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

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Abstract

Background and objective: The purpose of this study was to investigate the effect of specific warm-up on squat and bench press resistance training.

Methods: 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 (3×6 repetitions) with 80% 1RM (training load) after completing a specific warm-up and without warming up, in random order. The warm-up comprised 2×6 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.

Results: 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.

Conclusion: The specific warm-up seems to enhance neuromuscular actions that enable a higher movement velocity during the first training repetitions and to allow greater peak velocities in less time.

Keywords

Power; Pre-exercise; Strength; Velocity; Work

1. Introduction

Warming-up before physical exercise is usually recommended in all sports and physical activities [1, 2]. 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 [1–3]. 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 [4–7]. Still, little is known about the effect of warming-up in strength-specific activities, such as resistance training performance [1].

Muscular performance at maximal or submaximal efforts can be considered essential to succeed in each exercise performance [8, 9]. 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 [1, 10]. However, several studies verified that including a general component followed by a specific warm-up brings no extra benefits on maximal load, the number of repetitions, and fatigue index [11–13]. Furthermore, recent research found acute short-term performance enhancements (e.g., movement velocity in bench press throw, time under tension in the bench press) after a brief high intensity/loading conditioning exercise [14, 15]. This is usually known as post-activation performance enhancement (PAPE) and it emphasizes the importance of specific warm-up [16].

Although there is a scientific consensus on the positive influence of using only the specific warm-up [17–19], some contradictory findings still exist. Wilcox *et al.* [17] 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 minutes 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 [18, 19]. On the contrary, others found no significant effects between specific warm-up compared to no warm-up in maximal dynamic strength performance [20] and causing fatigue in submaximal resistance training repetition performance [13]. Research has tried to elucidate the effects of warm-ups on strength through 1RM performance and the number of repetitions until failure [13, 17, 20]. 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 the 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 [21–23]. 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 [21, 22], 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

increase propulsive velocity and mechanical power produced in bench press and squat exercises and optimize resistance training.

2. Methods

2.1 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 (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). 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) was used to measure the bar velocity and automatically calculate the kinematic variables parameters for every repetition [21, 24].

2.2 Subjects

Thirty-four men aged 19–29 years volunteered to participate in the current study. Among these, 12 were evaluated in the squat exercise and 22 in the bench-press exercise. Based on previous similar outcomes [19, 25], apriori analysis suggested that a minimum sample size of 12 subjects was needed to observe a 0.5 m·s^{-1} change in movement velocity, with an α = 0.05, and statistical power = 0.80 (G*Power, v.3.1.7, University of Kiel, Kiel, Germany). 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 have previous experience with the back squat and bench press exercise. Only those who reported that were familiarized and had enough training experience to perform back squat or bench press with the needed technical requirements were included. The participants were not included if there was an 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 study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the University of Beira Interior Research Ethics Committee (under the project d1576, October 2015).

2.3 Isoinertial strength assessment

In the squat exercise, the participants started from the up-right position (knees and hips fully extended) and the barbell resting across the back at the level of the acromion. Then, they start to descend until the top of the thighs was below 90° (eccentric phase) and the concentric phase was made at the maximum velocity to the initial position [24, 25]. Trained spotters (i.e., two strength coaches) were present on both sides of the barbell to ensure safety.

In the bench press exercise, each participant lay in the 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 pause at the chest between the eccentric and concentric actions occurred to minimize the contribution of the rebound effect and thus allow for more reproducible, consistent measurements [26]. The subjects were not allowed to bounce the bar off their chest nor to raise their shoulders or trunk off the bench [24]. In both exercises, the squat and bench press, the evaluator and strength coaches controlled the movement to guarantee that all repetitions were performed with the required technique, with a similar range of movement.

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 m·s^{-1} in the bench press and 0.6 m·s^{-1} in the squat, correspondent to 85% 1RM in both [22, 25]. Inter-set recoveries ranged from 3 minutes (light) to 5 minutes (heavy loads). The 1RM was calculated from the last MPV attained during the progressive loading test as follows: $(100 \times \text{load})/(-5.961 \times \text{MPV}^2) - (50.71 \times \text{MPV}) + 117$ for the squat [25], and $(100 \times \text{load})/(8.4326 \times \text{MPV}^2) - (73.501 \times \text{MPV}) + 112.33$ for the bench press exercise [22].

