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## ORIGINAL ARTICLE

**Acute effect of open and closed kinetic chain training on lower limb muscle strength in young adults**

***Efeito agudo de um treino em cadeia cinética aberta e fechada na força muscular de membros inferiores em adultos jovens***

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### Resumo

Dentre as variações de prescrição de treinamento para melhoria da força muscular, podemos destacar os exercícios de cadeia cinética aberta (CCA) e cadeia cinética fechada (CCF). O objetivo deste estudo foi investigar o efeito agudo dos exercícios em CCA e CCF na força muscular de membros inferiores em adultos jovens. Dez adultos jovens sedentários foram convidados a participar de um treinamento agudo composto por três exercícios em CCA e três exercícios em CCF e realizaram três séries de dez repetições. Para avaliar o torque e a potência muscular foram utilizados um dinamômetro isocinético e uma plataforma de força. As variáveis analisadas foram: pico de torque, tempo para pico de torque, potência média e potência média. Análises univariadas foram utilizadas para comparar o desempenho dos participantes nos exercícios em CCA e CCF nos testes de torque e potência. O pico de torque foi maior nos movimentos extensor e flexão plantar do que nas articulações do joelho e tornozelo, respectivamente. Ao comparar os exercícios em CCA e CCF, os exercícios CCA produziram maior pico de torque e potência média em todas as articulações do que

CCF. Concluímos que os exercícios em CCA podem ser usados para melhorar a força em adultos jovens.

**Palavras-chave:** treino agudo; cadeia cinética aberta; cadeia cinética fechada; torque; potência.

### Abstract

Among training prescription variations for improving muscle strength, we can highlight open kinetic chain (OKC) and closed kinetic chain (CKC) exercises. The aim of this study was to investigate the acute effect of OKC and CKC exercises on lower limb muscle strength in young adults. Subjects were invited to participate in an acute training consisting of three OKC exercises and three CKC exercises and performed three sets of ten repetitions. To evaluate the torque and muscle power, an isokinetic dynamometer and a force platform were used. The analyzed variables were: peak of torque, time to peak torque, mean power and average power. Univariate analyses were used to compare the performance of participants in OKC and CKC exercises in torque and power tests. Peak torque was higher in the extensor and plantar flexion movements than knee and ankle joints, respectively. When comparing OKC and CKC exercises, OKC exercises produced a higher peak of torque and mean power in all the joints than CKC. We concluded that OKC exercises can be used for improving strength in young adults.

**Keywords:** acute training; open kinetic chain; closed kinetic chain; torque; power.

### Introduction

Skeletal muscle is a dynamic tissue sensitive to acute and chronic adaptations promote by exercise. Closed and open kinetic chain exercises should be considered in exercise prescription, once there is a variation in muscle recruitment and joint moment patterns between these types of exercise [1]. Although, there is no yet consensus on the definition and use of the terms open and closed kinetic chain [2]. Closed Kinetic Chain (CKC) exercises can be characterized by multi-joint movements performed with the distal segment supported on a solid surface and supported by body weight [1, 3–5]. Open kinetic chain (OKC) exercises can be characterized by single joint movements distal segment of the body being free to move in space and not supporting body weight [1,3,5]. The difference between CKC and OKC exercises has been constantly studied in the context of resistance training (RT) and rehabilitation [1, 5–7].

In rehabilitation context, the difference between OKC and CKC exercises in different clinical cases is discussed, such as after anterior cruciate ligament (ACL) reconstruction [5,8,9], osteoarthritis [3] and patellar chondropathy [4]. OKC exercises are

usually prescribed after the inflammation period, without additional external load or isometric exercise to minimize muscle atrophy. CKC exercises are often applied for their functionality in daily life and sports activities that improve balance, proprioception, muscle co-contraction, q-angle reduction, joint crackling, pain sensation, increased strength and muscle circumference [3,4,8]. Therefore, in rehabilitation CKC exercises decrease the risks of shear forces, increases proprioception, muscle coordination, joint stability and appears to be clinically safer than OKC exercises [6].

