Exercise Physiology

Caffeine intake improves muscular endurance and induces depletion of anaerobic work capacity in the bench press

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Abstract - Aim: To investigate the effects of caffeine (CAF) ingestion on anaerobic work capacity (AWC) and muscular endurance in the bench press exercise at predictive intensities equivalent to 20, 25, and 30% of 1RM. **Methods:** Thirteen males (age: 23 ± 3 years; body mass 83.5 ± 4.9 kg; height 172.8 ± 5.0 cm and 1RM 82 ± 24 kg) had their 1RM test evaluated in the bench press exercise and the time until failure was performed at intensities equivalent to 20%, 25%, and 30% of 1RM to CAF (350mg) or placebo (PLA, cellulose). AWC was measured from the linear equation: "Force = Critical Force + (AWC x 1/timeout)". **Results:** CAF enhanced the time until failure at 20% of 1RM (PLA = 202.6 ± 29.1s; CAF = 243.2 ± 20.6s), but there was no ergogenic effect at 25% (PLA = 188.8 ± 23.5 s; CAF = 195.6 ± 27.1 s), and 30% (PLA = 147.4 ± 15.8 s; CAF = 145.4 ± 14.8 s). AWC in CAF was lower than PLA (PLA = 6378.0 ± 1214.9 J; CAF = 3246.4 ± 1389.7 J; p = 0.03; *Effect size* = 0.88). Critical Force (N) was not different between treatments PLA 29.97 ± 11.54% of 1RM and CAF 3.74 ± 3.69% of 1 RM (p=0.47; *Effect size*= 0.28). **Conclusion:** Acute CAF intake (350mg) reduces the AWC and increases the time until failure at 20% of 1 RM, but not Critical Force and muscular endurance at 25% and 30% of 1 RM in the bench press.

Keywords: Resistance training, anaerobic capacity, critical force, 1RM.

Introduction

Caffeine (1,3,7-trimethylxanthine) (CAF) is a safe ergogenic resource widely used by amateurs and athletes to delay the onset of fatigue[1,2]. Caffeine acts in central and peripheral tissues by different mechanisms: (i) antagonism of adenosine receptors; (ii) intracellular calcium release; (iii) phosphodiesterases inhibition; (iv) glycogenolysis; (v) increases fatty acid oxidation and others. Several studies have reported the ergogenic effects of acute CAF intake, mainly in endurance performance tasks[3-5]. However, the results are contradictory for high-intensity exercises, especially in strength exercises[5,6].

Some studies have not found improvements in resistance performance with acute CAF intake in the number of maximal repetitions[7], perceived exertion[7,8], and perception of pain[7]. On the other hand, ambiguous data have seen CAF ergogenic effect on the number of repetitions[8-10], torque[11], perceived exertion, and pain perception in resistance exercise[7]. The CAF ingestion had contradictory evidence on resistance exercise performance, specifically to muscular endurance[8,9,11,12]. Astorino et al.[13] reported in strength-trained men, after acute CAF intake, increases in EPOC and energy expenditure. In other high-intensity exercises, the CAF increases the time to exhaustion and other physiological variables[14]. Specifically, the CAF increases peak lactate concentration from rates of ATP resynthesis dependent on catecholamine and calcium releases to activate phosphorylase and phosphofructokinase enzyme catalysis[3,15-18]. On the other hand, Doherty et al.[18] did not find CAF intake influenced exercise blood lactate concentration. In addition, CAF intake, despite improving time to exhaustion at MAOD predictive intensities in a supramaximal cycling test, did not alter the phosphagen energy system[22]. Thus, possible changes in lactate concentration, EPOC, and ATP resynthesis caused by the acute ingestion of CAF may interfere with the assessment of anaerobic capacity.

The anaerobic capacity (AC) is defined as the maximal amount of ATP resynthesized via non-mitochondrial pathways during a specific short-duration and maximal exercise[19]. The maximal accumulated oxygen deficit (MAOD) has been assumed the "gold standard" method to evaluate the AC. Some studies investigated the CAF intake (5 mg·kg^{-1}) on MAOD and reported an increase in AC[18,20]. On the other hand, studies are showing that caffeine seems to have no apparent effect on AC measured by MAOD[21,22], but the time to exhaustion improved at an intensity equivalent to 115% of VO_2max in the cycling test[22]. Furthermore, the AC estimated by the critical power model was influenced by CAF supplementation[21]. Thus, further studies are needed to understand better and expand the evidence on CAF intake and AC. To date, no study investigated whether CAF ingestion can change the AC from the Critical Force model in resistance exercise.

