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Evaluation of strength, skin temperature and muscle activation in traditional and eccentric training in Paralympic Powerlifting athletes

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Paralympic Powerlifting (PP) is a maximum strength modality, where male athletes demonstrated greater relative and absolute strength compared to conventional powerlifting. This study aimed to assess the acute effects of traditional training (TT) and eccentric training (ET) methods on Maximum Isometric Strength (MIF), Time to Maximum Isometric Force (Time), Muscle Activation (sEMG), and Skin Temperature (Thermo) in twelve male PP athletes (mean age 30.25 ± 8.13; body weight 72.36 ± 18.47). The training consisted of 5 sets of 5 repetitions (5 × 5), with 80% 1RM in the TT method and in the ET 80% was adopted in the concentric phase and 110% in the eccentric phase, adopting a minimum rest of 3 min between sets and the cadence used was approximately 2 s in the eccentric phase and 1 s in the concentric phase for the ET and 1 s in each phase for the TT. Athletes competing nationally and internationally underwent Thermo, Time, and MIF assessments during TT (80%-1RM for both concentric and eccentric phases) and ET (80%-1RM concentric and 110%-1RM eccentric) at pre-training, post-training, 24 h, and 48 h. sEMG was evaluated in the clavicular portion of the pectoralis major (PMCP), sternal portion of the pectoralis major (PMSP), anterior Deltoid (AD), and Triceps Brachii (BT) during the final series (5 sets of 5 repetitions) of a training session. Athletes exhibited thermal differences in the PMCP muscle at 24 h between TT and ET ($p = 0.020$); Also, after the first 24 h, the AD showed differences between ET and TT ($p = 0.016$) and BT demonstrated differences between ET and TT ($p = 0.028$). The sEMG showed no significant differences between TT and ET ($p > 0.05$). The MIF displayed differences after 48 h between TT and ET ($p = 0.004$). The time showed no significant difference between TT and ET ($p > 0.05$). In conclusion, muscles involved in the bench press exhibited a significant increase in skin temperature with the ET method compared to TT, suggesting greater muscular fatigue. Furthermore, a higher MIF production was observed after the application of the TT in relation to ET, 48 h after training. In the ET, a lower MIF was observed than in the TT, indicating greater fatigue in this type of training.

Keywords Paralympic Powerlifting, Muscle strength, Strength training, Surface electromyography, Thermography

Abbreviations

1RM	1 Repetition maximum
AD	Anterior deltoid
BT	Brachii triceps
CP	Conventional powerlifting
TT	Traditional training
ET	Eccentric training
MIF	Maximum isometric force
PP	Paralympic Powerlifting
PMCP	Pectoralis major clavicular portion
PMSP	Pectoralis major sternal portion
sEMG	Surface electromyography
Therm	Skin temperature

Time	Time until maximum isometric force
WPPA	World para powerlifting
MVIC	Maximum voluntary isometric contraction
RMS	Mean square

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Paralympic Powerlifting (PP) is a muscular strength modality, divided by body weight category, adapted from Conventional Powerlifting (CP), in which the athlete only performs the bench press movement[1]. This movement is done with the lower limbs extended over the bench and can be fixed by straps for eligible deficiencies[1]. Paralympic world record holders demonstrated greater strength (relative and absolute) when compared to conventional ones in six of the eight weight categories for men. Hence, the results of Paralympic athletes were better, presenting greater strength when compared to conventional athletes[2]. The mechanisms underlying the superior strength of Paralympic powerlifting (PP) athletes compared to conventional powerlifting (PC) athletes have not yet been fully elucidated. Data indicate that PP athletes outperform PC athletes in six out of eight body weight categories[3], although the biomechanical and physiological bases of this performance remain unclear. Resende et al.[4] investigated the effects of warm-up in Paralympic athletes and found that, even in the absence of prior warm-up, these individuals exhibited strength levels comparable to those recorded after structured warm-up. The authors suggested that the continuous use of wheelchairs or crutches as a means of locomotion imposes a constant demand on the upper limb musculature, with movement patterns partially analogous to the bench press, acting as a natural warm-up and enhancing neuromuscular readiness for the sport. Thus, the greater daily functional demand on the involved muscles, associated with the aforementioned modes of locomotion, may promote specific neuromuscular adaptations in PP athletes, contributing to superior strength gains compared to PC athletes.

Although the execution of PP is similar to that of CP, there are possible disparities between the training methods used by the athletes[5]. These muscle strength training, used in the preparation of CP and PP, have been shown to be effective in improving performance in competition[5,6]. The training model used plays an important role in periodization. Among the most researched methods for gaining strength, the traditional training method (TT)[7,8] and the eccentric training method (ET)[9,10]. The TT model consist of 1 to 5 repetitions with a heavy load regimen that normally increases strength[11] (80% to 100% of 1 Repetition Maximum (1RM)). However, the magnitude of the eccentric load tends to influence performance responses[10]. Although heavy loads are necessary to achieve maximal gains in isotonic strength, lighter loads also promote substantial increases in this outcome[12]. In the same direction, it was observed that eccentric training would improve muscle mechanical function and provide morphological and architectural adaptations of the muscle–tendon unit. Thus, eccentric loads would be superior to traditional training in terms of strength, power and speed[13].