However, the effect of OKC and CKC exercises in RT program on muscle function performance in healthy subjects is not totally clear. Augustsson *et al.* [10] investigated the chronic effect of RT with CKC vs. OKC exercises on 3-repetition maximum (3-rm) test performance, isokinetic strength and vertical jump. The results revealed significant improvement in the 3-rm test in both groups, but the group that performed CKC exercise showed a greater increase when compared to the OKC group, 31% vs. 13% respectively. For the vertical jump test, only the CKC group showed a significant improvement, with an increase of 10% (5 cm) in the height of vertical jump. However, no significant improvement was observed in isokinetic tests after six weeks in both groups. Yet, CKC strength exercises of extensor lower limbs are more highly related to jumping performance than exercises in OKC [11] and provide more simultaneous activity in the different portions of the quadriceps muscle than OKC, with earlier onset and greater amplitude of electromyography (EMG) activity in vastus medialis obliquus [12]. In addition, OKC and CKC exercises promote an increase on the overall thickness of quadriceps muscles, as an acute effect of the exercises. However, quadriceps muscles can be selectively improved depending on the type of the exercise, with a greatest increase on the thickness of vastus intermedius and vastus medialis oblique, respectively in OKC and CKC exercises [13]. Thus, it seems that CKC and OKC exercises promote different neural and muscle adaptations, with a better coordination of muscle recruitment in CKC, which result in a better performance of muscle function tests when compare to OKC exercises.

Moreover, potentiation and fatigue are coexistence acute process related from prior muscle activation [14], and are determined by the interaction of several factors like individual characteristics and parameters related to the exercise prescription [15]. Post-activation potentiation (pap) is the post-contraction increase in force production, and voluntary pap refers to the increase in muscular force production during a voluntary contraction. Previous works have already revealed improvement in muscle function performance as acute effect related to pap promoted by CKC exercises, with an increase of the height of vertical jump tests and peak power output in healthy adults [16] and in the height of vertical jump performance in athletes [17]. However, other studies revealed

that muscle damage and fatigue induced by exercise is an acute effect that promotes a decrease in muscle strength and on the performance of vertical jump tests [18–20]. Thus, the acute effect of CKC and OKC exercise on muscle function performance should be considered in RT programs. In addition, CKC exercises involve co-contraction of agonist, antagonist and synergistic muscles of multiple joints, while OKC enables isolation of specific muscle groups during the exercises [1, 2]. Thus, CKC and OKC possibly induce different adaptations in agonist and antagonist muscles and also in dominant and non-dominant limbs.

In this context, there is a need for further studies that investigate the acute effect of CKC and OKC exercises on muscle function performance, with an analysis on the peak of torque, time to peak torque and muscle power of lower limbs in healthy subjects, providing insights for better and safer RT prescription aiming performance and injury prevention and rehabilitation. Also, it is important to analyze asymmetry on muscle function performance of dominant and non-dominant lower limbs and on agonist and antagonist muscles. Thus, the aim of this study was threefold: 1) investigate the acute effect of OKC and CKC exercises on lower limb muscle strength in young adults; 2) investigate the acute effect of OKC and CKC exercises on muscle torque and power of dominant and non-dominant lower limbs; 3) investigate the acute effect of OKC and CKC exercises on muscle torque and power of flexion and extension of hip, knee and ankle. Our hypothesis was: 1) muscle torque and power in CKC is greater than OKC; 2) no difference in muscle torque and power will be observed between dominant and non-dominant limbs; 3) extensor muscles of hip, knee and ankle will reveal higher values of muscle torque and power when compared to flexor muscles.

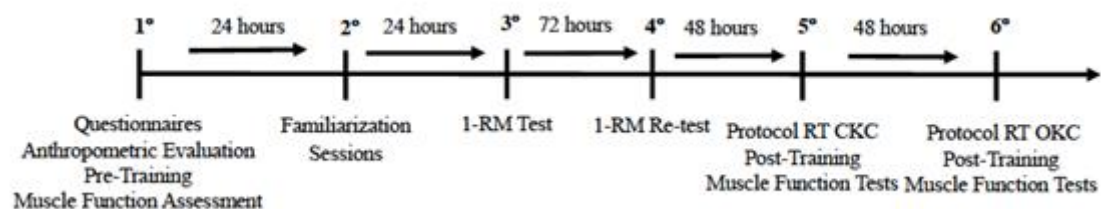
## Methods

### *Participants*

This is a cross-sectional study with healthy male young adults, aged between 18 and 25 years. The exclusion criteria were: history of musculoskeletal injuries in lower extremities in the 6 months preceding the experiment and obesity (body mass index above 30). The research study was approved by the Research Ethics Committee of Universidade Federal do Espírito Santo (process number 2.598.751). After agreeing to participate in the study, the participants signed a consent form according to the rules established by the resolution number 466/2012 of the National Health Council of Brazil.