An alternative method to evaluate the AC can be the AWC. The AWC in the Critical Power Model has been reported as a limited reserve of anaerobic energy stored in the skeletal muscle, derived from high-energy phosphates and glycolysis leading to net lactate formation, to be used during short-term and high-intensity exercise[23,24]. AWC is the supply of energy from phosphagen reserves and mobilization of anaerobic glycolysis, historically called the monocompartmental model[24] or the three-component hydraulic model[25,26]. AWC can be calculated in resistance exercise from the adaptation of the critical power model, specifically AWC - W' derivation, resulting from the relationship between the mechanical force generated at exhaustion in various intensities[27]. The main advantage of this method is that the anaerobic capacity can be estimated in specific, non-invasive, and low-cost protocols. However, the sensitivity of CAF supplementation on the critical power model was reported in cycling test[21], but in the resistance exercise is not yet known.

Thus, the present study investigated the effects of acute caffeine ingestion on anaerobic work capacity and time until failure at predictive intensities equivalent to 20, 25, and 30% of 1RM in the bench press exercise. We hypothesized that caffeine intake increases the time until failure in predictive intensities and consequently the AWC expenditure.

Methods

Participants

Thirteen healthy male resistance exercise practitioners for at least 3 months of resistance training (age: 23 ± 3 years; body mass 83.5 ± 4.9 kg; height 172.8 ± 5.0 cm and 1RM 82 ± 24 kg), volunteered for this study. All participants completed all experimental tests. The local ethics committee approved the study (registration number 86006817.0.0000.5013).

Experimental approach to the problem

Participants visited the laboratory 4 times. A minimum interval of 48 hours was adopted between each visit. At the first visit, height and body mass were evaluated before the 1RM test to detect the maximum repetition load in the bench press exercise. Intensities equivalent to 20%, 25%, and 30% of 1RM were performed until failure in random and counterbalanced order to CAF or PLA treatments. Participants received verbal stimulation throughout the exercise to ensure maximum repetitions until failure was controlled by a digital metronome with 3 s of concentric phase and 3 s of the eccentric phase. A warm-up was performed with 20 repetitions, with a bar (10 kg), without additional load, at the same pace of tests.

Participants were instructed not to use caffeinated, alcoholic, or dietary supplements 24 hours before the test days. They were also instructed to standardize their diet within 24 hours before the test days. All tests were performed at the same time of day to avoid circadian variability.

1RM tests

On the first visit, a 1RM bench press test was performed to verify the maximum load that an individual could support in a single repetition, without the possibility of a second repetition.

The 1-RM test was performed on the bench press, with some guidelines taken into account[28].

1- The participants were familiarized and oriented concerning breathing patterns, hand distance, and movement techniques.
2- The warm-up was performed by the participants in two sets of 15 to 20 repetitions varying from 30% to 60% of 1RM.
3- The maximum weight for the first attempt will be the subject's body weight or the reported weight.
4- In the case of a new attempt, it was increased by at least 5% of the weight lifted.
5- Three to five minutes of recovery between each attempt were carried out to promote the restoration of muscle reserve of ATP (adenosine triphosphate) and CP (creatine phosphate).
6- For the attempted overcoming of the lifted weight to be accepted as valid, it was taken into account if the execution established the standards of correctness and motor correction of the exercise such as elbow angulation in the eccentric phase of the movement, the speed of movement and execution control in the concentric phase.

After 3 attempts, if the load was not reached, the participant would rest for 24 hours to find his maximum load.

Critical force test

Predictive intensities until exhaustion were performed at visits 2, 3, and 4, separated by at least 48 hours apart. Throughout the exercise, subjects received verbal stimulation to ensure maximum exhaustion timeout recorded by a digital timer. Movement execution velocity was controlled by a digital metronome that beeped every 6 s corresponding to the final phase of the movement, with 3 s in the concentric phase and 3 s in the eccentric phase. Subjects were instructed to touch the bar on the chest for maximum range of motion. The participant was considered exhausted when there was a pattern of 3 sequential errors without performing the exercise correctly or outside the metronome's time.