In the context of Paralympic powerlifting, the choice of training methods is pivotal for athletic performance. The TT, emphasizing concentric contraction, has demonstrated benefits in enhancing muscle strength and power[11]. Conversely, the ET, focusing on the muscle lengthening phase, has proven effective in promoting strength gains, particularly in athletic populations[14]. Given the specificity and complexity of the bench press in Paralympic Powerlifting, leveraging different training methods may yield advantages, optimizing strength gains. Given the absence of a consensus on the most effective training method for athlete preparation, this study is aimed to evaluate the effects of different strength training methods (traditional and eccentric) on static strength indicators (maximum isometric force and time to maximum isometric force), muscle activation, and skin temperature in Paralympic Powerlifting. Our hypotheses were that eccentric training would promote higher skin temperature (I), lower static strength indicators (II), and greater muscle activation than traditional training (III).

Methods

The studied population was made up of Paralympic Weightlifting athletes from the Federal University of Sergipe—Brazil. At the beginning of the training season, the athletes were invited to participate in a meeting, where they explained: the research, the evaluations, the expected benefits, the ethical considerations and any doubts that may exist.

Inclusion criteria required athletes to provide supporting documentation confirming their classification in the competition. To be eligible, athletes needed to be in the top ten in their respective categories, have at least 1 year of competitive experience, have participated in at least one national-level competition in the previous year and commit to participating in the study. Exclusion criteria included refusal to participate and the presence of motor limitations or comorbidities that prevented involvement in the planned evaluations. All pre-selected individuals were submitted to anamnesis to determine their characteristics.

The assessments were carried out over 3 weeks to assess the acute effects of each training method. During the initial week, a familiarization session was held, including collecting the athlete's weight and performing the 1RM test. In the second and 3rd weeks, data collection took place between 9 am and 12 pm, maintaining a room temperature of 25 °C, according to the availability of the subjects. Measurement of Maximum Isometric Force (MIF), Time until Maximum Isometric Force (Time), Skin Temperature (Thermo) and Muscle Activation (sEMG) were acquired for traditional and eccentric training methods, during a single exercise session training. The athletes demonstrated proficiency in training at intensities greater than 80%, employing a variety of training methods in their annual preparations.

During the TT method, a fixed overload of 80% of 1RM was used in the concentric and eccentric phases throughout the movement, as described by Austin and Mann[7]. For the ET method, concentric overload of 80% of 1RM and eccentric overload of 110% of 1RM were used, as described by Taber et al.[10], where in this method a system was adapted for the end of the eccentric phase of the movement. The intervention consisted of 5 sets of 5 repetitions (5X5), with a minimum rest between sets of 3 min and an approximate cadence of 1 s in the concentric phase and 2 s in the eccentric phase. As the weight touched the ground and an additional load of 30% was removed from the bar, thus remaining 80% for the concentric phase of the movement. During training sessions, athletes received verbal encouragement to perform their maximum effort. The sEMG was performed in the last series of each training method. The Thermo, MIF and Time were performed moments before, after, 24 h and 48 h of the procedure, as shown in Table 1.

Sample

In the first stage, individuals received the guidelines relevant to the study and fully complied with the ethical guidelines established in Resolution 466/12 of the National Health Council, which regulates standards for carrying out research on human beings. When agreeing to participate, they signed the Free and Informed Consent Form, approved by the Research Ethics Committee of the Federal University of Sergipe—CAAE: 2,637,882, according to resolution 466/2012 of the National Research Ethics Committee, of the National Health Council, in accordance with the Declaration of Helsinki, guaranteeing the protection of the rights, well-being and dignity of research participants.

Instruments and procedures

To collect body mass, the athletes remained seated on the Micheletti electronic wheelchair scale (Mic Wheelchair Model) of the digital electronic platform type (Micheletti, São Paulo, Brazil), which has a maximum capacity of 300 kg. For the bench press exercise: a bench, bar and powerlifting bench press clip were used from official competitions homologated by the WPPO (Eleiko Sport AB, Halmstad, Sweden)[1].

Maximum load determination

To determine the load, the 1 Repetition Maximum (1RM) test was performed on the bench press, using official equipment, where each athlete used a load to perform only one repetition, with an increase or decrease of 2.4 to 2.5% of the load until reaching 1RM, with an interval of 3 to 5 min for recovery between sets[4].

At the beginning of each test day, the athletes performed a prior warm-up for the muscles involved in the movement with three sets of 10 to 20 repetitions followed by a specific warm-up on the bench press with 30% of the load for 1RM with 10 slow repetitions followed by 10 fast repetitions[15].