### *Procedures*

Data collection was carried out in six days. In the first day, an anamnesis was performed to obtain sociodemographic information, health status and physical activity level with baecke questionnaire [21]. Also, in the first day, an anthropometric evaluation and lower limb muscle function assessment with isokinetic and jump test were performed to collect pre-training data. In the second visit in the laboratory, participants were familiarized with the testing procedure, performing two CKC sessions (back squat, sumo deadlift, and seated calf raise) and two OKC sessions (leg extension, lying leg curl, ankle dorsiflexion). The familiarization protocol consists of one set of fifteen repetitions, with 1-minute rest and muscle contraction phases of two seconds in concentric and two seconds in eccentric. The 1-rm test and re-test were performed in the third e fourth visit to the laboratory, respectively 24 and 72 hours after the familiarization session. After the maximum load determination test, the CKC and OKC rt sessions were performed respectively in the fifth and sixth day, with a 48-hour interval between sessions of training (figure 1). During the OKC and CKC sessions of rt, three sets of ten repetitions were performed, with 2 seconds of muscle contraction per each phase (60% of 1-rm) and one-minute interval between sets and exercises. Moreover, five minutes after both sessions, lower limb muscle function assessment were realized with isokinetic and jump tests.



**Figure 1** - Schematic representation of the study

### *Experimental tasks*

#### One-repetition maximum test (1rm)

Initially a warm up session, consisted of 5-10 repetitions with 40% of predicted 1rm, was realized. After a 1-minute rest, participants performed 3-5 repetitions with 60% of predicted 1rm. Two minutes after warm up, up to 5 attempts of the 1-rm protocol were applied with 5 minutes rest between attempts and 10 minutes between exercises (OKC protocol: leg extension, lying leg curl, ankle dorsiflexion; CKC protocol: back squat, sumo deadlift and seated calf raise). Re-test was performed 72 hours later. All 1rm measurements were reported in kilograms for subsequent data analysis [22,23].

#### Isokinetic dynamometer assessment

Isokinetic tests were realized with a Biodex system 4 dynamometer (Biodex Medical Systems, Inc., Shirley, NY, USA). The flexion and extension movements of the hips, knees and ankles were evaluated. After experimental instructions, participants were familiarized with the procedure by performing five repetitions in each velocity with submaximal contractions. The test consisted of concentric isokinetic contractions with predetermined angular velocity. For all joints, five repetitions were executed at 60°/s and 10 repetitions at 180°/s with 1 minute of rest between different velocities assessments. Participants were verbally encouraged to develop maximal contraction during test. All assessments were performed on both right and left sides, starting with the dominant limb (defined as the limb used to kick a ball). The positioning, stabilization, calibration and gravity correction procedures were performed according to the manufacturer's recommendations.

#### Jump assessments

Participants were positioned on a force plate (Biomec400, Emg System of Brazil, Ltda., SP) sampled at 100 Hz and filtered with a 10 Hz low pass to perform the vertical counter-movement jump (cmj). Participants were instructed to jump with their hands on the waist while avoiding bending the legs during flight. Moreover, participants performed three CMJ on the force plate with two-minute rest intervals. The average power was calculated by Emglab Software (emg system). The takeoff time, in which the foot detached from the ground, and the time of impact were initially identified through the vertical ground reaction force component. In this period, the average power was calculated based on body weight, flight time and ground force reaction.

Experimental tasks (isokinetic protocol and counter-movement jump) were performed in separate blocks and counterbalanced within the participants.

#### *Dependent variables*

The dependent variable used to evaluate lower limb muscle function performance were the peak of torque and time to peak torque at 60°/s and mean power at 180°/s in the isokinetic test and the average power at jump test.

#### *Statistical analysis*

Data are presented as mean  $\pm$  sd. All statistical analyses were conducted using SPSS version 19.0 software (Spss Inc., Chicago, IL, USA). The normality and variance

homogeneity were assessed with Shapiro-Wilk test and the Levene test, respectively. The data presented normal distribution. Thus, three-way anovas (moment [pre-sessions, OKC, CKC] x movement, [flexion, extension] x limb [dominant, non-dominant]) were carried out as repeated measures for peak of torque, time to peak torque and mean power isokinetic variables in each joint (hip, knee and ankle). Furthermore, One-Way Anova (moment [pre-session, OKC, CKC]) was carried out as a repeated measure for average power variable (jumps - force plate data). Post hoc tests with Bonferroni adjustments were performed for main and interaction effects. The significance level was set at  $p \leq 0.05$ .