2.4 Resistance training assessment

In the control condition (no warm-up), the subjects were required to remain seated for 5 minutes before the resistance training performance. The warm-up condition comprised six repetitions with 40% of the training load followed by six repetitions with 80% of the training load (1 minute interval). After 5 minutes of rest, each participant was required to perform the resistance training session. The resistance training session consisted of three sets of six repetitions with 80% 1RM load, with 3 minutes 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 [8, 27, 28]. All the participants were asked to self-report

their fatigue level at the start of each session and 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 [21, 22]. 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) [24], the peak velocity (PV: maximum instantaneous velocity value reached during the concentric phase at a given load) [29], 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).

2.5 Physiological and psychophysiological variables

Heart rate values were assessed at rest (baseline), 1 minute after the warm-up and immediately after training (1 minute). Additionally, the RPE values were recorded using a 16-points Borg scale (6–20 rates) [30] immediately after the warm-up and following the resistance training.

2.6 Statistical analysis

The means and standard deviations (SDs) were calculated for all measures, and the 95% confidence intervals were determined for the differences between experimental conditions. The normality of all distributions was verified with the Shapiro–Wilk test, and the parametric statistical analysis was adopted. The reliability of the MPV measures per set and all three sets combined was calculated with the intraclass correlation coefficient ($\text{ICC}_{2,k}$) using a two-way mixed-effects model. To compare the two sessions, the Student's paired t-tests were used, and the level of statistical significance was set at $p \leq 0.05$. The Hedges 'g (effect size: ES) was calculated and magnitude values were considered trivial (0–0.19), small (0.20–0.59), moderate (0.60–1.19), large (1.20–1.99), very large (2.00–3.99) extremely large (4.00 and higher) [31]. All statistical data treatment was performed using the Statistical Package for Social Sciences (IBM SPSS Statistics for Windows, Version 27.0, IBM Corp., Armonk, NY, USA).

3. Results

The participants that were evaluated in the squat exercise were 23.58 ± 2.78 years old (1.76 ± 0.08 m height; 77.50 ± 11.23 kg body mass) and those evaluated in bench press exercise were 23.50 ± 2.15 years (1.76 ± 0.06 m height, 77.23 ± 8.93 kg body mass). The repeatability analysis of all training movement velocities resulted in ICC values of 0.97 (95% CI = 0.94–0.99) and 0.98 (0.95–0.99) during squat resistance training, with and without warm-up, respectively.

T A B L E 1. Mean values $\pm$ 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 ($\pm$95% CI)	*p*-value	ES
MPV (set 1) (m·s^{-1})	0.64 $\pm$ 0.06	0.68 $\pm$ 0.05	0.04 ($\pm$0.03)	<0.01**	0.88
MPV (set 2) (m·s^{-1})	0.67 $\pm$ 0.07	0.67 $\pm$ 0.07	0.01 ($\pm$0.02)	0.52	0.19
MPV (set 2) (m·s^{-1})	0.64 $\pm$ 0.07	0.66 $\pm$ 0.08	0.02 ($\pm$0.03)	0.20	0.38
MPVmin (set 1) (m·s^{-1})	0.55 $\pm$ 0.07	0.56 $\pm$ 0.09	0.01 ($\pm$0.04)	0.54	0.18
MPVmin (set 2) (m·s^{-1})	0.55 $\pm$ 0.08	0.57 $\pm$ 0.09	0.01 ($\pm$0.03)	0.39	0.25
MPVmin (set 2) (m·s^{-1})	0.54 $\pm$ 0.07	0.53 $\pm$ 0.09	−0.01 ($\pm$0.05)	0.60	0.15
PV (total) (m·s^{-1})	1.20 $\pm$ 0.11	1.32 $\pm$ 0.12	0.12 ($\pm$0.06)	<0.01**	1.18
Time to PV (set 1) (ms)	653.58 $\pm$ 156.53	593.75 $\pm$ 117.01	−59.83 ($\pm$41.70)	<0.01**	0.88
Time to PV (set 2) (ms)	615.17 $\pm$ 139.40	608.42 $\pm$ 118.55	−6.75 ($\pm$47.63)	0.76	0.09
Time to PV (set 2) (ms)	631.17 $\pm$ 155.25	608.92 $\pm$ 123.89	−22.25 ($\pm$49.01)	0.34	0.28
VL (set 1) (%)	14.41 $\pm$ 3.91	17.57 $\pm$ 9.77	3.17 ($\pm$6.12)	0.28	0.32
VL (set 2) (%)	17.15 $\pm$ 5.30	16.61 $\pm$ 5.93	−0.55 ($\pm$4.22)	0.78	0.08
VL (set 2) (%)	15.60 $\pm$ 5.30	19.94 $\pm$ 7.34	4.34 ($\pm$4.47)	0.06	0.60
VL (total) (%)	23.00 $\pm$ 3.44	26.47 $\pm$ 9.24	3.47 ($\pm$5.19)	0.16	0.41

