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William Ebben
Marquette University, william.ebben@marquette.edu

Erich Petushek
Marquette University

McKenzie Fauth
Marquette University

Luke Garceau
Marquette University

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EMG Analysis of Concurrent Activation Potentiation

William P. Ebben
Program in Exercise Science, Department of Physical Therapy, Marquette University
Milwaukee, WI

Erich J. Petushek
Program in Exercise Science, Department of Physical Therapy, Marquette University
Milwaukee, WI

Mckenzie L. Fauth
Program in Exercise Science, Department of Physical Therapy, Marquette University
Milwaukee, WI

Luke R. Garceau
Program in Exercise Science, Department of Physical Therapy, Marquette University
Milwaukee, WI

Abstract: Purpose: This study evaluated the effect of remote voluntary contractions (RVC) on concentric isokinetic knee extensor and flexor peak torque, rate of torque development, power, and work, the activation of the affected muscles, and gender differences therein. **Methods**: Eleven men and 12 women were evaluated with EMG and isokinetic dynamometry during knee extension and flexion tests in RVC and baseline (NO-RVC) test conditions. The RVC condition included jaw clenching, hand gripping, and the Valsalva

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maneuver. A two-way mixed ANOVA with repeated measures for test condition was used to evaluate the main effects for each isokinetic measure, as well as the EMG of the prime movers, their antagonist, and the muscles involved in the RVC, and the interaction between test condition and gender. **Results**: Significant interactions between test condition and gender indicate differences in response to RVC during knee extension tests for power and work ($P \leq 0.05$) and for knee flexion tests for peak torque and power ($P \leq 0.05$). All subjects produced higher peak torque and power during knee extension in the RVC condition ($P \leq 0.05$). Men produced a higher rate of torque development and work during knee extension ($P \leq 0.05$) and a higher peak torque and power during knee flexion in the RVC condition ($P \leq 0.05$). Prime mover activation was greater in the RVC condition for most tests ($P \leq 0.05$). Women demonstrated lower bilateral flexor digitorum superficialis activation than men during all tests in the RVC condition ($P \leq 0.05$). **Conclusions**: RVC increased the performance of several outcome variables assessed, which coincides with the concomitant increase in EMG of the prime movers.

The search for methods that enhance performance has led to the investigation of potentiation phenomenon, such as postactivation potentiation (PAP), which has yielded ergogenic benefits in some cases (13). Recently, the concept of concurrent activation potentiation (CAP) has been described in the literature (6) with evidence supporting the effectiveness of remote voluntary contractions (RVC) and the concomitant increase in torque and rate of torque development during a variety of test conditions (9,10,14,22). However, the gender response, as well as the potential role of muscle activation in mediating the CAP effect, has yet to be examined.

Historically, a relationship between RVC such as jaw clenching and posture has been thought to enhance sport performance, although a review of the literature found most studies to be methodologically flawed (12). RVC have been proposed to facilitate reflexes via the activation of muscles remote from the reflex (4). RVC such as jaw clenching increase the activation of muscles in the neck and trunk (11) and have also been shown to increase peak torque in isometric but not isokinetic conditions of plantarflexion (22). CAP has recently been proposed as a possible strategy that increases the performance of a prime mover as a result of activation of muscles remote from the prime mover (6). Research examining the effect of CAP demonstrated that an aggregate of RVC such as jaw clenching, hand gripping, and

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the Valsalva maneuver yielded 14.6% and 14.8% higher isometric average torque and peak torque, respectively, compared with the test condition in which RVC were not performed (10). CAP has also been shown to enhance peak force and rate of force development during the countermovement jump when performed with the jaw clenched, compared with a nonclenched condition (9). Although CAP shows potential as a potentiation phenomenon, gender differences in response to CAP have yet to be studied.

Previous research examining the effect of CAP used only men as subjects (10) or used both genders but did not specifically assess gender differences (9). Gender differences in isometric and isokinetic strength have been demonstrated in the literature, with women achieving 55.9% to 63.0% of the values of their male counterparts (16,17,19). Tests of muscular power demonstrated that women attain between 51.0% and 76.0% of the values of men (17,18). When well-trained athletes are studied, measures of power such as countermovement jump height revealed smaller gender differences with women achieving 73.2% of the men's values (8). Whereas gender differences in strength and power have been established, neither the potential gender differences nor the mechanism responsible for enhanced performance associated with CAP has been studied. Gender-specific responses to other types of potentiation phenomena seem limited to small differences in the PAP acute time course of twitch force potentiation (21).

