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The Effects Of Jaw Clenching, Jaw Alignment Via Performance Mouthpiece, And The Combination Of Both On Power And Force Production

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University of Mississippi

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THE EFFECTS OF JAW CLENCHING, JAW ALIGNMENT VIA PERFORMANCE MOUTHPIECE, AND THE COMBINATION OF BOTH ON POWER AND FORCE PRODUCTION

A Dissertation
presented in partial fulfillment of requirements
for the degree of Doctorate of Philosophy
in the Department of Health, Exercise Science, and Recreation Management
The University of Mississippi

by

CHARLES R. ALLEN JR

December 2015
ABSTRACT

Jaw clenching has been demonstrated to elicit concurrent activation potentiation (CAP), which is the ergogenic advantage of increased prime mover muscular force production during physical activity. Further, jaw aligning mouthpieces have been shown to improve the force production capabilities of individuals with temporomandibular joint disorder (TMD) and are purported to have similar effects on persons without symptoms of TMD. Previous research examining these phenomena has focused solely on jaw alignment via mouthpiece use or jaw clenching as mutually exclusive factors explaining the reported performance benefits. However, these factors do not appear to be mutually exclusive. No previously published investigations have attempted to determine whether observed performance improvements can be attributed exclusively to jaw clenching, jaw alignment via mouthpiece use, or if the combination of clenching and the presence of a mouthpiece further facilitates performance improvement. Therefore, the purpose of this study was to examine the effects of jaw clenching, jaw alignment via mouthpiece use, and the combination of the two on measures of force production and muscle activation. Participants (n=36) were required one familiarization visit and three testing visits to the lab. The familiarization visit consisted of participant prescreening, obtaining informed consent, basic anthropometric measurement, mouthpiece fitting and instruction, and familiarization of the countermovement vertical jump (CMVJ) and isometric mid-thigh clean pull (MTCP) assessments. The testing conditions, counterbalanced for all participants were as follows: performance mouthpiece with jaw clenched (PMP-C), performance mouthpiece with jaw relaxed (PMP), traditional mouthpiece with jaw clenched (MP-C), traditional mouthpiece
with jaw relaxed (MP), no mouthpiece with jaw clenched (NoMP-C), and no mouthpiece with jaw relaxed (NoMP). The dependent variables examined were rate of force development (RFD), peak force (PF), relative peak force (nPF), and muscle activation during both CMVJ and MTCP assessments. A 3 x 2 (mouthpiece x clench condition) ANOVA for repeated measures was conducted to analyze each of the dependent performance variables. Post-hoc analysis for multiple comparisons were performed using a Bonferroni correction. Paired samples t-tests were used to further analyze observed interaction significance. Results revealed that clenching significantly improved all measured force production variables during the MTCP (p < 0.05). There was no difference between clench conditions for the CMVJ assessment. There was no difference in any force production variables between mouthpiece conditions for either the CMVJ or the MTCP. Muscle activation, measured via electromyography, was significantly greater under clench conditions during the CMVJ assessment (p < 0.05). Jaw aligning mouthpiece and no mouthpiece conditions lead to greater muscle activation than the traditional mouthpiece condition during the CMVJ assessment as well (p < 0.05). There were no differences in muscle activation between conditions during the MTCP. These results support the use of jaw clenching as a viable strategy for eliciting CAP during isometric muscle actions. Future studies should attempt to identify the mechanisms behind the observed changes in force production, as the current results do not support increased neural drive as the underlying factor.
DEDICATION

