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The Effects of Concurrent Activation Potentiation on Countermovement Jump Performance

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CAP on CMJ Performance

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ABSTRACT

The purpose of this study was to assess the effects of concurrent activation potentiation (CAP) on countermovement jump (CMJ) performance. Twenty-four resistance trained males (mean ± *SD,* age 25 ± 4 years; body mass: 78.7 ± 10.3 kg) performed a CMJ on a force plate under four different conditions: a) a control condition where the CMJ was performed with hands on hips and lips pursed, thus preventing jaw or fist contraction from occurring, b) a jaw condition where the CMJ was performed with maximal contraction of the jaw, c) a fist condition where the CMJ was performed with maximal contraction of the fists, and d) a combined condition where the CMJ was performed with maximal contraction of both jaw and fists. Jump height (JH), peak force (PF), rate of force development (RFD) and time to peak force (TTPF) were calculated from the vertical force trace. There was no significant difference in PF ($P = 0.88$), TTPF ($P = 0.96$), JH ($P = 0.45$), or RFD ($P = 0.06$) between the four conditions. Effect size (ES) comparisons suggests a potential for the BOTH condition to augment both PF (2.4%; ES: 0.62) and RFD (9.9%; ES: 0.94) over NORM. It is concluded that CAP via singular and combined contractions has no significant impact on CMJ performance, however, substantial inter-individual variation in the response to CAP was observed and such techniques may therefore warrant consideration on an individual basis.

Key Words: Jendrassik Maneuver, remote voluntary contraction, rate of force development, time to peak force, peak force, jump height

INTRODUCTION

Peak force (PF) and rate of force development (RFD) are important facets of sport performance (1) and maximising these attributes is therefore an important goal of strength and conditioning training. One method of acute augmentation of these attributes may be by virtue of concurrent activation potentiation (CAP) (2, 12, 13, 14, 15, 18, 19). CAP refers to the augmentation of force output in a prime mover by means of a simultaneous, remote voluntary contraction (RVC) (12), for example, the augmentation in force output of the knee extensors by means of a RVC of the jaw musculature (2, 12, 13, 14, 15, 18, 19). The term CAP has been shaped from previous studies that have examined the Jendrassik Maneuver (JM) and various forms of RVC (2, 12, 15, 18, 19), several of which have demonstrated an ergogenic effect on sporting performance (2, 14, 15 18, 19).

The JM is a medical maneuver devised in the 1880's in order to increase the amplitude of tendon reflexes in the lower limb, and is an example of multiple RVCs that involve the clenching of teeth and hooking of flexed fingers (15). It is theorised that the response to the JM goes through 3 phases, referred to as the triphasic response: (i) H-reflex facilitation develops before electromyographic activity begins in the active muscle, (ii) a maximal contraction transpires due to the electromyographic activity taking place, which then gradually decreases and finally, (iii) a contraction of reduced intensity remains, until the contraction ends. During this third phase, H-reflex facilitation is no longer significant, which leads to the decrease in contraction intensity (8, 9). Research has associated the JM with CAP by demonstrating how the contraction of distant muscles can improve reflexes, thus explaining the potentiation effect (12). For the purpose of the current study the term CAP will be used for all aspects involving the JM and RVC.

An important concept in relation to CAP is cortical connection theory. This refers to the various interrelated subdivisions existing in the motor cortex area of the brain and how they are accountable for muscle force and direction (12, 13). Literature supports the notion that JM originates from this cortical effect and not by alpha motor neuron or muscle spindle fluctuations as was originally assumed (12). Research on the cortical connection theory had originally focused on animal studies (25), however, research conducted in humans has since explained this using a theoretical concept termed motor overflow (12). It is believed that the reason for JM increasing reflex strength is a consequence of this motor overflow, an involuntary movement occurring during the production of a voluntary movement, for example the involuntary action of fidgeting or grasping whilst biting (12). Motor overflow theory supports the concept of functional cortical connection, meaning activation of a section of the motor cortex can lead to other sections being affected. This synergistic effect could be another potential reason behind the CAP theory (13, 24), and there is evidence to show unilateral muscle contractions demonstrate contralateral effects at a cortical level (24).