Previous research investigating CAP has demonstrated performance enhancement of a variety of outcome variables using a dynamic exercise such as jumping (9), as well as isometric exercises assessed on a dynamometer (10). To date, the mechanisms for this performance augmentation, including the potential role of increased muscle activation, are unclear. EMG is frequently used and is an effective and reliable method for assessing muscle activation (2,3) and a diagnostic tool for assessing the activation of potentiated muscle (24). The purpose of the present study was to test the hypotheses that differences in peak torque, rate of torque development, power, and work exist between the RVC and baseline (NO-RVC) conditions during dynamic tests, that gender differences exist in response to CAP, and that enhanced EMG activity would be present in muscles engaged in

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RVC and in the prime movers, in the RVC compared with the NO-RVC condition.

Methods

Subjects

Twenty-three subjects participated in the study including 11 men (mean ± SD: age = 21.5 ± 1.9 yr, body mass = 83.47 ± 10.01 kg) and 12 women (mean ± SD: age = 20.8 ± 1.3 yr, body mass = 65.34 ± 6.79 kg). Inclusion criteria required subject participation in weekly lower body resistance training with exercises that included knee extension for at least 2 months, previous or current participation in NCAA Division I, club, or intramural sports, and previous involvement in high school sports. Exclusion criteria included any history of knee pathology that resulted in functional limitation of the leg that was to be assessed in this study. The women subjects demonstrated NO-RVC concentric isokinetic knee extension and flexion peak torque that were 70.4% and 70.0%, respectively, of the values of the men. Thus, the women subjects demonstrated lower-than-average gender differences in lower body strength (16,17,19). The subjects were informed of the risks associated with the study and provided informed written consent. The study was approved by the institution's internal review board.

Instrumentation and experimental procedures

Subjects participated in a habituation session and a test session. Before both sessions, subjects warmed up and performed dynamic stretching exercises for the lower body for approximately 15 s for each major muscle group. For each session, subjects were positioned in a dynamometer (System 4; Biodex, Inc., Shirley, NY) according to the manufacturer's specifications. The knee was positioned goniometrically at 90° and calibrated with the system software, and the mass of the limb was determined. The isokinetic tests were performed in the concentric phase with the right leg at 60° s^{-1}. During the habituation session, subjects performed one set of three repetitions of knee extension and knee flexion in both the RVC and NO-RVC conditions at approximately 75% and at 100% of their self-perceived maximum

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ability. All habituation session exercises were counterbalanced between test conditions, and subjects were given a 3-min rest between all sets. Subjects recovered for at least 72 h before returning for the test session.

The RVC condition included maximal volitional jaw clenching on a dental vinyl mouth guard (Cramer Products, Inc., Gardner, KS), the Valsalva maneuver using brief forced expiration against a closed glottis, and maximal bilateral hand gripping using hand dynamometers (Model 78010, Lafayette Industries, Lafayette, IN). The NO-RVC condition included performing the exercises with an open mouth and pursed lips to limit the likelihood of jaw clenching and consistent cycling between inspiratory and expiratory flow to reduce the Valsalva effect. In the NO-RVC condition, subjects also held dynamometers that were used to confirm the absence of hand gripping. The isokinetic test procedures were similar to those previously used (10).

During the test session, subjects completed the dynamic warm-up as well as the test-specific warm-up by performing one set of three repetitions of isokinetic knee extension and flexion in both the RVC and NO-RVC conditions at 90% of their self-perceived maximum ability. Subjects rested for 5 min between the warm-up and test sets. During this time, surface EMG electrodes were placed on the muscles to be assessed. Subjects then performed the test that included two sets of maximal effort concentric isokinetic right knee extension and flexion for three repetitions, with one set in the RVC condition and one set in the NO-RVC condition. The order of the test conditions was counterbalanced. Counterbalancing and 4 min of recovery between all test sets were used to reduce the order and fatigue effects. Subjects were instructed to perform maximally and equally encouraged for all test sets.