## Results

A total of 10 inactive college men participated in this study, nine participants were right-handed and one was left-handed. Table I presents the clinical and anthropometric characteristics of the sample.

**Table I - Clinical and anthropometric characteristics of the sample**

Participants	Age (years)	Mass (kg)	Height (m)	Body index (kg/m <sup>2</sup> )	Baecke (score)
1	23	65.4	1.7	22.9	7.4
2	20	87.3	1.8	26.4	9.9
3	21	80.8	1.8	24.1	10.1
4	22	77.5	1.8	25	8.5
5	22	64.9	1.8	19.8	6.5
6	24	81.9	1.8	24.2	8.6
7	24	69.1	1.8	22.3	10.5
8	21	76.4	1.8	24.4	7.4
9	21	59.7	1.7	19.7	8.6
10	24	63.2	1.6	23.2	9.4
<b>Media</b>	<b>22.2</b>	<b>72.7</b>	<b>1.8</b>	<b>23.2</b>	<b>8.6</b>
<b>Standard deviation</b>	<b>1.4</b>	<b>8.9</b>	<b>0.06</b>	<b>2.03</b>	<b>1.3</b>

### *Isokinetic dynamometer data*

#### Hip joint

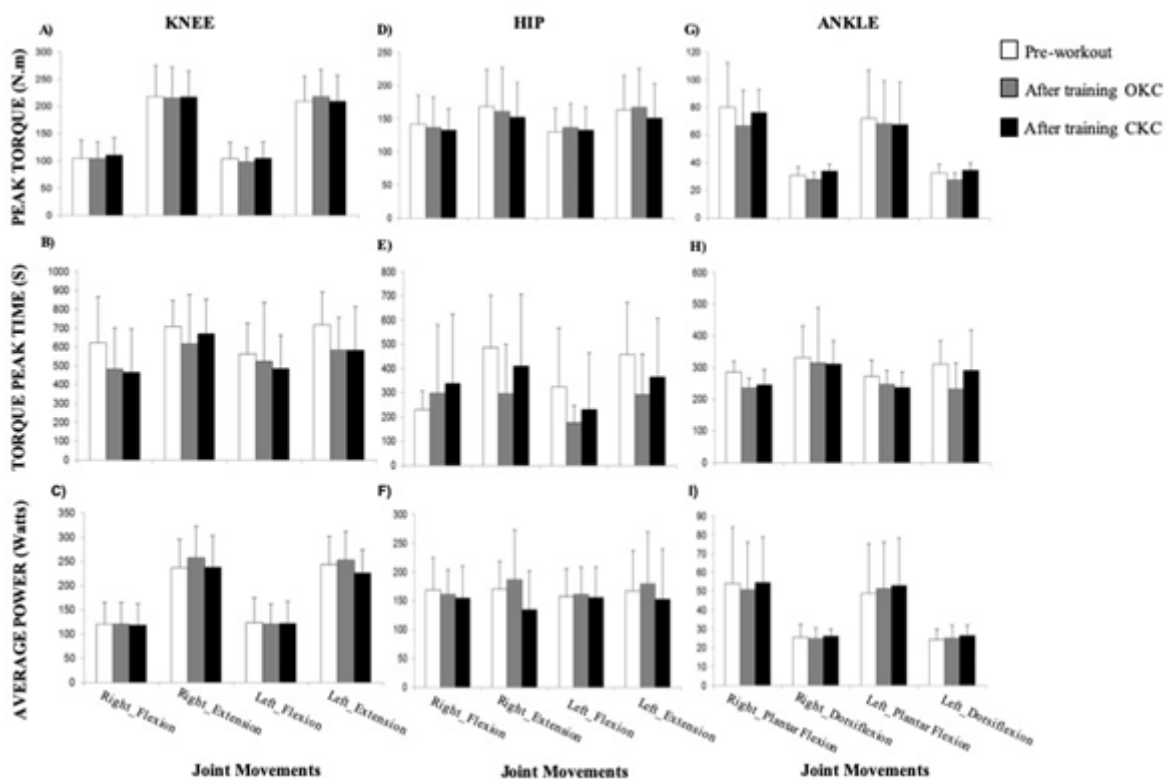
Three-way anova showed a moment effect ( $f_{2,18} = 6.05$ ,  $p = 0.011$ ) for the right limb. The mean power was higher after OKC (182.63 w) compared to CKC (144.89 w) exercises for hip extension and flexion movements (figure 2f).