Two independent investigations have demonstrated that the use of CAP can improve PF and RFD of the knee extensors and flexors using isokinetic dynamometry (2, 14), for example, jaw clenching was demonstrated to improve RFD of the knee extensors by 13.9% (14). Ebben et al. (10) were the first to examine the effect of CAP on kinetic variables during jumping, reporting improvements in RFD of 19.5% in experienced NCAA track and field athletes. Improvements were also observed in time to peak force, although not in PF, suggesting that CAP may be more beneficial to ballistic activities such as jumping. Similarly, Ebben et al. (11) noted improvements in PF and RFD within the first 100 $m.s^{-1}$ of contraction (RFD100) in males performing back squats and jump squats in the CAP condition. The investigators reported that improvements in RFD100 were larger than improvements in the overall RFD (RFD to PF), suggesting that the use of CAP may be more effective in the early stage of a contraction (<100 $m.s^{-1}$) and may therefore carry a greater potential benefit to ballistic activities (11). Hiroshi et al. (22) also demonstrated improvements in PF and RFD as a consequence of CAP; respective increases of up to 12.3% and 15.8% were observed during a hand gripping task (22).

Not all investigations have found a beneficial effect of CAP. Fauth et al. (15) reported no effect of CAP on kinetic variables during either squats or jump squats, whilst Gallegos et al. (17) reported no effect on kicking or throwing performance. It is important to note that both of these investigations sampled female athletes as it appears that the potential benefits of CAP may be greater in males than in females. For instance, Ebben et al. (14) observed increases in peak knee extensor torque of 10.6% and 4.2% in males and females respectively. Similar inter-gender differences were observed by Garceau et al. (18).

As such, the benefits of CAP to jump performance remain contested and further research is required to elucidate its potential impact. The aim of the current study was therefore to determine if CAP is beneficial to CMJ performance, an activity common to a wide range of sports. In addition, the study sought to determine any potential differences between jaw clenching and fist clenching protocols, and examine the potential for any cumulative benefit. It was hypothesized that maximal contraction of the fist and jaw, and also in combination, will potentiate CMJ performance.

METHODS

EXPERIMENTAL APPROACH TO THE PROBLEM

Participants performed a CMJ under four conditions in a randomised crossover design, with each participant's maximal results used for comparison. The four conditions were as follows:

1) A control of no RVC (NORM)
2) Jaw contraction (JAW)
3) Fist contraction (FIST)
4) Fist and jaw contraction (BOTH)

CMJ performance was analysed in terms of jump height (JH), PF, time to peak force (TTPF) and RFD including RFD within the first 100 ms. Effect size and repeated measures ANOVA procedures were used to analyze differences between the four conditions within the same participants (23).

SUBJECTS

Twenty-four experienced male athletes (mean ± *SD;* age: 24.7 ± 4.14 years, body mass: 78.64 ± 10.25 kg) participating in recreational and intercollegiate sport volunteered to participate in the study. Participant inclusion criteria stated that they must have been performing resistance training at least once a week for the last two years. Exclusion criteria included being female, and being free from any history or current ankle, knee or hip pathology that would result in limitations in assessment. Participants were requested not to partake in any sporting activity 48 hours prior to testing and all provided written informed consent. This study was approved by the London Sport Institute, Middlesex University Ethics sub-Committee review board.

EXPERIMENTAL PROCEDURES

Participants were familiarized with the testing protocol immediately prior to testing, with all regularly performing jump based exercises as part of training, including the regular monitoring of jump height. During testing, participants were first instructed to warm-up for 5 minutes on a cycle ergometer (Monark Ergometer 828E) at a comfortable, self-selected wattage, and to perform dynamic stretching for each major muscle group of the lower extremities (Table 1), consistent with previously published protocols (6, 10, 11). If participants were unsure of which warm up exercises to perform they were coached on how to carry out the relevant exercises with the correct technique as outlined by Chaouachi et al. (6) Participants also performed two maximal CMJ's in each condition as the last section of their warm-up.