EMG was used to quantify muscle activation using an eight-channel telemetered EMG system (Myomonitor 4; DelSys, Inc., Boston, MA). Electrode placement was chosen to assess the potential differences in muscle activation between test conditions. The activation of muscles invoked in the RVC was evaluated with electrodes placed on the rectus abdominus (RA), right flexor digitorum superficialis (R-FDS), left flexor digitorum superficialis (L-FDS), and right masseter (R-

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M). The activation of the prime mover and homologous prime mover was assessed with electrodes placed on the right rectus femoris (R-RF) and left rectus femoris (L-RF), respectively. The activation of the antagonist to the prime mover was assessed with an electrode placed on the right hamstring belly (R-H). All electrodes were placed on the longitudinal axis of the muscles with specific electrode locations consistent with methods previously used (1,7,20) and described in Table 1. A common reference electrode was placed 10 mm anterior and halfway between the medial condyle and lateral malleolus of the tibia. Skin preparation included shaving hair if necessary, light abrasion, and cleaning the surface with alcohol. An elastic tape was applied to ensure electrode placement and to provide strain relief for the electrode cables. EMG data were recorded at 1024 Hz using rectangular-shaped (19.8 mm wide and 35 mm long) bipolar surface electrodes with 1 x 10 mm, 99.9% Ag conductors, and an interelectrode distance of 10 mm. Surface electrodes were connected to an amplifier and streamed continuously through an analog-to-digital converter (DelSys, Inc.) to an IBM-compatible notebook computer. The input impedance was 10^{15} Ω, and the common mode rejection ratio was >80 dB.

Data reduction

All data were filtered with a 10- to 450-Hz band-pass filter, saved, and analyzed with the use of a software (EMGworks 3.5; DelSys, Inc.). Root mean square (RMS) EMG data were analyzed for the each muscle for each test exercise. The RMS EMG data were calculated using a 125-ms moving window with data analyzed for the entire concentric phase of knee flexion and extension, which was determined from synchronization with a single-axis fiber-optic goniometer (Goniometer Biosignal Sensor; DelSys, Inc.). An EMG normalization procedure was not used because no comparison between subjects or muscles was sought and all testing was conducted in a single session. All resultant RMS EMG values obtained were based on the average of three repetitions of testing. Torque curves for each participant were analyzed using the manufacturer's software (Advantage Software 4.0; Biodex, Inc.). Peak torque, rate of torque development, power, and work were calculated for concentric knee flexion and extension using the average of three repetitions of the

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isokinetic test. Rates of torque development were calculated for the first 300 ms of each test exercise performance and were normalized to 1 s.

Statistical analyses

All data were analyzed using SPSS 16.0 (IBM Corp., Chicago, IL, USA). A two-way mixed ANOVA with repeated measures for test condition was used to evaluate the interaction between RVC and NO-RVC conditions and gender and to assess the main effects. Significant main effects were further evaluated with a paired-samples *t*-test. Handgrip force differences between the RVC and NO-RVC conditions and between the RVC condition and baseline measures were assessed for the left and right hand using a paired-samples *t*-test. To determine whether the increased prime mover activation was related to the enhanced performance in the RVC condition, the Pearson correlation was used to examine the relationship between the differences in agonist activation in the RVC compared with the NO-RVC condition and the differences between the peak torque, rate of torque development, power, and work in the RVC compared with those in the NO-RVC condition. Finally, to obtain a general measure of subject characteristics with respect to gender differences in strength, the concentric knee extension and flexion torque in the NO-RVC condition was assessed using an independent-samples *t*-test. Assumptions for linearity of statistics were tested and met. Statistical power (d) and effect sizes (η_p^2) are reported, and all data are expressed as means ± SD. The *a priori* α level was set at $P \leq 0.05$.

Results

Isokinetic knee extension testing

A two-way mixed ANOVA with repeated measures for test condition was used to evaluate the main effects for test condition and the interaction between test condition and gender for peak torque, rate of torque development, power, and work during isokinetic knee extension testing. The analysis of peak torque revealed significant main effects for test condition ($P \leq 0.001$, $\eta_p^2 = 0.51$, $d = 0.96$) but not for the interaction between test condition and gender ($P = 0.10$).