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 ** $p < 0.01$.

The entire bench press resistance training showed ICC values of 0.96 (0.92–0.98) and 0.96 (0.92–0.98), with and without warm-up, respectively. When analysing each single set, ICC values ranged from 0.91 to 0.98 in squat exercise, and 0.88 to 0.96 in bench press, in both experimental conditions, revealing good to excellent reliability.

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. There was a moderate effect of warm-up in MPV ($t_{11} = 3.16$) and time to PV values ($t_{11} = 3.16$) and a large effect in PV ($t_{11} = 4.25$). 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 ($t_{11} = 2.14$). In Fig. 1, it can be observed a tendency for higher MPV values in all repetitions after the warm-up. The first repetitions of the first set showed moderate (first repetition: $t_{11} = 2.63$, $p = 0.02$, ES = 0.73, third repetition: $t_{11} = 3.37$, $p < 0.01$, ES = 0.94) and large effect sizes (second repetition: $t_{11} = 4.74$, $p < 0.01$, ES = 1.32) between warm-up and no warm-up conditions.

Table 2 presents the results recorded regarding the mechanical power and work produced during the squat performance, and no significant differences were found between experimental conditions. Small or trivial effects were found in MPP, minimal values of MPP and work produced between doing and not doing the warm-up before squat resistance training.

When analyzing the velocity and time-related variables in bench press exercise (Table 3), there was a small difference between conditions in MPV in the first set, showing that the participants were faster after warming-up ($t_{21} = 2.61$). However, no other variable was found to be highly influenced
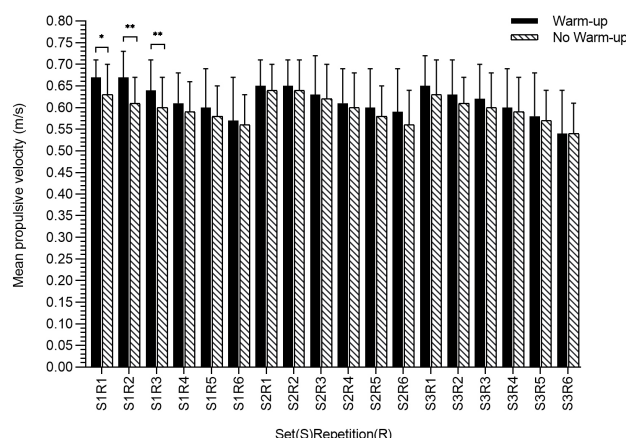

F I G . 1. Mean propulsive velocity values in each repetition performed during the squat exercise training. Values obtained in the six repetitions (R1 to R6) during the first (S1), second (S2) and third set (S3) of squat after warm-up and without warm-up. *$p \leq 0.05$, ** $p < 0.01$.

by warm-up performance and effect size showed to be trivial in most of the variables.