This dissertation is dedicated to everyone who supported me throughout my pursuit of the doctoral degree as well as those who helped to positively shape the person I am today. I am, and will continue to be, forever grateful.
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tr>
<td>CAP</td>
<td>Concurrent activation potentiation</td>
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<tr>
<td>TMJ</td>
<td>Temporomandibular joint</td>
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<td>TMD</td>
<td>Temporomandibular joint disorder</td>
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<tr>
<td>VDO</td>
<td>Vertical dimension of occlusion</td>
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<tr>
<td>SA</td>
<td>Self-adapted</td>
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<tr>
<td>CM</td>
<td>Custom made</td>
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<tr>
<td>CMVJ</td>
<td>Countermovement vertical jump</td>
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<tr>
<td>MTCP</td>
<td>Mid-thigh clean pull</td>
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<tr>
<td>PMP</td>
<td>Performance mouthpiece with jaw relaxed</td>
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<tr>
<td>PMP-C</td>
<td>Performance mouthpiece with jaw clenched</td>
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<tr>
<td>MP</td>
<td>Traditional mouthpiece</td>
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<td>MP-C</td>
<td>Traditional mouthpiece with jaw clenched</td>
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<tr>
<td>NoMP</td>
<td>No mouthpiece</td>
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<tr>
<td>NoMP-C</td>
<td>No mouthpiece with jaw clenched</td>
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<tr>
<td>RFD</td>
<td>Rate of force development</td>
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<tr>
<td>PF</td>
<td>Peak force</td>
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<td>nPF</td>
<td>Relative peak force</td>
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<tr>
<td>MORA</td>
<td>Mandibular orthopedic repositioning appliance</td>
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<tr>
<td>K-MORA</td>
<td>Kinesiologically designed mandibular orthopedic repositioning appliance</td>
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<tr>
<td>RVC</td>
<td>Remote voluntary contraction</td>
</tr>
<tr>
<td>JM</td>
<td>Jendrassik maneuver</td>
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<tr>
<td>EMG</td>
<td>Electromyography</td>
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<tr>
<td>MVC</td>
<td>Maximum voluntary contraction</td>
</tr>
<tr>
<td>MG</td>
<td>Medial gastrocnemius</td>
</tr>
<tr>
<td>MH</td>
<td>Medial hamstring</td>
</tr>
<tr>
<td>VMO</td>
<td>Vastus medialis oblique</td>
</tr>
<tr>
<td>ES</td>
<td>Erector spinae</td>
</tr>
<tr>
<td>1RM</td>
<td>One repetition maximum</td>
</tr>
<tr>
<td>3PQ</td>
<td>Plyo-press power quotient</td>
</tr>
<tr>
<td>PAP</td>
<td>Post-activation potentiation</td>
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5. Percentage of Muscle Activation during MTCP Relative to MVC – MP Conditions

6. Percentage of Muscle Activation during MTCP Relative to MVC – Clench Conditions
I. INTRODUCTION

The first reported performance improvements attributed to the use of a mouthpiece occurred in 1977 when concussed University of Notre Dame football players experienced reduced concussion symptom frequency and severity following physiological fitting with a mouthpiece designed to correct the mal-occluded jaw position associated with temporomandibular joint disorder (80). The following year, Smith (79) examined the hypothesis that oral strength and proper jaw alignment would exhibit a positive relationship with overall muscular strength of the body, concluding that a positive correlation was present. Kaufman & Kaufman (58) observed significant improvements in bench press performance of collegiate football players with the use of a mandibular orthopedic repositioning appliance (MORA), and reported that strength may be positively influenced by the use of a jaw aligning mouthpiece, regardless of whether TMJ disorder was present or not. Several other early studies examining the effects of various mouthpiece designs on numerous performance variables revealed primarily positive results (1,4,9,86,88).

While the research touched on above provides evidence in support of a positive relationship between proper jaw alignment and improved performance, it has also received criticism from others for lack of statistical analysis in some studies, and poor experimental design in others (56,67). The skeptical authors postulated that a placebo effect may be responsible for the reported performance improvements.
Recent investigations examining mouthpieces the manufacturers of which claim to improve various aspects of performance have yielded positive results (8, 27, 44-46). Only one of the aforementioned studies reported definitively whether specific instructions to clench the jaw or refrain from clenching were provided to participants (27). Some authors have stated that clenching of the jaw is a natural occurrence during forceful exertion (30, 31) and there is considerable research demonstrating a relationship between clenching and improvements in performance. Without knowledge of whether participants in the previous studies refrained from clenching the jaw during performance assessment, it becomes difficult to attribute the observed performance improvements solely to the mouthpiece.

Clenching the jaw during forceful exertion is one example of a remote voluntary contraction (RVC). RVCs are defined as muscle activation isolated from but synchronized with the activation of a prime mover in an exercise (20). The Jendrassik maneuver may be the first documented example of an RVC. Other examples include clenching or griping with the fists, and the Valsava maneuver, and all have potential to elicit a phenomenon known as concurrent activation potentiation or CAP (28).

The term CAP was first used by Ebben (28) to describe the ergogenic advantage of increased force production of a muscle group attained through the use of RVC simultaneously with prime mover activation, and the phenomenon has been demonstrated in several recent studies (29-32). While the specific mechanisms leading to CAP are not well understood, presynaptic modulation and changes in motor neuron excitation threshold resistance remain viable contributing factors (24) as well as motor overflow (49).
Previous research has focused solely on jaw alignment via mouthpiece use or jaw clenching as mutually exclusive factors explaining the observed and reported performance benefits. However, these factors are not mutually exclusive. Many of the jaw alignment studies did not report control of jaw clenching as a potential confounding factor influencing performance. Conversely, several jaw clenching studies utilized mouthpieces to provide participants an object to bite against. No previous investigations have attempted to determine whether any observed performance improvements can be attributed exclusively to jaw clenching, jaw alignment via mouthpiece use, or if the combination of clenching and the presence of a mouthpiece further facilitates performance improvement. Therefore, this investigation will test the hypothesis that the use of a performance mouthpiece in combination with jaw clenching may positively impact performance of recreationally resistance trained individuals during the selected strength and power assessments.