Analysis of the rate of torque development showed significant main effects for test condition (P = 0.01, η_p^2 = 0.28, d = 0.78) but not for the interaction between test condition and gender (P = 0.11). The analysis of power revealed significant main effects for test condition (P ≤ 0.001, η_p^2 = 0.50, d = 0.99) and the interaction between test condition and gender (P = 0.01, η_p^2 = 0.34, d = 0.88). Analysis of work showed significant main effects for test condition (P = 0.01, η_p^2 = 0.31, d = 0.82) and the interaction between test condition and gender (P = 0.02, η_p^2 = 0.25, d = 0.72). Significant main effects were further evaluated with paired-samples *t*-tests with results demonstrated in Table 2.

Isokinetic knee flexion testing

A two-way mixed ANOVA with repeated measures for test condition was used to evaluate the main effects for test condition and the interaction between test condition and gender for peak torque, rate of torque development, power, and work during knee flexion testing. The analysis of peak torque revealed significant main effects for test condition (P = 0.02, η_p^2 = 0.23, d = 0.67) and the interaction between test condition and gender (P = 0.03, η_p^2 = 0.21, d = 0.60). Analysis of the rate of torque development showed significant main effects for test condition (P = 0.04, η_p^2 = 0.19, d = 0.57) but not for the interaction between test condition and gender (P = 0.18). The analysis of power revealed significant main effects for test condition (P = 0.02, η_p^2 = 0.23, d = 0.64) and the interaction between test condition and gender (P = 0.049, η_p^2 = 0.16, d = 0.45). Analysis of work showed significant main effects for test condition (P = 0.04, η_p^2 = 0.19, d = 0.56) but not for the interaction between test condition and gender (P = 0.13). Significant main effects were further evaluated with paired-samples *t*-tests with results demonstrated in Table 2.

EMG results from isokinetic knee extension testing

A two-way mixed ANOVA with repeated measures for test condition was used to evaluate the main effect of muscle activation and the interaction between the test condition and gender during knee extension testing. The activation of the ipsilateral rectus femoris was analyzed to evaluate the potential effect of RVC on a prime mover

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during knee extension. Analysis of the R-RF activation revealed main effects for the test condition (P = 0.01, η_p^2 = 0.25, d = 0.72) but not for the interaction between RVC condition and gender (P = 0.15). The R-H muscle group was evaluated to understand the effect of RVC on the activation of the antagonist to the prime mover. Results revealed no significant main effect for test condition (P = 1.00) or the interaction between test condition and gender (P = 0.10). The L-RF was evaluated to assess the effect of RVC on the activation of the homologous muscle group. Results demonstrated no significant main effect for test condition (P = 0.39) or the interaction between test condition and gender (P = 0.49). The activation of R-M, L-FDS, R-FDS, and RA was also evaluated to provide a measure of activation of muscles involved in RVC. Significant main effects for test condition were found for each of these muscles ($P \leq 0.001$). No significant test condition X gender interaction existed for the R-M (P = 0.85) and RA (P = 0.34), although a significant interaction was found for the L-FDS (P = 0.05, η_p^2 =0.18, d =0.48) and R-FDS (P =0.01, η_p^2 = 0.27, d = 0.75). Significant main effects were further evaluated with paired-samples t-tests with results demonstrated in Table 3.

EMG results from isokinetic knee flexion testing

A two-way mixed ANOVA with repeated measures for condition was used to evaluate the main effect of muscle activation and the interaction between the test condition and gender during knee flexion testing. The R-H was analyzed to evaluate the potential effect of RVC on the activation of the prime mover during knee flexion. Analysis of R-H activation revealed main effects for the test condition (P = 0.01, η_p^2 = 0.36, d = 0.91) but not for the interaction between test condition and gender (P = 0.37). The R-RF was evaluated to understand the effect of RVC on the activation of an antagonist to the prime mover. Results revealed no significant main effect for test condition (P = 0.15) or the interaction between test condition and gender (P = 0.57). Results from the analysis of the L-RF demonstrated no significant main effect for test condition (P = 0.42) or the interaction between test condition and gender (P = 0.17). The activation of R-M, L-FDS, R-FDS, and RA was also evaluated to provide a measure of activation of muscles involved in RVC. Significant main effects for test condition were found for each of these muscles ($P \leq 0.001$). No significant test