Maximal isometric force (MIF) and time until maximal isometric force (Time)

Measurements of maximum isometric force (MIF) and time until maximum isometric force were determined by a Chronojump load cell (Chronojump, BoscoSystem, Barcelona, Spain) Mendonça[16], with a capacity of 500 kg,

Weeks		Day 1	Day 2	Day 3	Other days
Week 1 (Familiarization) 1RM, MIF, Time, Thermo e sEMG		Before, after	24 h	48 h	Rest
	→				
Week 2 (Tradicional Training) MIF, Time, Thermo e sEMG		Before, after	24 h	48 h	Rest
	→				
Week 3 (Eccentric Training) MIF, Time, Thermo e sEMG		Before, after	24 h	48 h	Rest
	→				

Table 1. Experimental drawing—Weekly test schedule. 1RM, One Repetition Maximum; MIF, maximum isometric force; Time, time until maximum isometric force; Thermo, Temperature skin; sEMG, Muscle activation. The tests were carried out using the bench press exercise a homologated by the WPPO[1].

output impedance of 350 ± 3Ω, insulation resistance greater than 2000 cc, input impedance 365 ± 5 Ω, 24-bit analog to digital converter, 80 Hz. Spider HMS Simond carabiners (Simmond, Chamonix, France) were used to fix the equipment on the bench, with breaking load of 21 KN, (UIAA). To fix the load cell to the bench, a steel chain with a breaking load of 2300 kg was used. A perpendicular distance between the load cell and the center of the bench was used as a reference[17,18].

Maximum isometric strength (MIF) and Time until Maximal Isometric Force (Time), was determined by the maximum strength of the upper limbs, and an elbow angle close to 90° was maintained, and at a distance of 15 cm from the bar to the chest. Athletes were instructed to make a single maximum movement (as fast as possible). The fatigue index (FI) was determined in the same way as the MIF, where the athletes maintained the maximum contraction for 5.0 s[19].

The MIF was measured by the maximum force generated by the muscles of the upper limbs during the bench press exercise[1]. The MIF is determined in Newtons (N) by the formula $N = (M) \times (C)$, where M = mass in kg and C = 9.80665, measured between the load cell cable attachment point and the bench press. For the isometric test, the elbows were positioned at an angle close to 90°, and the angle was checked using a pendulum fleximeter model FL6010 (Sanny, São Bernardo do Campo, Brazil). The athletes were instructed to perform a maximum movement, seeking to extend their elbows with maximum speed, to evaluate the MIF. The athletes had to maintain the maximum contraction for 5 s to evaluate the time until MIF[17,18].

Surface electromyography (sEMG)

The electromyographic signals were captured using simple electrodes (MAXICOR—Shanghai Intco Electrode Manufacturing Co Ltd, China) fixed to the skin after shaving and cleaning it with alcohol. The electrodes (11 mm contact diameter and 2 cm center-to-center distance) were positioned in the arrangement of the muscle fibers, two centimeters from the center, at the point of greatest muscular area of the pectoralis major muscles, sternal and clavicular portions, anterior deltoid and long head triceps brachii, with the reference electrode fixed to the olecranon, as recommended by SENIAM (Surface Electro Myo Graphy for the Non-Invasive Assessment of Muscles)[20].

The equipment used for recording and analyzing muscle biopotentials was a MIOTEC electromyograph with 8 channels (MIOTEC, Porto Alegre, RS, Brazil). Data were high-pass filtered with a frequency of 20–500 Hz and a notch of 60 Hz. The calculation of the signal amplitude was performed using the root mean square (RMS), with a window of 100 RMS, with normalization by percentage of maximum voluntary isometric contraction (MVIC), considering the beginning and end of the movement.

The signal normalization was performed before the test in each target muscle, with the determination of MVIC through the execution of 1RM isometric bench press, lasting 6 s. The MVIC values obtained were recorded in the electromyography software and used for normalization[6,15].

Thermography (Thermo)

To collect the thermographic image, a room was prepared with artificial lighting, temperature controlled by air conditioning and hygrometer (HM-01; HIGHMED, USA), with a temperature of around 24 °C and relative humidity of around 50%[5,21].

To obtain the thermograms, the athletes remained seated, did not make sudden movements and were instructed not to perform vigorous physical activity in the last 24 h, not to consume alcohol or caffeine and not to use any type of cream or lotion on the skin up to 6 h before evaluation[22]. The images were obtained with a thermal camera (Seek Thermal Compact Pro, Moscow, Russia) (Fig. 1), with a resolution of 320 × 240 pixels and a temperature range of − 4 to 330 °C, at a distance of 0.91 m to 5.48 m from the athlete. The body regions of interest were the pectoralis major, sternal and clavicular portions, anterior deltoid and long head of the triceps brachii[5,15]. The region of interest evaluated was the anterior and posterior faces of the trunk and arms[23] (Fig. 2).

Statistical analysis

The descriptive statistics were performed using measures of central tendency, mean (X) ± Standard Deviation (SD) and 95% confidence interval (95% CI). To check the normality of the variables, the Shapiro–Wilk test was used, considering the sample size. Data for all analyzed variables were homogeneous and normally distributed. To evaluate performance, two-way ANOVA within repeated measures was used[24] was performed, with Bonferroni Post Hoc, in two conditions (TT and ET), and at four moments (before, after, 24 h and 48 h), considering the values: low effect (≤ 0.05), medium effect (0.05 to 0.25), high effect (0.25 to 0.50) and very high effect (> 0.50). For the t test, an effect size (Cohen's d) was considered, adopting the values: low effect (≤ 0.20), medium effect (0.20 to 0.80), high effect (0.80 to 1, 20) and very high effect (> 1.20))[25]. The statistical treatment was performed in SPSS, version 22.0 (IBM, Armonk, NY, USA). The significance level adopted was $p < 0.05$.