AWC was measured from the linear equation (Equation 1) and the model represented in Figure 1 as previously described[29]. The SI unit for Critical Force (CF) and AWC was assumed as Newton(N) and Joule (J) respectively.

$$\text{Force} = \text{Critical Force} + \left(\text{AWC x}\frac{1}{\text{timeout}}\right) \quad (1)$$

Supplementation

Anhydrous powder caffeine (350 mg) and placebo (PLA, Cellulose, 300 mg) were encapsulated by a local pharmaceutical establishment (Ao Pharmaceutico®). The CAF and PLA capsules were ingested with 250 mL of water. The CAF and PLA capsules had the same size (size 0), volume, color, and shape.

Statistical analysis

Data are presented as mean ± standard error. Shapiro-Wilk test was used to verify the normality of the residuals and paired student t-test was used to examine differences between conditions. Linear regression was used to calculate critical force and from it AWC verification. Cohen's Effect Size was calculated and interpreted using the following scale: Trivial (0-0.19), small (0.20-0.49), medium (0.50-0.79), and larger (0.80 and higher).

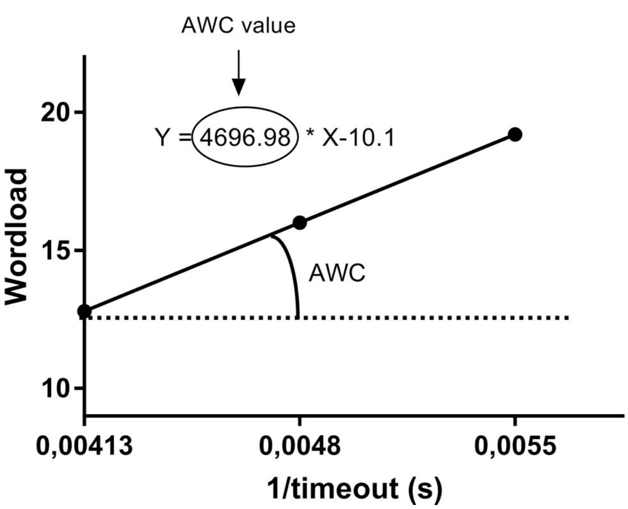

Figure 1 - AWC calculation model was obtained by 3 tests with loads at 20, 25, and 30% of 1-RM, from a representative subject of the sample. AWC = anaerobic work capacity. The SI unit for AWC was assumed as Joule (J).

Data were analyzed using SPSS® 17.0 software and the significance level adopted was $p < 0.05$.

Results

Time until failure

CAF enhanced the time until failure at 20% of 1RM, but there was no ergogenic effect at 25 and 30% of 1RM (Table 1).

AWC (J) e r^2

AWC in CAF group was lower than PLA ($p = 0.03$; *Effect size* = 0.88, Figure 2A). The r^2 of linear regression for PLA and CAF groups were $r^2 = 0.87 \pm 0.04$ and $r^2 = 0.94 \pm 0.01$, respectively. Figure 2B represents AWC monocompartmental model, percentage differences between treatments, and representative AWC (J) depletion in the CAF group.

Critical force (N)

There was no difference in Critical Force variable between PLA (29.97 ± 11.54% of 1RM) and CAF (3.74 ± 3.69% of 1 RM) treatments ($p = 0.47$; $t = 0.75$; *Effect size* = 0.28).

Discussion

This is the first research that compared the effects of acute CAF intake on the Critical Force model and their variables, time until exhaustion, AWC, and Critical Force on bench press exercise. The main finding of the present study was the effectiveness of CAF to increase AWC contribution and time until failure at 20% of 1RM. AWC was calculated from the angular coefficient of a linear regression fitted over 3 intensities (20, 25, and 30% of 1RM). The longer time to exhaustion in the CAF group at the intensity equivalent to 20% of 1RM shows that the angulations of the straight line and consequently the AWC may be more dependent on lower predictive intensity than 25 and 30% of 1RM intensities compared to PLA. AWC is not modified at an intensity less than or equal to critical power, but at higher intensities, the anaerobic reserve expenditure influences failure time[23]. Thus, the acute CAF

Table 1 - Values for the time until failure (s) at 20, 25, and 30% of the 1RM.