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condition X gender interaction existed for the R-M (*P* = 0.81) and RA (*P* = 0.60), although a significant interaction was found for the L-FDS (*P* = 0.04, η_p^2 = 0.18, *d* = 0.52) and R-FDS (*P* = 0.01, η_p^2 = 0.27, *d* = 0.72). Significant main effects were further evaluated with paired-samples *t*-tests with results demonstrated in Table 3.

Handgrip testing

Handgrip force differences between the RVC and NO-RVC conditions and between the RVC condition and a baseline condition consisting of neither the RVC knee extension/flexion nor the NO-RVC knee extension/flexion were assessed for the left and right hand using paired-samples *t*-tests. Results demonstrate significant differences (*P* ≤ 0.001) between the RVC (32.04 ± 13.32 kg) and NO-RVC (0.00 ± 0.00 kg) conditions for left handgrip. Results also showed significant differences (*P* ≤ 0.001) between the RVC (33.96 ± 8.54 kg) and NO-RVC (0.00 ± 0.00 kg) conditions for right handgrip. Left handgrip was 16.2% lower (*P* ≤ 0.001) in the RVC condition (32.04 ± 13.32 kg) compared with the baseline condition (38.22 ± 14.59 kg). Similarly, right handgrip was 22.0% lower (*P* ≤ 0.001) in the RVC condition (33.96 ± 8.54 kg) compared with the baseline condition (43.52 ± 12.46 kg).

Relationship between agonist activation and performance in the RVC condition

The Pearson correlation was used to examine the relationship between the differences in agonist activation in the RVC compared with the NO-RVC condition and the differences among the peak torque, rate of torque development, power, and work in the RVC compared with the NO-RVC condition. Results show that during isokinetic knee extension, there are significant correlations (*P* ≤ 0.05) between the change in rectus femoris activation and peak torque (*R* = 0.54), rate of torque development (*R* = 0.49), and work (*R* = 0.50) but not for power (*R* = 0.28). During isokinetic knee flexion, the analysis demonstrates significant correlations (*P* ≤ 0.05) between the change in hamstring activation and peak torque (*R* = 0.48), rate of torque development (*R* = 0.48), power (*R* = 0.42), and work (*R* = 0.59).

Gender differences in isokinetic peak torque

In the evaluation of gender differences in strength, men demonstrated greater knee extensor peak torque, averaged for three repetitions, than women in the RVC ($P \leq 0.001$) and NO-RVC conditions ($P \leq 0.001$). Three-repetition average knee flexor peak torque was also greater for men, compared with that for women, in the RVC ($P \leq 0.001$) and NO-RVC ($P \leq 0.001$) conditions.

Discussion

Main findings

This study demonstrates the ergogenic effect of CAP during isokinetic testing and is the first to show that the performance enhancement seems to be mediated by increased muscle activation of the prime movers during the RVC compared with that during the NO-RVC condition. Men demonstrated higher mean performance of 6.2% to 12.5% for a variety of outcome variables in the RVC compared with the NO-RVC condition, with most differences attaining statistical significance ($P \leq 0.05$). Women demonstrated higher mean performance of 0.05% to 4.2% in the RVC compared with the NO-RVC, with only peak torque and power during knee extension demonstrating statistical significance between the test conditions. This study reveals the existence of gender differences in the response of men and women to the CAP, which coincides with a reduced magnitude of FDS activation for women in the RVC condition. Thus, the comparatively lower ability of women in activating hand gripping RVC may explain, in part, the gender difference in response to CAP. The lower relative activation of the FDS for women, compared with men, is presumably the consequence of reduced cortex activation for this muscle group.