*** Table 1 About Here ***

During the main section of testing, participants were instructed to jump three times, under each of the four different conditions in a counterbalanced order. For the JAW condition, participants were directed to maximally contract their jaw muscles for 3 seconds before and maintain it during the CMJ. CMJ depth was not monitored during testing, as participants were instructed to mimic the jump action which they perform on the field of play. A contraction time of 3 seconds was chosen in line with research from Hayes (21) demonstrating that contractions should be long enough to attain a maximal contraction, but brief enough not to diminish potentiation of the H-reflex. Under the FIST condition, participants were asked to maximally contract and clench their fists while keeping them down at hip level, so not to elevate jump scores. As with the JAW condition, participants were again instructed to clench their jaw 3 seconds before their jump and asked to keep the contraction through the jump. A mouthguard was not utilized during testing so it can relate to jumping sports which require no mouthguard, e.g. basketball, volleyball. During the BOTH condition, participants were required to contract both jaw muscles and fists, again implementing this contraction for 3 seconds before and during the jumps. For the NORM condition, participants were instructed to jump with their jaws relaxed and hands on hips to avoid either jaw or fist contractions. For both the NORM and FIST conditions, participants were instructed to purse their lips to limit the likelihood of jaw clenching while also protecting teeth, which was consistent with previous research (11).

Prior to the performance of each CMJ, participants were given five seconds to get in the ready position next to the embedded force plate (Kistler Force Plate, Kistler instrument Cooperation, Amhurst, NY; type 9286AA). The participant was then instructed to step onto the force plate into a comfortable, ready position; the ready position was not standardized (10). A countdown from five was vocalized, using a timer for accuracy, then the word "contract" was declared. This indicated to the participant to maximally contract his jaw, fists or both, depending on the jump condition being tested. This maximal contraction was held for three seconds, followed by the CMJ which was signalled by the word "jump". Rest periods between each jump were 15 seconds. One minute rest times were implemented between each set as this is shown to provide sufficient time to maintain maximal jump performance (28). The same procedure was reproduced for all participants. In all test conditions, participants were instructed to perform each jump maximally and encouraged by verbal communication. Data was collected at 1000 Hz and filtered using a fourth-order zero-lag Butterworth low-pass filter with a 16Hz cut-off frequency. Filter settings were determined by plotting the residual between the filtered and unfiltered signal as a function of cut-off frequency as described by Winter (29). Jump height was calculated using the impulse-momentum method (26), with the particiapnt remaining stationary on the plate for 2 s before jumping (enabling an accurate measurement of bodyweight). Vertical ground reaction force data was then averaged across this period and the jump was deemed to start when this value was reduced by 5 standard deviations (27). Force plate assessment enabled additional analysis including the calculation of peak force (PF), rate of force development

(RFD), including at 100 ms, and time to peak force (TTPF); RFD was calculated as PF divided by TTPF, and RFD at 100 ms by dividing the force corresponding to this point by 0.1; all force trace values were bodyweight adjusted.

STATISTICAL ANALYSES

All statistical procedures were conducted using SPSS 21.0 (IBM Corporation., Chicago, IL, USA). Data reliability was assessed through intra class correlations (ICC) and the standerd error of measurement (SEM). Normality of all variables was assessed using the Shapiro-Wilks test (16); all variables were found to be normally distributed. For the main analysis of data, differences in results from the four CAP conditions were analyzed using a repeated measures ANOVA with an alpha level of $P \leq 0.05$. The main effects were compared with confidence interval adjustment and Bonferroni post-hoc analyses applied where appropriate. Magnitude-based effect sizes (ES) were calculated and interpreted using procedures and thresholds outlined by Hopkins (23), where: <0.20 = trivial, 0.20 to 0.60 = small, >0.60 to 1.20 = moderate, >1.20 to 2 = large, and >2 = very large (22). ES were calculated with 95% confidence limits.