The sampling power was calculated a priori using the open software G*Power version 3.1.9.6 (University of Kiel, Germany), with the "F family (ANOVA)" considering a standard $f = 0.8$, $\alpha < 0.05$, $1 - \beta = 0.80$. Hence, it was possible to estimate a sampling power of 0.88 for a minimum sample of twelve subjects per group, suggesting that the study has statistical strength to answer the research[5]. This can be confirmed from the partial mean values of Eta squared ($\eta 2p = 0.425$) found and classified as a high effect[24].

Results

The sample consisted of 12 male athletes with national and international participation representing the Brazilian Paralympic Committee and the World Para Powerlifting (WPPO)[1], aged 30.25 ± 8.13 years, meeting our inclusion criteria and successfully completing all specified tests. The sample characteristics are detailed in Table 2, using descriptive statistics with mean and standard deviation for each variable.

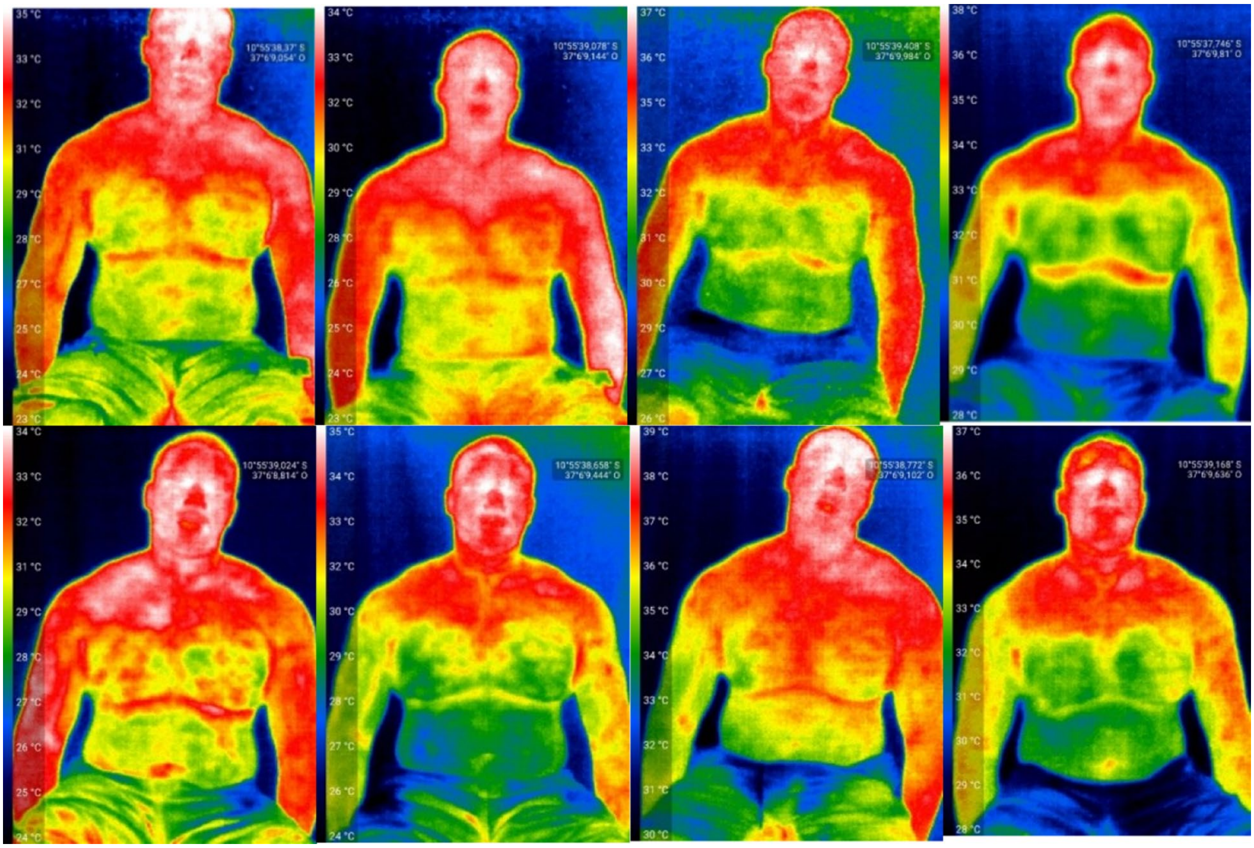

Fig. 1. Illustration of thermal images at before, after, 24 h and 48 h in TT and ET, respectively.