Isokinetic testing

The results of this study confirm the ergogenic effect of CAP for men, for the outcome variables assessed, consistent with previous theory (6) and research (9,10). Past research revealed that isometric mean and peak knee extensor torque was approximately 14.6% and

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14.8% greater, respectively, in the RVC compared with the NO-RVC condition (10), which is slightly higher than the 10.6% increase in peak torque accrued during knee extension in the present study. Thus, CAP may be somewhat less effective during dynamic testing.

Other work in this area revealed that compared with the non–jaw-clenching condition, jaw clenching produced 15.8% and 19.5% increases in the rate of force development during hand gripping (14) and the countermovement jump (9), respectively. On the other hand, previous research examining the relationship between jaw clenching and plantarflexion force found increased peak torque during isometric but not isokinetic conditions (22). The range of rate of force development augmentation demonstrated in these studies is higher than the rate of torque development of the men in the present study, who produced 6.2% and 6.8% higher values in the RVC condition compared with those in the NO-RVC condition.

Men and women in the present study demonstrated statistically significant differences in power during knee extension, and men produced higher power in knee flexion as well as higher values for work during extension in the RVC condition. Previous studies have not tested these variables (9,10,22). The percentage differences in these variables are less than the magnitude of differences demonstrated in previous research that used isometric dynamometry (10). Previous isometric measures of average torque during the CAP condition resulted in values that were 14.6% greater in the RVC condition compared with the NO-RVC condition (10). These results demonstrate that the CAP effect is not exclusive to the knee extensors or isometric conditions. The results of the tests of power and work provide information about the nature of the CAP stimulus beyond the acute maximal effects demonstrated by enhanced rate of torque development, although the acute time course of the expression of CAP remains unknown.

EMG

The relationship between RVC such as jaw clenching and neck and trunk muscle activation was previously established using EMG for subjects at rest (11). Other research examining the relationship

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between jaw clenching and EMG of plantar flexors failed to find any increase in prime mover muscle activation during isokinetic testing (22). In the present study, analysis of muscle activation via EMG affirms that a variety of muscles involved in the RVC are more active in the RVC compared with the NO-RVC condition. This finding confirms that the subjects were able to activate these muscles associated with the RVC condition, which has been thought to be important during CAP (6). Subjects also activated the prime movers to a greater degree in the RVC versus the NO-RVC condition, and correlation analysis shows that this activation is related to enhanced functioning as assessed by most of the outcome variables used in this study. Thus, CAP seems to function because of increased activation of prime movers. This finding is consistent with the belief that RVC potentially function via cortical connections and motor overflow as has been suggested to occur during the Jendrassik maneuver and are manifested through local activation via the alpha motor neuron (5,15). Approximately 16% to 22% lower handgrip forces produced in the RVC compared with a baseline condition consisting of neither the RVC knee extension/flexion nor the NO-RVC knee extension/flexion seem to demonstrate that motor resources are finite and overflow-mediated enhancement of the prime movers during knee extension and flexion occur with a concomitant decrease in handgrip force.

Given the increased mean prime mover activation of 12.6% to 25.6% in the RVC condition in the present study, it is not surprising that men and women demonstrated enhanced performance of a variety of outcome variables in this condition, including greater knee extension peak torque, rate of torque development, power, and work for men and peak torque and power for women. Men also demonstrated higher activation of the hamstring in the RVC condition during the knee flexion test and a concomitant increase in peak torque, power, and work. Women failed to demonstrate a significant difference in hamstring activation between the RVC and the NO-RVC conditions. Thus, it is not surprising that women showed no differences in peak torque, rate of torque development, power, and work between RVC and NO-RVC conditions during knee flexion. It should be noted that for the subjects in the present study, the increase in performance associated with the RVC condition was less than the increase in muscle activation of the prime mover. In this study, the antagonist to the

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prime mover demonstrated a nonsignificant increase in activation in the RVC condition as well. Thus, CAP may increase the activation of the prime mover as well as its antagonist, potentially attenuating the potential performance augmentation of the prime mover to some degree.

