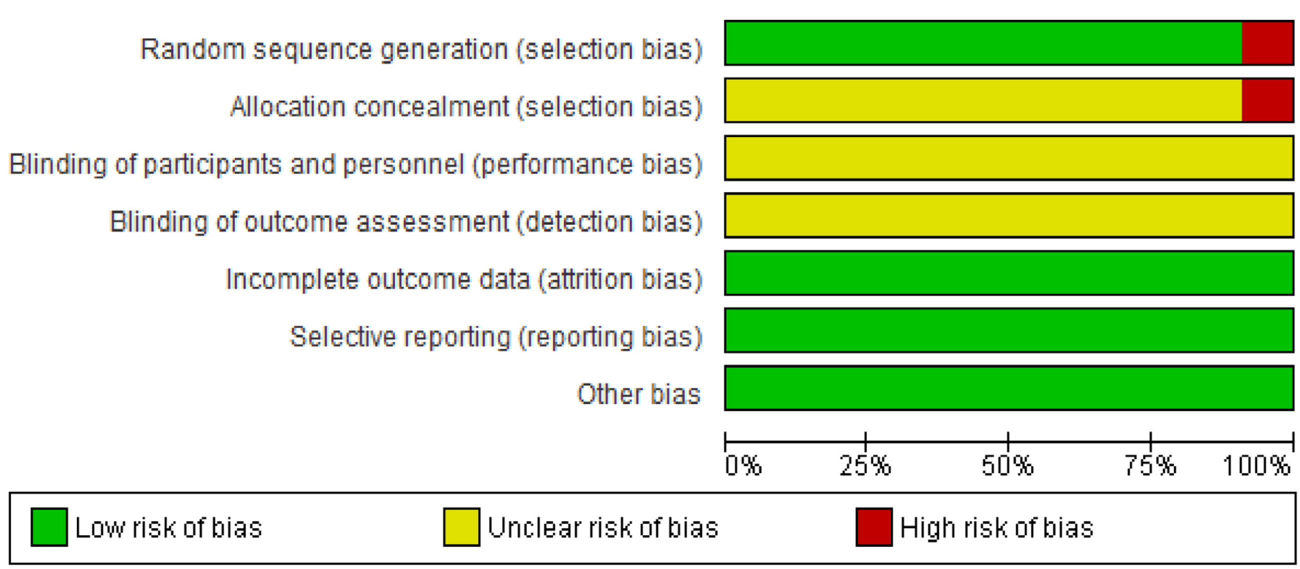

Figure 2. Risk-of-bias item presented as percentages across all included studies.

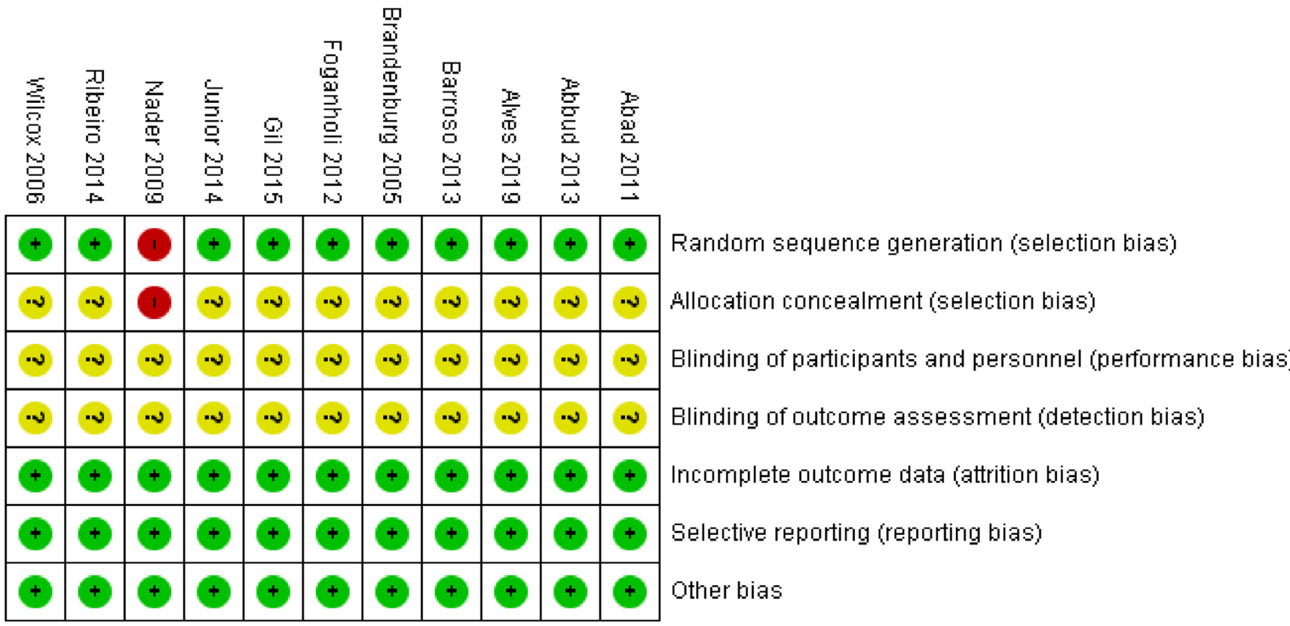

Figure 3. Judgments about each risk-of-bias item for each included study+ indicates low risk, ? indicates unclear risk, – indicates high risk.

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., 2016). The key role of warm-up in strength performance is an asset to optimize training for all technical and research communities.

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 compared to no warm-up condition (Conrado de Freitas et al., 2018, 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., 2016; 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 PAP protocols increased performance, by increasing the total number of repetitions and total work performed during bench press resistance training (Conrado de Freitas et al., 2018). 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 PAP 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 exercises without fatigue compared to the treadmill and bicycle warm-up exercises (Ribeiro et al. 2014, Gil et al., 2016). 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 lead 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-up 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 results in the same bench press maximal performance. On 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, a 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 excitability of the fast-twitch units, which are known to play a significant role in maximal strength performance (for detail, Conrado de Freitas et al., 2018). 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, highlighting that specific warm-up seems to provide the necessary changes 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 PAP 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.

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