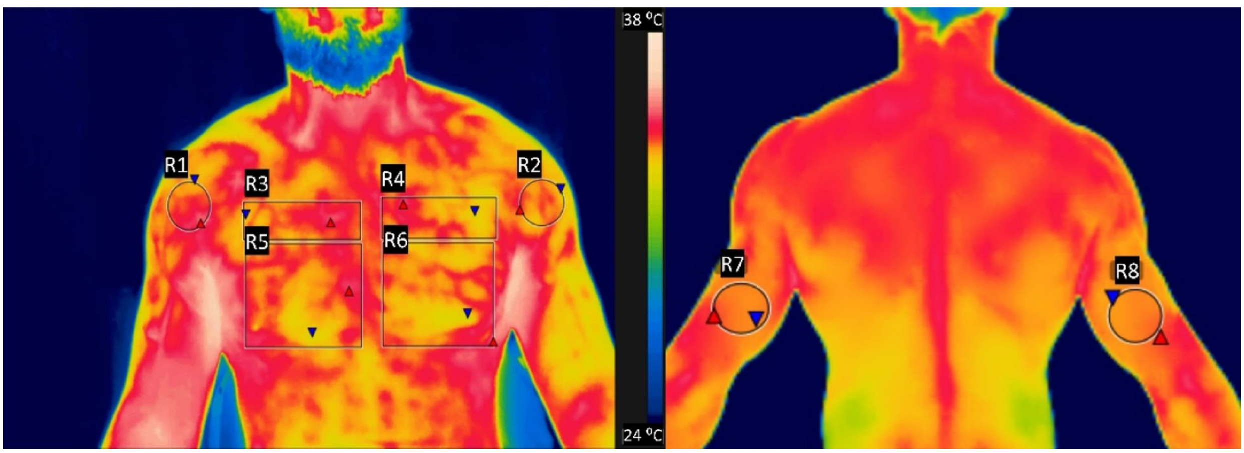

Fig. 2. Illustration of the regions of interest (ROI) in the thermal images acquired.

Figure 3 presents the results of muscle activation through surface electromyography (sEMG) (A) Peak and (B) Average, of different muscle groups.

There was no difference between muscle electrical activity (EMG) in different muscles in relation to Traditional and Eccentric Training ($p > 0.05$).

Figure 4 shows the results of skin temperature (Thermo) in the muscles (A) Pectoralis Major Sternal portion, (B) Pectoralis Major Clavicular portion, (C) Anterior Deltoid, and (D) Brachii Triceps, in the moments before, after, 24 h and 48 h.

(A) There was a difference in Eccentric Training, at the Before moment related to the 24-h period ("a" $p = 0.022$; an increase of 2.17 °C; 6.28%) and related to the 48-h period ("b" $p = 0.030$; the increase of 2.08 °C; 6.05%; $\eta 2p = 0.177$, Medium Effect). (B) There was a difference in Eccentric Training between the Before and 24-h moments ("a" $p = 0.011$; the increase of 2 °C; 5.71%) and 48 Hours ("b" $p = 0.049$; the increase of 1.92 °C;

Variables	Value
Age (years)	30.25 ± 8.13
Experience (years)	5.92 ± 1.37
Body weight (Kg)	72.36 ± 18.47
1RM test in bench press (Kg)	125.00 ± 37.83
1RM/Body weight	1.74 ± 0.31

Table 2. Characterization of the sample. RM, repetition maximum in bench press. Values expressed as mean and standard deviation.

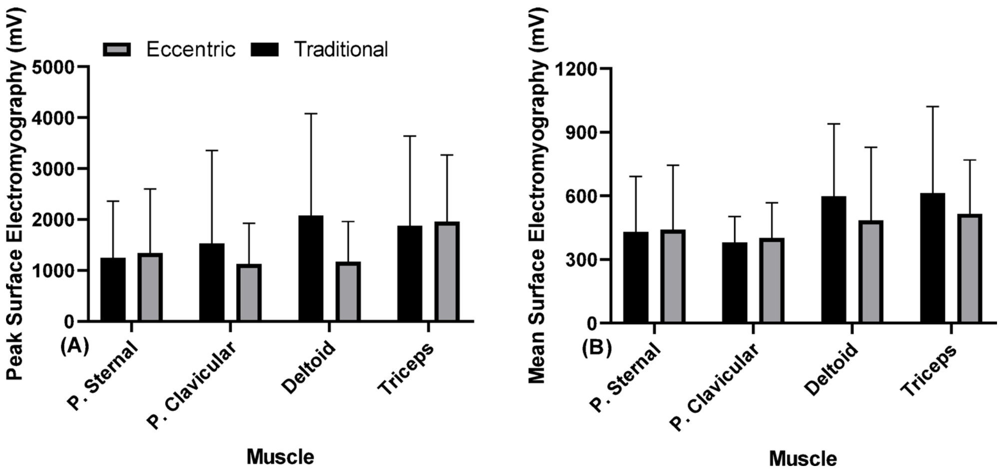

Fig. 3. The muscle electrical activity through surface electromyography (sEMG) (**A**) Peak and (**B**) Average, of the different muscle groups. Legend: Pectoralis Major Sternal Portion (P. Sternal), Pectoralis Major Clavicular Portion (P. Clavicular), Anterior Deltoid (Deltoid), Triceps Brachii, Long Head (Triceps). Values represented by mean and standard deviation.