Gender differences in response to RVC

The women subjects in this study demonstrated statistically greater performance in the RVC compared with that in the NO-RVC condition for only knee extension peak torque and power. Thus, the effect of RVC on women was less comprehensive than it was for men. This finding is without precedent in the limited literature examining CAP. However, in a study designed to assess the effect of using dynamometer handgrips on subject stability during isokinetic testing, gripping the dynamometer's handles resulted in an 8.4% greater knee extensor torque compared with the condition where subjects crossed their arms over their upper torso (23). This force augmentation was only experienced by the men in this study (23). Although the goal of the study by Stumbo et al. (23) was not to assess the CAP effect, it demonstrates gender differences in the role of hand gripping on prime mover performance, consistent with the findings of the present study. In the present study, significant gender differences were found in the degree of activation of the right and left FDS between RVC and NO-RVC conditions during both flexion and extension. Men demonstrated 90.7% to 97.8% higher activation of these muscles in the RVC compared with the NO-RVC condition, whereas women produced 64.0% to 88.5% greater activation of these muscles during the RVC compared with the NO-RVC condition. The comparatively lower ability of women to activate muscles involved in hand gripping may be evidence of differences in the cortex-mediated ability to activate muscles involved in hand gripping tasks. This potential centrally mediated difference in the activation of the motor cortex responsible for the activation of gripping women, may explain, in part, the findings of Stumbo et al. (23) as well. A previous literature review on this topic identified no likely gender differences in response to CAP (6), and previous investigations of CAP and the potential effect of RVC identified no gender differences (9,10,14). Similarly, few gender differences have been found in response to PAP (21).

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Gender differences in subject strength

The female subjects demonstrated in the NO-RVC condition isokinetic knee extension and flexion torque that was 70.4% and 70.0%, respectively, of the values of the men. Thus, the female subjects demonstrated lower-than-average gender differences in lower body strength, which typically range between approximately 59% and 63% of male values when untrained subjects were studied (16,17,19). Thus, the women in the present study seem to be well trained with respect to the men, thus reducing the likelihood that gender differences in response to CAP were a function of training status. Similar levels of sports and resistance training participation support the likelihood that gender differences in the study results were not a function of different training experiences.

CAP as a potentiation phenomenon

A review of another potentiation phenomena such as PAP, demonstrates that 5 of 12 studies found no significant potentiation effect (13). Of the 7 studies that found significant PAP, performance enhancement ranged from 2.0% to 9.5% in the potentiated condition for a variety of outcome variables assessed. In contrast, the men in the present study demonstrated a mean CAP performance enhancement of 6.2% to 12.5% in the RVC compared with the NO-RVC condition for the outcome variables assessed. Although different outcome variables were evaluated in the PAP research and the present study, the magnitude of the performance enhancement of CAP is larger than the enhancement found in previous PAP research. Results from the present study expand the findings of the developing CAP literature demonstrating an ergogenic effect of CAP that seems to be greater in men, potentially manifested in differences in hand gripping in the RVC condition. The present study demonstrates that increases in peak torque, rate of torque development, power, and work are correlated to and seem to be the function of RVC-mediated increases in muscle activation.

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Notes

- Address for correspondence: William P. Ebben, Ph.D., M.S.S.W., Program in Exercise Science, Department of Physical Therapy, Marquette University, PO Box 1881, Milwaukee, WI 53201; E-mail: webben70@hotmail.com.
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Appendix

Table 1

EMG electrode placement

Muscle	Anatomical Landmarks
L-RF and R-RF	1/2 distance between the greater trochanter and the medial epicondyle of the femur
R-H	1/2 distance between the gluteal fold and the popliteal fossa
RA	3 cm superior and 2 cm lateral to the umbilicus
L-FDS and R-FDS	1/4 distance from the medial epicondyle of the humerus to the skinfold at the wrist
R-M	3/4 inch anterior to and 1/2 inch above the angle of the jaw