RESULTS

Intraclass correlations revealed that data was reliably assessed across all conditions (see Table 2), with only RFD at 100ms deemed unreliable (*r* = 0.52), and thus not analysed further. Values for SEM are also included in Table 2. There were no significant differences between conditions in regards to JH ($F_{1, 23}$ = 0.889; P = 0.451), PF ($F_{1, 23}$ = 3.11; P = 0.884) and TTPF ($F_{1, 23}$ = 0.105; P = 0.957). RFD also demonstrated no significant difference ($F_{1, 23}$ = 2.66; P = .055) (Table 2). ES comparisons between BOTH and NORM revealed a moderate and large ES for PF and RFD respectively (Table 3).

Table 2 and Table 3 Near Hear

Substantial inter-subject variation in was observed in JH as a consequence of the three CAP conditions (Figure 1).

Figure 1 Near Here

DISCUSSION

The primary aim of the current study was to determine the effect of CAP on CMJ performance. The current study reports that the use of jaw clenching, fist clenching, or a combination of the two techniques, carries no significantly beneficial effect to CMJ performance. However, ES analysis suggests a potential for the BOTH condition to augment both PF (2.4%; ES: 0.62) and RFD (9.9%; ES: 0.94) over NORM.

Several studies have shown that the use of CAP, through jaw and/or fist clenching, can improve characteristics of force production in male athletes (2, 10, 11, 13, 14, 18, 20). However, other investigations have also demonstrated no beneficial effect of CAP (5, 15, 17). The disparity observed within the literature, coupled with the questionable ecological validity of isokinetic performance measures, has resulted in the potential application of CAP to be largely discounted when encouraging its conscious application within sporting performance. The findings of the current study suggest that CAP has no beneficial effect on JH during a CMJ. To the authors knowledge, there is only one other investigation to report the effects of CAP on JH directly. In contrast to the findings of the current study, Ebben et al. (11) reported an improvement in JH of 2.9 – 32.3% during an RVC using an RVC involving a jump squat while clenching the jaw on a mouth gurad, forcefully gripping and pulling the barbell down in to the trapezius, and performing the valsalva maneuver.

The current study is most similar to the investigation by conducted by Ebben et al. (10) in that the kinetics of an unloaded CMJ were examined. Ebben et al. (10) reported that jaw contraction augmented RFD by 19.5%, concluding that the major muscle groups of the lower extremities are influenced by the H-reflex enhancement and motor overflow induced by the RVC. We observed a 9.9% improvement in RFD over control when using a combination of jaw and fist contraction, although no effect of these contractions in isolation. The improvements in JH observed by Ebben et al. (11) were coupled with a 32.2% increase in

RFD. A potential explanation for the discrepancies between the findings of the current study and those of Ebben et al. (10, 11) may lie within the performance of the RVCs. In the current study, participants held a maximal contraction of 3 seconds before jumping, following the protocols outlined by Hayes (21) which stated that contractions should be maximal and lasting not longer than six seconds. However, investigations which reported significant improvements, such as Ebben et al. (10, 11), required participants to only perform the RVCs during the concentric phase of the jump and required no pre-jump contraction at all. As the triphasic response to CAP is transient in nature (8, 9), it is possible that the CAP protocols employed by the current study were too long in duration, resulting in the CMJ being performed during the third phase of this response, where contraction intensity is in decline. It may be hypothesized that the RVCs should only occur moments before the jump action in order for CAP to carry the maximal potentiative effect.

The current study observed that the BOTH condition was more likely to benefit characteristics of force production than JAW and FIST in isolation. Out of the 24 participants, 17 had a greater PF during the BOTH condition in comparison to the NORM. This is in agreement with the findings of Ebben et al. (13) that suggest a cumulative benefit is associated with the combination of multiple RVCs. Moreover, they reported that contraction of the jaw alone did augment torque output but that fist clenching did not; JH and RFD in the current study were lowest, and TTP highest in the FIST condition, although notable differences were not observed. The diversity in results could be a consequence of the different types of performance tests utilised by Ebben et al. (13) (isokinetic knee extension) and by the current study (CMJ), but also of differences in the participant population. Ebben et al. (13) utilised participants with prolonged experience (> 1 year) of resistance training whereas the current study used participants who by default engegd in resitance training, but whos involvement was more based on sporting background rather than strength characteristics. Considering that it has been demonstrated with the post-activation potentiation phenomenon that stronger athletes are likely to experience a greater degree of potentiation than weak athletes (7), it is possible that strength may modify the potential CAP response in a similar manner. Indeed, this could also explain why certain individuals responded favourable to the CAP intervention/s in the current study whilst others did not.