In Fig. 2, it can be verified that each repetition of the first set performed in the bench press was faster after warming-up. There was a moderate effect size in the first ($t_{21} = 2.87$, $p < 0.01$, ES = 0.60) and a small effect in the second and third repetitions ($t_{21} = 2.16$, $p = 0.04$, ES = 0.46 and, $t_{21} = 2.14$, $p = 0.04$, ES = 0.45, respectively). Then, in the following repetitions, the no warm-up condition resulted in similar or higher MPV values (trivial effect sizes).

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).

The warm-up caused the heart rate to increase in the squat (no warm-up: 76 $\pm$ 6 bpm vs. warm-up: 139 $\pm$ 15 bpm, $t_{11} = -15.67$, $p < 0.01$, ES = 4.37, extremely large effect) and in the bench press (77 $\pm$ 6 bpm vs. 110 $\pm$ 13

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	0.56
MPP (set 2) (W)	505.22 ± 87.92	514.57 ± 94.76	9.37 (±20.15)	0.33	0.29
MPP (set 2) (W)	488.75 ± 102.61	498.01 ± 94.77	9.26 (±31.58)	0.53	0.18
MPPmin (set 1) (W)	416.95 ± 76.72	425.40 ± 89.28	8.45 (±35.93)	0.62	0.14
MPPmin (set 2) (W)	411.43 ± 70.49	421.79 ± 84.62	10.34 (±24.51)	0.37	0.26
MPPmin (set 2) (W)	409.29 ± 100.19	397.68 ± 94.39	−11.61 (±44.08)	0.57	0.16
Work (set 1) (j)	2338.85 ± 552.93	2394.62 ± 559.22	55.77 (±126.29)	0.35	0.27
Work (set 2) (j)	2356.21 ± 540.60	2381.62 ± 506.41	25.41 (±147.63)	0.71	0.11
Work (set 2) (j)	2321.40 ± 584.77	2360.48 ± 511.27	39.08 (±141.42)	0.56	0.17
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.

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*	0.55
MPV (set 2) (m·s^{-1})	0.48 ± 0.08	0.48 ± 0.09	0.01 (±0.05)	0.82	0.05
MPV (set 2) (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	0.06
MPVmin (set 2) (m·s^{-1})	0.32 ± 0.07	0.31 ± 0.10	0.02 (±0.05)	0.91	0.02
PV (m·s^{-1})	0.80 ± 0.13	0.81 ± 0.11	0.01 (±0.09)	0.74	0.07
Time to PV (set 1) (ms)	657.23 ± 283.01	545.86 ± 540.52	−111.36 (±181.16)	0.22	0.27
Time to PV (set 2) (ms)	647.68 ± 287.01	545.68 ± 278.91	−102.00 (±196.37)	0.29	0.23
Time to PV (set 2) (ms)	639.55 ± 285.38	586.32 ± 270.58	−53.23 (±172.75)	0.53	0.13
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 2) (%)	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 * $p \leq 0.05$.

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	0.17
MPP (set 2) (W)	281.95 ± 90.70	312.91 ± 102.20	30.95 (±60.80)	0.30	0.22
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 2) (W)	186.23 ± 74.52	197.86 ± 68.30	11.64 (±44.66)	0.59	0.11
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 2) (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	0.15