Table 2

Isokinetic test data for RVC and NO-RVC conditions

	Men				Women			
	NO-RVC	RVC	% Change	*P*	NO-RVC	RVC	% Change	*P*
PT (N·m), EXT	169.27 ± 33.61	189.40 ± 40.55	10.6	0.003	119.18 ± 22.65	124.26 ± 20.22	4.2	0.02
PT (N·m), FLEX	87.39 ± 15.23	95.96 ± 13.79	8.9	0.03	61.08 ± 12.31	61.43 ± 9.52	0.05	0.75
RTD (N·s^{-1}), EXT	453.93 ± 123.06	486.59 ± 115.69	6.2	0.01	300.67 ± 78.39	308.73 ± 72.45	2.6	0.37
RTD (N·s^{-1}), FLEX	249.02 ± 46.61	267.15 ± 40.33	6.8	0.10	157.02 ± 41.14	161.40 ± 43.27	2.7	0.14
Power (W), EXT	164.30 ± 31.59	187.80 ± 38.90	12.5	0.002	116.18 ± 22.66	120.10 ± 20.24	3.3	0.08
Power (W), FLEX	90.98 ± 18.52	102.29 ± 16.16	11.2	0.06	64.18 ± 11.00	65.43 ± 11.77	1.9	0.22
Work (J), EXT	210.56 ± 47.35	230.37 ± 50.25	8.6	0.002	153.34 ± 29.44	154.64 ± 27.37	0.9	0.80
Work (J), FLEX	117.05 ± 24.37	126.78 ± 21.28	17.7	0.09	88.23 ± 20.91	89.78 ± 22.19	1.8	0.34

Values are presented as mean ± SD for 11 men and 12 women.
EXT, extension; FLEX, flexion; PT, peak torque: RTD, rate of torque development.

Table 3

EMG data expressed in millivolts for the muscle assessed in the RVC and NO-RVC condition

	Men				Women			
	NO-RVC	RVC	% Change	*P*	NO-RVC	RVC	% Change	*P*
R-RF EXT	0.113 ± 0.035	0.152 ± 0.065	25.7	0.047	0.119 ± 0.053	0.139 ± 0.060	14.4	0.045
R-RF FLEX	0.008 ± 0.008	0.013 ± 0.009	38.5	0.18	0.008 ± 0.006	0.019 ± 0.035	57.9	0.27
L-RF EXT	0.008 ± 0.023	0.005 ± 0.011	−40.0	0.45	0.003 ± 0.007	0.002 ± 0.004	−50.0	0.73
L-RF FLEX	0.016 ± 0.021	0.018 ± 0.024	11.2	0.22	0.017 ± 0.034	0.007 ± 0.007	−58.9	0.26
R-H EXT	0.011 ± 0.009	0.013 ± 0.009	15.4	0.39	0.010 ± 0.009	0.008 ± 0.005	−20.0	0.20
R-H FLEX	0.134 ± 0.061	0.155 ± 0.073	13.6	0.01	0.099 ± 0.031	0.112 ± 0.038	11.7	0.10
RA EXT	0.012 ± 0.013	0.019 ± 0.025	36.8	0.39	0.011 ± 0.016	0.029 ± 0.025	62.1	0.01
RA FLEX	0.004 ± 0.007	0.010 ± 0.013	60.0	0.35	0.007 ± 0.014	0.016 ± 0.020	64.2	0.01
R-FDS EXT	0.011 ± 0.027	0.189 ± 0.117	94.2	0.00	0.013 ± 0.015	0.095 ± 0.044	86.4	0.00
R-FDS FLEX	0.004 ± 0.004	0.177 ± 0.120	97.8	0.01	0.027 ± 0.039	0.091 ± 0.055	70.4	0.01
L-FDS EXT	0.021 ± 0.039	0.224 ± 0.177	90.1	0.01	0.013 ± 0.021	0.113 ± 0.069	88.5	0.00
L-FDS FLEX	0.011 ± 0.022	0.209 ± 0.167	94.8	0.01	0.040 ± 0.085	0.111 ± 0.082	84.0	0.06
R-M EXT	0.012 ± 0.035	0.080 ± 0.066	85.8	0.01	0.003 ± 0.003	0.076 ± 0.042	96.1	0.00
R-M FLEX	0.002 ± 0.002	0.061 ± 0.049	96.8	0.01	0.008 ± 0.019	0.071 ± 0.038	88.1	0.00

Values are expressed as mean ± SD for 11 men and 12 women.
EXT, extension; FDS, flexor digitorum superficialis; FLEX, flexion; H, hamstring belly; L, left; M, masseter; R, right; RA, rectus abdominus; RF, rectus femoris

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