In terms of JH, a high degree of inter-individual variability was observed in the current study. Several participants responded favourable to all three CAP techniques, whilst several responded negatively to all three. Changes in JH were commonly in excess of the largest observed SEM, highlighting that CAP may have a real impact on performance at an individual level. Garceau et al. (19) has previously suggested that individuals may be classified as responders and non-responders to CAP, and that responders exhibit potentiation of force output characteristics during the first 100 ms of contraction.

In conclusion, the current study reports that the singular and combined contraction of the jaw and fists during a CMJ has no significant effect on JH, PF, RFD and TTP, in comparison to a normal CMJ. However, ES analysis revealed that combined contraction of the jaw and fists may augment certain characteristics of force production versus a normal CMJ. Substantial inter-individual variation was observed and CAP protocols were observed to be beneficial to several individuals whilst detrimental to others.

PRACTICAL APPLICATIONS

Strength and conditioning professionals should be cautious if seeking to employ CAP techniques during CMJ performance. On the whole, no significant benefits of jaw, fist or combined RVCs were observed in any characteristic of force production when initiated three seconds prior to the CMJ. However, as some individuals responded positively and some negatively to these techniques, it is important that strength and conditioning professionals evaluate each athlete individually if seeking to employ CAP. It may be considered unwise to encourage conscious implementation of this specific during the performance of a CMJ on a widespread basis within groups of athletes.

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FIGURE LEGENDS

Figure 1 - Percentage changes in individual participants' (n = 24) jump heights in each of the three CAP conditions (JAW, FIST and BOTH) relative to the control condition (NORM).

Table 1. The dynamic warm-up exercises performed by each of the participants during warm-up.

Plantar Flexors	Participant raised foot from the floor, pointing the foot in a dorsiflexed position.
Hip Extensors	Participant flexed the knee and hip, bringing the thigh up to chest level.
Hamstrings	Participant flexed and extended the hip in a swinging action.
Adductors	Participant adducted and abducted the leg in a swinging action.
Quadriceps	Participant flexed knee, bringing heels up to buttock level.

Table 2. Descriptive statistics (mean ± standard deviation) and reliability data for the kinetic variables assessed during the countermovement jump (CMJ) in all four conditions (n = 24).