	Time (s) 20%	Time (s) 25%	Time (s) 30%
PLA	202.6 ± 29.1	188.8 ± 23.5	147.4 ± 15.8
CAF	243.2 ± 20.6	195.6 ± 27.1	145.4 ± 14.8
p-value	0.02*	0.719	0.482
Effect size	0.46	0.07	0.16

Values are expressed as mean ± standard error. Time = time until failure; PLA = placebo; CAF = caffeine.
*Difference from PLA condition ($p < 0.05$).

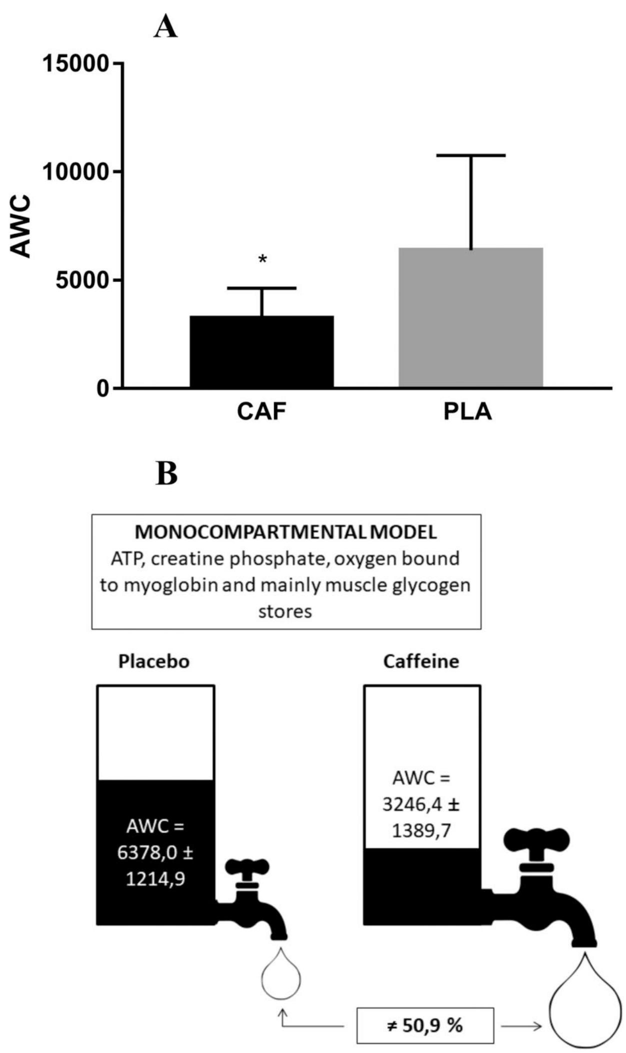

Figure 2 - A and B. AWC values (J). Data presented as mean ± standard error. * improvement in CAF condition in comparison to PLA condition. AWC = Anaerobic Work Capacity; PLA = placebo; CAF = caffeine ($p < 0.05$).

intake may increase the ATP expenditure, anaerobic contribution suggesting that caffeine could access an anaerobic "reserve" that is not used under normal conditions[16]. These data reinforce that the higher depletion of AC induced by CAF intake may improve the performance in the high-intensity effort. On the other hand, Machado et al.[30], evaluated the CAF intake in 8 subjects, using the Critical Power test in cycle ergometer, and reported improvement of AWC, contradicting our study. However, the dosage of CAF used by Machado et al.[30] was 6 mg.kg^{-1} body weight, while the present study offered a fixed dosage of 350 mg.

The main response of caffeine is the antagonism of adenosine receptors and as one of the consequences, it decreases the rating of perceived exertion (RPE)[32]. Although RPE was not evaluated in our study, the longest time until exhaustion may have occurred by a central mechanism. It is still unclear whether the AWC changes were predominantly due to peripheral bioenergetic factors or central mechanisms. Perhaps, the reductionist monocompartmental model is not sensitive to this critical question, and other more complex models are needed to explain fatigue in resistance exercise. Keller et al.[31] reported that performance fatigability was unvarying at intensities below or above CF, but suggested that peripheral fatigue likely contributed to a greater extent above CF. Thus, the mechanisms of CAF in high-intensity efforts, especially in resistance exercise, are not yet well established. In our study, CAF supplementation increased the Tlim compared to PLA at 20% of 1RM. For all predictive loads, the Tlim of our study was higher than Arakelian et al.[32] data in the leg press exercise at 60, 75, and 90% of 1RM, but lower compared to Tlim of Keller et al.[31]. Furthermore, Arakelian et al.[32], showed that Tlim in the elderly was higher, while the RPE was lower compared to young subjects. Perhaps, the highest Tlim values in the elderly group were influenced by the absolute load of the 1RM test and RPE, showing the sensibility of the model 1/tlim in relation to age differences. Thus, the mechanisms of CAF in high-intensity efforts, especially in resistance exercise, are not yet well established.