5.49%; η2p = 0.192, Medium Effect). There was also a difference in the 24-Hour Moment between Eccentric and Traditional Training ("*" $p = 0.020$; the increase of 1.58 °C; 4.52%; η2p = 0.213, Medium Effect). (C) There was a difference in Eccentric Training between the Before and 24-Hour moments ("a" $p = 0.012$; the increase of 1.83 °C; 5.21%; η2p = 0.202, Medium Effect). There was also a difference in the 24-Hour Moment between Eccentric and Traditional Training ("*" $p = 0.016$; the increase of 1.58 °C; 4.50%; η2p = 0.228, Medium Effect). (D) There was a difference in Eccentric Training between the Before and After moments ("a" $p = 0.014$; the increase of 1.08 °C; 3.27%;) and 48 h ("b" $p = 0.028$; the increase of 1 0.33 °C; 3.99%; η2p = 0.421, High Effect). Also, there was a difference in the 24-Hour Moment between Eccentric and Traditional Training ("c" $p = 0.028$; the increase of 1.08 °C; 3.24%; η2p = 0.143, Medium Effect).

The Fig. 5 shows the results of (A) Maximum Isometric Force (MIF) and (B) Time until Maximum Isometric Force (Time), in the moments before, after, 24 h and 48 h later.

(A) There was a difference in Traditional training, between the moments before and after ("a" $p = 0.003$; reduction of 120.37N; − 19.36%;), between the moments after and 48 h ("b" $p = 0.002$; increase of 159.20N; 20.38%;) and between 24 and 48 h ("c" $p = 0.005$; increase of 129.34N; 16.56%;). In Eccentric training, there were differences between the moments before and after ("d" $p = 0.001$; reduction of 137.19N; − 23.45%;) and between after and 48 h ("e" $p = 0.034$; increase of 85 0.52N; 12.75%; η2p = 0.494, High Effect). There were also differences at the 48-h time point between Traditional and Eccentric training ("*" $p = 0.004$; The TT was greater than the ET at 110.50N; 14.15%; η2p = 0.360, High Effect). (B) There was no difference in relation to Time until MIF ($p > 0.05$).

Discussion

The objective of this study was to evaluate the acute effects of different strength training methods (traditional and eccentric) on static strength indicators (maximum isometric force and time until maximum isometric force), muscle activation and skin temperature in athletic athletes Paralympic Powerlifting, after 3 weeks of traditional training (80% of 1RM) and eccentric training (110% of 1RM).

Corroborating our hypothesis I, an increase in Thermo was observed 24 h after Eccentric training (3.27–6.28%), in addition to an increase in Thermo among the training methods evaluated (3.24–4.52%) during the bench press. These elevations in Tsk in athletes identify a systemic inflammatory response following training methods. In relation to our hypothesis II, a reduction in strength was found in the initial phase (− 19.36%), followed by an increase in the final phase (20.38%) of traditional training. Likewise, in relation to eccentric