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

bpm, $t_{21} = -13.10$, $p < 0.01$, ES = 2.81, very large effect). Immediately after performing the three sets of resistance training, no differences were found in heart rate values in the squat exercise (144 ± 14 bpm vs. 146 ± 12 bpm, $t_{11} = -0.63$, p = 0.54, ES = 0.18, trivial effect) and in the bench press (131 ± 11 bpm vs. 129 ± 10 bpm, $t_{21} = 1.77$, $p = 0.09$, ES = 0.38, small effect). A small effect was found in the perceived effort after the squat training between conditions (15.33 ± 1.23 vs. 15.83
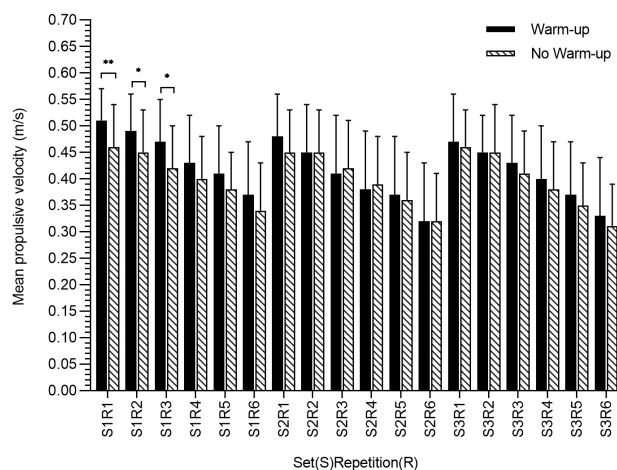
FIG. 2. Mean propulsive velocity values in each repetition performed during the bench press exercise training. Values obtained in the six repetitions (R1 to R6) during the first (S1), second (S2) and third set (S3) of squat after warm-up and without warm-up. *$p \leq 0.05$, ** $p < 0.01$.

$\pm$ 1.47, $t_{11} = -2.17$, $p = 0.05$, ES = 0.59), while no differences occured regarding the bench press training (14.10 $\pm$ 1.18 vs. 14.33 $\pm$ 1.16, $t_{21} = -1.31$, $p = 0.20$, ES = 0.28, small effect).

4. 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. These improvements in movement velocities and time to PV would induce different adaptations to resistance training.

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 [10, 32]. The specific warm-up should not only increase body temperature but also facilitate the neuromuscular readiness to perform the following exercise [2, 3, 10]. In fact, previous findings suggested that a specific warm-up is needed to obtain maximal strength performance, such as 1RM or multiple RM [18, 20]. 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 [32–34]. 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 [17]. In agreement, others suggested that a warm-up including submaximal loads resulted in optimized performances during subsequent exercise [35, 36]. The specific warm-up could provide a PAPE effect and augment the muscle force-generating capacity [10, 16]. Several studies suggested that there is an increase in voluntary force production or exercise performance induced by prior muscle activity [14, 15, 35, 36]. In this case, it seems that a specific warm-up with progressive loads might be responsible for the improvement of type II muscle fiber activity and favouring velocity performance [37].

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. Interestingly, 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. This could be an unequivocal sign that the repetitions performed during the first set had a potentiation effect (i.e., PAPE) on the second set. 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 [25]. 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 practical significance in the strength and conditioning field with higher values recorded 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 [38]. 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 [24].

Some limitations should be addressed to the current study. The outcomes are limited to the analyzed exercises and extrapolation as to other resistance training exercises remains speculative. For instance, the bench press and squat exercises are complex movements composed of multi-muscle group interactions, and a single muscle should be studied using a single joint test. Also, we should interpret the results knowing that there could exist possible variations in day-to-day performance and the number of participants in the squat exercise could have limited the detection of changes between experimental conditions. Future studies should repeat these assessments to increase the reliability of our findings. Further investigation is needed to 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.

5. Conclusions

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. 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 neuromuscular actions that allow to obtain greater movement velocities (i.e., MPV, PV and time to PV) 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.

Abbreviations

ES, effect size; MPP, propulsive mechanical power; MPV, mean propulsive velocity; PAPE, post-activation potentiation enhancement; PV, peak velocity; RPE, ratings of perceived exertion; SDs, standard deviations; VL, relative magnitude of MPV loss; 1RM, maximal strength load.

Author contributions

Study Design: HPN, AP. Data Collection: BR, ARA, and PPN. Data Analysis: MCM, DAM, HPN. Writing Original Draft: BR, ARA and PPN. Manuscript Review and Editing: MCM, DAM, HPN.

Ethics approval and consent to participate

The participants were informed about the study procedures and a written informed consent was signed. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the University of Beira Interior Research Ethics Committee (under the project d1576, October 2015).

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Conflict of interest

The authors declare no conflict of interest.

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