The ergogenic effect of CAF has been established in endurance tasks[2], while contradicting data have been reported in tasks involving strength, power, and muscular endurance[5,33]. The CAF as an antagonist of the adenosine receptors is consolidated and may reduce the perceived exertion, mainly in prolonged tasks, delaying the onset of fatigue. For high-intensity tasks, the physiological mechanism is not yet consolidated. A recent study from isolated muscles speculated that CAF in a micromolar concentration might increase calcium release from the sarcoplasmic reticulum and consequently muscle force[34]. The trial until exhaustion at 20% of 1RM was higher (243.2 ± 20.6 s) than 25 (195.6 ± 27.1 s) and 30% (145.4 ± 14.8 s) of 1 RM and probably, more dependent on antagonist of the adenosine receptors mechanism.

CAF as an ergogenic resource has been a source of many studies; there is still no consensus on the effects on anaerobic performance[6,7,33,35]. Although different physiological mechanisms of CAF, the predominant mechanism for each bioenergetics pathway is not well described. CAF on anaerobic exercises may be influenced by the duration of each exercise, training status of individuals, CAF concentration and time of administration, as well as genotypes[36]. Silveira et al.[37] reported that CAF action in high-intensity exercises is more pronounced at tasks greater than 3 minutes, corroborating our findings. CAF increased the time until failure at 20% of 1RM, over 200 s, while in other workloads less than 200s, 25 and 30% of 1RM, no differences were found between treatments. The acute CAF intake (6 mg.kg^{-1}) does not improve the number of repetitions to failure with 60% of 1RM, corroborating the hypothesis that the ergogenic effect may be sensible to the exercise duration[7]. On the other hand, Da Silva et al.[8] found an improvement in resistance performance at 80% of 1RM and 5 mg.kg^{-1} of CAF administration on the bench press and leg press exercises. A mechanism that could explain the ergogenic effect of caffeine on strength performance is the modulation of perceptual responses to exercise such as rating perceived exertion and pain perception.

It is noteworthy that few studies that analyze the performance of resistance training from critical force and even scarcer verify the effect of CAF on the bench press and AWC analysis, which precludes accurate comparisons to make a consensus inference. However, Papoti et al.[38] reported that some experimental studies and literature reviews have shown AWC significantly associated with the Wingate test, muscle ATP production, and AWC sensitivity to resistance training.

The non-cyclical characteristic of the FC model, the muscular group recruited, the absolute load of the 1RM test, and the percentage of the 1RM of the predictive loads are factors that can influence the time to exhaustion and, consequently, the mathematical model. Specifically, the time until exhaustion in resistance exercise below or close to the FC is lower than the time to fatigue at the CP of cyclic exercises. Dotan[39] wrote a letter to the editor criticizing the association of the CP model with the steady-state/anaerobic threshold. In resistance exercise, the time until fatigue near or below the FC seems to be even shorter, amplifying the distance from the definition of intensity that can be sustained indefinitely without exhaustion. Meireles et al.[40] reported that the FC was underestimated in the bench press, observing the Maximal Lactate Steady-State test adapted (20 min) at 110% of FC. Another aspect that deserves to be highlighted is the low intensity that FC occurs, 1 on the OMNI-RES scale[31].

Conclusion

In conclusion, acute CAF intake (350 mg) reduces the anaerobic work capacity and increases the time until failure at 20% of 1 RM. However, the Critical Force variable and time until exhaustion at 25% and 30% of 1 RM in CAF treatment did not change compared to the PLA group.

Declaration of interest statement

The authors declare that they have no conflict of interest in the present study.

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