## Knee joint

Three-way Anova revealed significant movement effect ( $f_{1,9} = 292.20$ ,  $p \leq 0.001$ ) for the right and left limbs. Participants had a higher peak of torque (figure 2a) in the extension (right = 244.23n/m, left = 211.92n/m) compared to flexion movement (right = 119.83n/m, left = 101.87n/m). However, the interaction effect between movement and moment ( $f_{2,18} = 11.10$ ,  $p = 0.002$ ) showed that mean power was greater in OKC (253.63 w) than CKC (225.81 w) in left knee extension movement (figure 2c).

## Ankle joint

Three-way anova showed movement effect ( $f_{1,9} = 39.21$ ,  $p \leq 0.001$ ) for the right lower limb. The data showed a higher peak torque (figure 2g) in the plantar flexion (74.35n/m) compared to the dorsiflexion movement (30.95n/m). However, for the left ankle joint, it was revealed a moment effect ( $f_{2,18} = 6.47$ ,  $p = 0.008$ ), with a greater time to peak torque in pre-session (292 ms) compared to OKC (239.5 ms) for plantar flexion and dorsiflexion movements (figure 2h).

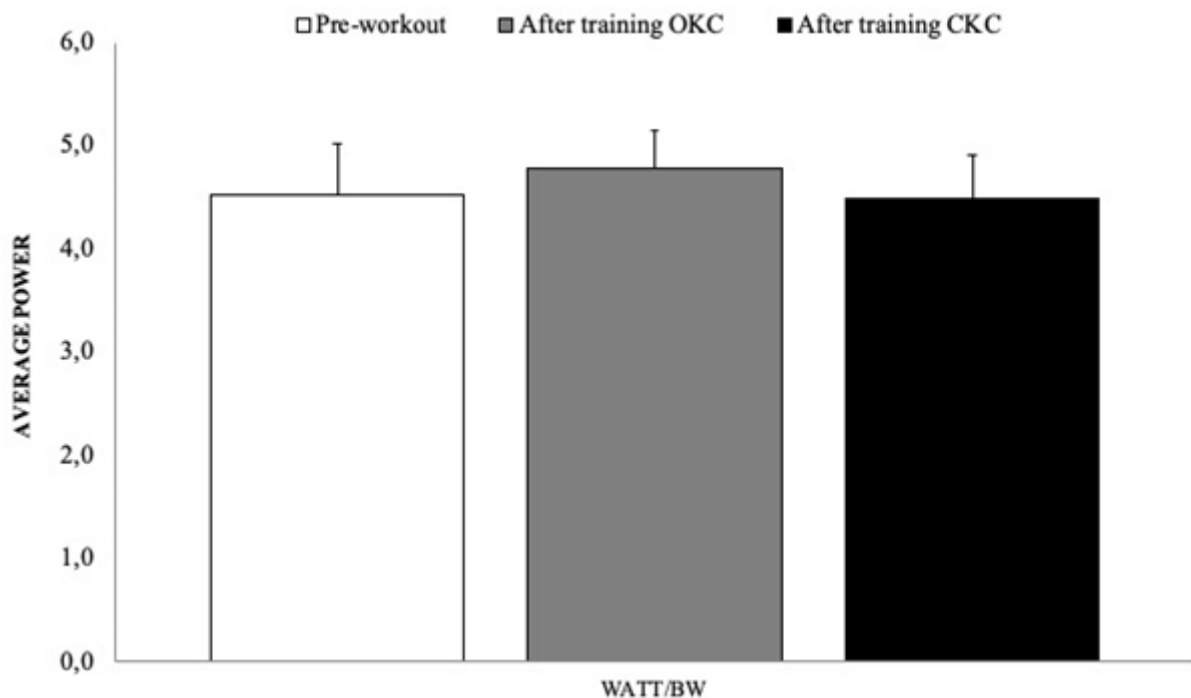


**Figure 2** - Mean and standard deviation of the following variables: peak of torque, time to peak torque and mean power for knee (a-c), hip (d-f) and ankle (g-i) joints at pre-training, OKC and CKC



### Force plate data

The mean power (jumps) did not present significant statistical differences ( $f_{2,18} = 2.98$ ,  $p = 0.94$ ) among the interventions (pre-sessions, OKC and CKC) (figure 3).