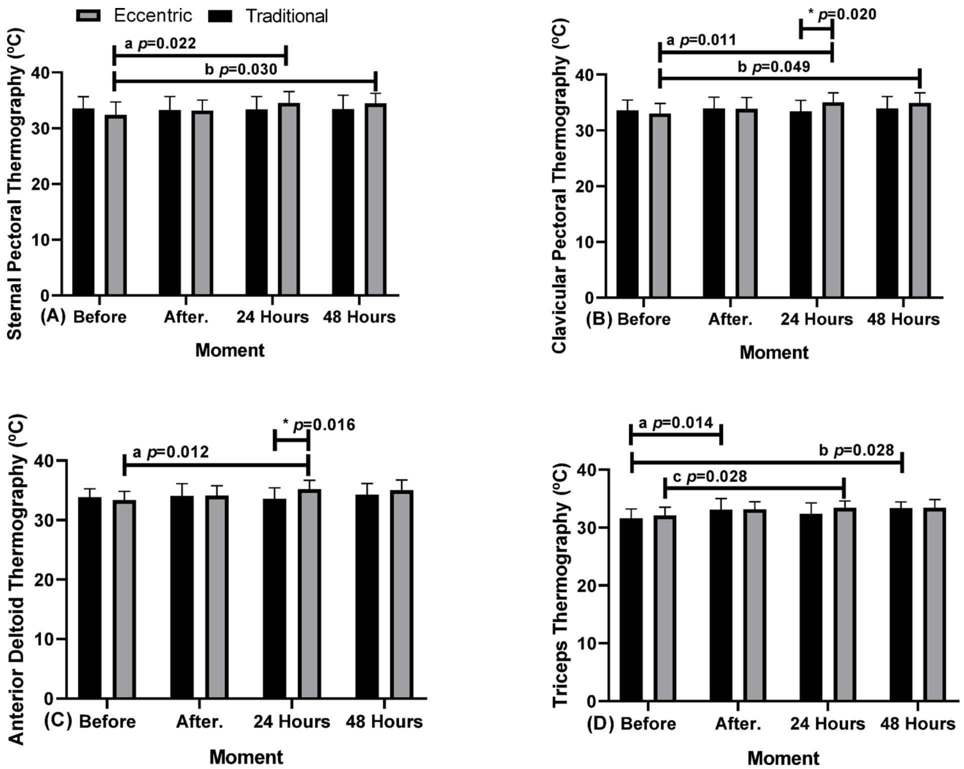

Fig. 4. Skin temperature in the muscles (**A**) pectoralis major sternal portion, (**B**) pectoralis major clavicular portion, (**C**) anterior deltoid, and (**D**) Brachii Triceps, in the moments before, after, 24 h, and 48 h. Values represented by mean and standard deviation.

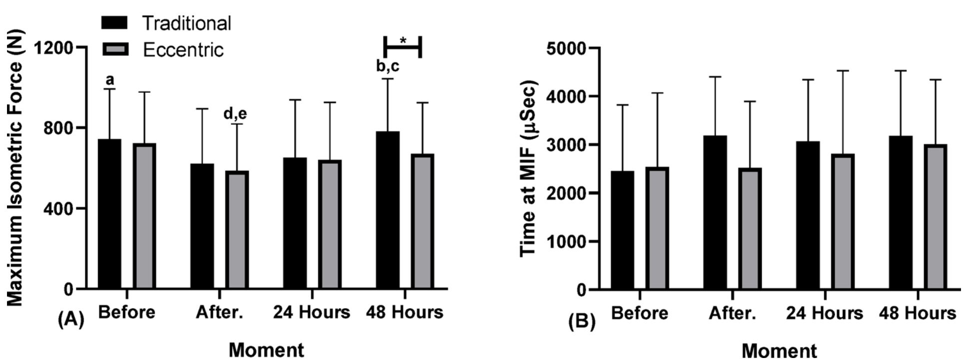

Fig. 5. (**A**) Maximal isometric force (MIF) and (**B**) Time until maximum isometric force (Time), in the moments before, after, 24 h and 48 h later. Values represented by mean and standard deviation.

training, there was a reduction in the initial phase (−23.45%), followed by an increase in the final phase (12.75%). However, no significant difference was observed in relation to Time. In relation to our hypothesis III, although the Deltoid was requested more during the movement, no statistical difference was observed in muscle activation between the training methods evaluated.

Thermography

The infrared thermography allows qualitative and quantitative analyzes to be carried out, identifying regions of hyperthermia/hypothermia, which contributes to the assessment of the athlete's physical state. This physiological process is associated with heat transfer by methods such as convection, conduction, radiation and evaporation[26]. This condition differs from biochemical markers, such as creatine kinase, which do not determine the anatomical location of the site that presents the greatest inflammatory process[22]. It is known that the more vascularized the injured area, the faster the healing will be, compared to poorly vascularized areas.

In the Eccentric training method, an increase in Thermo was observed after 24 h in all muscles evaluated, remaining increased until 48 h after training in the pectoralis major muscle, sternal portion, which indicates changes in blood flow in the areas of interest. Thus, changes in skin temperature occurred after exercise in the muscles studied, indicating a systemic inflammatory response[27]. These changes occurred mainly 24 h after exercise, as demonstrated by Dindorf[28] who observed that in this 24-h period the subjects' temperature returned to its initial state, reporting uncertainties in the temperature for the 48-h period. Our study investigated these changes within 48 h, as according to Stewart[27] this is the moment when the increase in Thermo arrives. The increase in temperature in the 24 h and 48 h post-exercise may reflect a delay in the anti-inflammatory response[15]. These differences in thermoregulatory processes may occur because trained individuals delay the increase in Thermo[28]. Hence, the muscle recovery process tends to increase Thermo up to 96 h after exercise, especially after high-intensity exercise[29].

The eccentric training promoted an increase in Thermo in up to 24 h in the muscles involved, compared to Traditional training. While increases in blood flow and skin temperature are indicators of muscle fatigue, measurable Thermo is linked to thermoregulatory effects such as skin blood flow or sweat gland activity[28]. This would be justified by the greater stimulation of vasoconstrictor responses, controlled by the adrenergic nerves of the sympathetic nervous system and modulated by the action of noradrenergic neurotransmitters[22]. Intense exercise tends to induce an initial decrease in body temperature, followed by a subsequent increase due to the resulting inflammatory process. This thermal variation was discussed by Neves[29], who suggests that, while the temperature rise is generally attributed to local inflammation, it may also be associated with the application of a localized vascular stimulus. This stimulus, in turn, could trigger a systemic endothelial adaptation. However, the direct relationship between this adaptation and the delayed temperature increase still requires further investigation to be fully understood.

Another explanation that can be found about the effect of ET in relation to TT is the load used, reaching a 30% difference in 1RM in the overload used in the methods, which could play an important role in directing blood flow. In this sense, elevations of pro-inflammatory cytokines are observed immediately after eccentric muscle injury, while circulating levels of C-reactive protein have been demonstrated uniformly at the time point 24 h after exercise[28]. Furthermore, measuring Tsk in individuals who use a wheelchair to move around during the assessment is difficult, making a true resting point difficult[4].