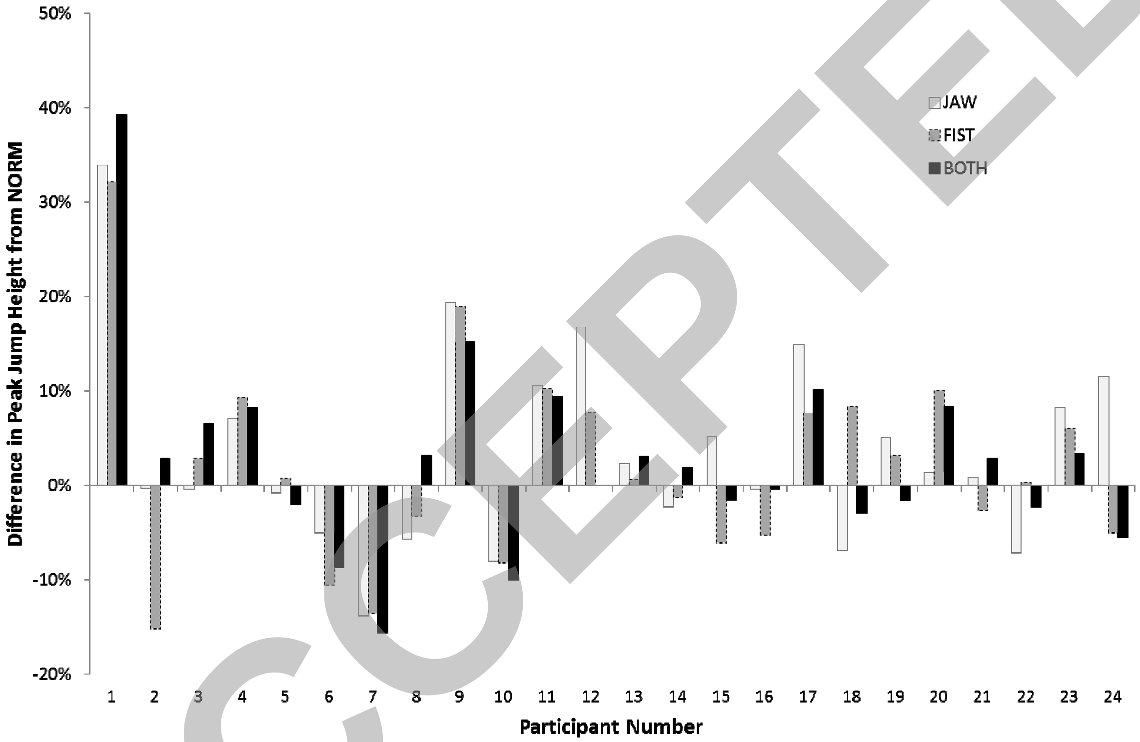
	NORM	JAW	FIST	BOTH
JH (m)	0.35 ± 0.08	0.36 ± 0.07	0.35 ± 0.07	0.36 ± 0.07
ICC (95%CI)	0.97 (0.95-0.98)	0.93 (0.87-0.97)	0.93 (0.87-0.97)	0.92 (0.86-0.96)
SEM	0.014	0.019	0.019	0.020
PF (N)	2200 ± 380	2158 ± 327	2202 ± 397	2254 ± 386
ICC (95%CI)	0.97 (0.86-0.96)	0.79 (0.62-0.89)	0.94 (0.87-0.97)	0.93 (0.87-0.97)
SEM	65.8	149.7	97.1	102.1
TTPF (s)	0.162 ± 0.03	0.164 ± 0.04	0.166 ± 0.04	0.164 ± 0.05
ICC (95%CI)	0.93 (0.68-0.92)	0.86 (0.74-0.93)	0.87 (0.75-0.94)	0.92 (0.86-0.97)
SEM	0.008	0.015	0.014	0.014
RFD ($N.s^{-1}$)	8526 ± 2042	8429 ± 1859	8345 ± 2374	9370 ± 3412
ICC (95%CI)	0.70 (0.41-0.83)	0.63 (0.41-0.80)	0.77 (0.60-0.89)	0.91 (0.83-0.96)
SEM	1118.3	1130.6	1138.6	1023.7

NORM = normal CMJ; JAW = CMJ with jaw contraction; FIST = CMJ with fist contraction; BOTH = CMJ with contraction of jaw and fist; JH = jump height; PF = peak force; TTPF = time to peak force; RFD = rate of force development; ICC = intraclass correlation coefficient, 95%CI = 95% confidence intervals; SEM = standard error of measurement.

Table 3. Effect size comparisons for the kinetic variables assessed during the countermovement jump (CMJ) in all four conditions (n = 24).

	Jump Height	Peak Force	Time to Peak Force	Rate of Force Development
JAW vs NORM	0.32	- 0.49	0.24	- 0.25
FIST vs NORM	- 0.03	0.08	0.44	- 0.02
BOTH vs NORM	0.03	0.62	0.15	0.94

NORM = normal CMJ; JAW = CMJ with jaw contraction; FIST = CMJ with fist contraction; BOTH = CMJ with contraction of jaw and fist. Negative effect sizes indicate a larger value in NORM.



JAW
FIST
BOTH
50%
40%
30%
20%
10%
0%
-10%
-20%
Difference in Peak Jump Height from NORM
1
2
3
4
5
6
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Participant Number