**Figure 3** - Mean and standard deviation of the average power variable evaluated in the force plate at the pre-training, OKC and CKC moments

## Discussion

The present study aimed at comparing the acute effect of rt in OKC and CKC exercises on lower limbs (hip, knee, and ankle joint) torque production and muscle power. The results of the present study showed: 1) OKC exercises generate higher peak torque and power in all joints compared to CKC, 2) for the knee and hip joints, exercises in OKC raised the average power of the evaluated members compared to exercises in CKC, and 3) for ankle joint, the time to peak torque after OKC exercise decreased compared to baseline data. In relation to the hypothesis of the study, it was expected that CKC exercises would generate greater torque and muscle power than OKC exercises, which was not found by the results.

Assessments on the isokinetic dynamometer were performed bilaterally on the lower limbs and no differences were revealed between dominant and non-dominant lower limbs for the effect of movement (flexion and extension). However, the bilateral comparison between flexors and extensors may show some difference, being

considered normal in values of 10% between dominant and non-dominant lower limbs [24]. Moreover, the results showed an increase for peak torque variable when comparing knee flexion and extension movements and ankle plantar flexion and dorsiflexion. For the knee joint, it was observed that the extension movement had higher peak torque compared to the flexion movement. In agreement with previous studies that demonstrate that knee extensor muscles are stronger than the flexors in the entire range of motion, regardless of age, sex, angular speed and training modality [25,26]. For the ankle joint, the results showed that plantar flexion movement had a higher peak torque compared to dorsiflexion movement, which agrees with Woodson *et al.* [27]. These authors observed that plantar flexors have greater capacity for generating strength than ankle dorsiflexors. In addition, exercises that work the ankle joint muscles favor the ones linked to the plantar flexion movement over the dorsiflexion movement.

In rehabilitation, studies showed that OKC exercises improve the strength of specific muscles, but when applied isolated, they are not advantageous for musculoskeletal rehabilitation after injuries, requiring a combination with CKC exercises. Tagesson *et al.* [7] showed that in the isokinetic test after rehabilitation, OKC exercise was more effective than CKC exercise in recovering quadriceps muscle strength. In addition, Mikkelsen *et al.* [28] recommends that the quadriceps needs training in OKC exercises to recover muscle torque and that this type of exercise helps restore total muscle function. However, CKC exercises distribute muscle work in the rehabilitation process, avoiding overloading the injured joints, allow functional movement patterns, provide isometric, concentric and eccentric contractions in several planes, providing greater stability to the joints in addition to stimulating proprioception and decrease shear forces [6,8].

In this sense, acute OKC exercises are more effective for torque production and muscle power output in healthy young adults without injuries, as this type of exercise recruits muscles individually, prioritizing muscle groups of a single joint (e.g: knee, hip, and or ankle) and increasing functional muscle strength. CKC exercises are more efficient for improving motor coordination, proprioception and joint stability. The vertical jumps results confirm the statements above, as they did not show an increase in the average power after the CKC exercises in comparison with the isokinetic dynamometer, which in its evaluation analyzes only OKC exercises.

As a limitation of the study, an insufficient load was observed for some OKC exercise machines. Despite this limitation, the participants used the maximum load on this equipment and had a greater significant result compared to the CKC exercises, which had a higher total volume. Another possible limitation was that the sequence of training in CKC and OKC was not randomized between the participants, what could have

promoted different effects on motor learning. Given the above, it is evident the need for future studies to better investigate the comparison between OKC and CKC exercises training in the torque production and muscle power in young and healthy individuals without muscle and joint problems.

## Conclusion

Acute OKC exercises are more efficient in producing torque and muscle power for all evaluated joints in young adults. Thus, the acute OKC exercises are more appropriate for future interventions with the proposal of improving strength in healthy young adults without musculoskeletal injury.

### Conflito de interesses

Os autores negam conflitos de interesses.

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### Contribuições dos autores

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