Surface electromyography

Our study found no significant differences in EMG activity between the performed training methods. Although greater muscle activity was observed in the anterior deltoid (AD) muscle, the difference was not statistically significant ($p > 0.05$).

The sEMG allows estimating which muscles are predominantly involved in the kinetics of a specific movement[20]. A similar non-significant finding was reported by Gottschall[30], who compared sEMG in various muscles during bench press and push-up exercises in beginner and advanced subjects. In their study, the authors reported that the anterior deltoid exhibited lower sEMG during the bench press, aligning with our non-significant result. Likewise, Alizadeh[31], in an investigation of sex-related sEMG during push-up and bench press exercises, found lower sEMG during the eccentric phase of the bench press movement, without statistical significance. In a separate study, Mendonça[16] compared sEMG in Paralympic Powerlifting athletes, observing a significant difference in the anterior deltoid muscle, however, this analysis involved partial repetitions. The direct relationship with muscle engagement during the bench press exercise is attributed to the high motor unit recruitment observed during the training session. This response occurs due to the demand for maximal force generation in lifts performed with loads exceeding 80% of 1RM.

Maximal isometric force and time

As for MIF in Traditional training, there was a reduction in strength in the initial phase, followed by an increase in the final phase. This finding is widely described in the literature as a response after a training session. In relation to Eccentric training, there was a reduction in the initial phase, continuing up to 48 h after the procedure. Qualitative and quantitative changes in tendon tissue that may be related to the magnitude of imposed stretch have also been reported with Eccentric training. The inclusion of eccentric loads appears to be superior to traditional training in the improvement associated with strength, power and speed performance[13].

The eccentric training showed an increase in MIF 48 h after the procedure. Other studies observed that MIF would be associated with range of movement[16] and pointed out that wider movements would induce greater fatigue, with greater loss in maximum isometric strength. It was also observed that the use of variable resistance (elastic bands) tends to promote greater loss of strength and increase fatigue in Paralympic Powerlifting athletes[8]. These findings corroborate ours, where athletes showed an increase in strength indicators in the TT method in relation to the ET method, indicating that the subjects continue to feel fatigue even after training.

The strength is supported by a combination of morphological and neural factors, including area motor unit recruitment, speed coding, motor unit synchronization, and neuromuscular inhibition. Traditional and Eccentric training can produce strength and power benefits, which may vary according to training time, type of muscle fiber and athlete's genetics. In our study, no significant difference was observed in relation to Time until Maximum Isometric Force ($p > 0.05$). A decrease in strength following a maximal training session is expected due to the mechanical stress induced by muscle contractions. In our study, although no statistically significant differences were observed, the ET exhibited greater fatigue and stress. This response may be associated with a decline in strength, characterized by a greater amplitude of reduction in Maximum Isometric Force.

Limitations

Our study has some limitations, as our athletes participate in a sport that has a single classification, not divided by disability, which could have different results. Differences in body weight were not taken into account, as lighter athletes tend to have greater relative strength and heavier athletes tend to have greater absolute strength, which could interfere with the results if they were separated by body weight category. Future research should investigate how best to implement traditional and eccentric training and examine how strength affects an athlete's ability to improve performance after various training methods.

Conclusions

In the present study, it was determined that the muscles involved in the bench press exercise showed a notable increase in skin temperature (Thermo) after implementing the Eccentric training method (ET) in contrast to the traditional method (TT). This observation was noted in the acute response to the bench press exercise, indicating a high occurrence of muscle fatigue. Additionally, there was a substantial increase in the production of Maximum Isometric Force (MIF) after performing Eccentric training, emphasizing its influence not only on muscular fatigue, but also on a further increase in the production of muscular force.

In practical application, as mentioned previously, the Eccentric training method (ET) appears to be more effective in the acute response to the bench press exercise, attributed to the use of heavy weights and resulting in greater neuromuscular adaptations. However, it is essential to recognize that muscle recovery time tends to be prolonged. Coaches must meticulously evaluate, plan and periodize the chosen training method and recovery period for Paralympic Powerlifting athletes.

Data availability

Data sets generated during the current study are available from the corresponding author on reasonable request.

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Conceptualization, J.A.S.L.J. and F.J.A.; methodology, F.J.A; software, J.L.M.; validation, P.F.A.N., B.G.A.T.C. and A.F.S.; formal analysis, G.B.; investigation, C.J.B.; resources, R.F.S.; data curation, J.A.S.L.J.; writing—original draft preparation, H.N.; writing—review and editing, G.B., F.H.Y., F.M.C, A.F.A; visualization, A.F.S; supervision, A.F.A and F.J.A

Declarations

Competing interests

The authors declare no competing interests.

Ethical approval and consent to participate

The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Institutional Review Board and approved by the Human Research Ethics Committee of the Federal University of Sergipe (UFS), under Statement Number 2637882/2018.Written informed consent was obtained from all individual participants included in the study.

Additional information

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