**Specific Aims**

Specific Aim 1:

To investigate the effect of a performance mouthpiece, clenching, and the combination of clenching and mouthpiece use on peak vertical ground reaction force, rate of force development, and vertical jump height during maximal vertical jump assessment.

Specific Aim 2:

To investigate the effect of a performance mouthpiece, clenching, and the combination of clenching and mouthpiece use on peak vertical ground reaction force and rate of force development during maximal isometric clean pull.
Specific Aim 3:

To investigate the effect of a performance mouthpiece, clenching, and the combination of clenching and mouthpiece use on maximal isometric force, percent muscle activation, and muscle activity of knee extensor, hip extensor, and spinal erector musculature.

The following null hypotheses will be tested:

$H_{01a}$: There will be no difference in PF during CMVJ between conditions.

$H_{01b}$: There will be no difference in nPF during CMVJ between conditions.

$H_{01c}$: There will be no difference in RFD during CMVJ between conditions.

$H_{02a}$: There will be no difference in PF during MTCP between conditions.

$H_{02b}$: There will be no difference in nPF during MTCP between conditions.

$H_{02c}$: There will be no difference in RFD during MTCP between conditions.

$H_{03a}$: There will be no difference in mean and peak EMG amplitude in MG during MVC between conditions.

$H_{03b}$: There will be no difference in mean and peak EMG amplitude in MH during MVC between conditions.

$H_{03c}$: There will be no difference in mean and peak EMG amplitude in VMO during MVC between conditions.

$H_{03d}$: There will be no difference in mean and peak EMG amplitude in ES during MVC between conditions.
Ho₄ₐ: There will be no difference in %Activation of MG during CMVJ between conditions.

Ho₄₆b: There will be no difference in %Activation of MH during CMVJ between conditions.

Ho₄₆c: There will be no difference in %Activation of VMO during CMVJ between conditions.

Ho₄₆d: There will be no difference in %Activation of ES during CMVJ between conditions.

Ho₅₆a: There will be no difference in %Activation of MG during MTCP between conditions.

Ho₅₆b: There will be no difference in %Activation of MH during MTCP between conditions.

Ho₅₆c: There will be no difference in %Activation of VMO during MTCP between conditions.

Ho₅₆d: There will be no difference in %Activation of ES during MTCP between conditions.
II. REVIEW OF LITERATURE

The purpose of this investigation is to assess the acute effects of a bite-aligning performance mouthpiece, jaw clenching, and the combination of the mouthpiece and clenching on strength, power, and muscle activity in an attempt to determine if jaw alignment, jaw clenching, or a combination of both have an ergogenic effect on performance. This chapter will provide insight to previous literature on the use of mouthpieces and jaw clenching to enhance performance as well as the proposed mechanisms of action behind these devices and techniques. This chapter is divided into three sections. The first section is a brief discussion about traditional strength and conditioning practices designed to improve performance and common methods of assessing strength and power performance. The next section will provide insight into the previous research examining the use of mouthpieces to improve various aspects of physical performance. This will be followed by evidence for the phenomenon of concurrent activation potentiation via remote voluntary contractions such as jaw clenching, and the resulting effects on performance.
Strength and Conditioning Training

In recent history, athletes shied away from resistance training for fear of becoming “muscle bound” and subsequently, losing muscle flexibility (33). However, the large volume of resistance training research published in the past 30 years has shed light on all the health and performance related benefits of resistance training. As a result, resistance training has become a valuable part of training for various team and individual sports. Although an exhaustive review of resistance training is too large for the current project, the objectives of resistance training as well as the principles that direct training program design warrant discussion as they are pertinent for the methodology.

Resistance training is a general term used to describe exercise performed against resistance, usually machines or free weights, with purposes ranging from injury prevention and rehabilitation to gaining a competitive edge in sport and even for improved aesthetics, such as with body building. Harre (54) defined training as the process of preparing an athlete physically and psychologically for the highest levels of performance. Known doctrines of physics, physiology, and other areas contributory to performance are applied and manipulated in order to obtain an optimum level of fitness for ideal performance capability in the given sport or physical activity (70). The pursuit of training optimization has led to the establishment of several principles that govern the training effort and provide an understandable structure for various training tasks. The foremost of the aforementioned principles are progressive overload, variation, and specificity (64).

The principle of progressive overload refers to the gradual stress increase placed on the body during training that is beyond its current capabilities in order to elicit continued adaptation toward training goals (6). Progressive overload is accomplished by altering, typically increasing,
one or more variables associated with resistance training such as exercise intensity, number of repetitions performed at a given exercise intensity, repetition performance speed or tempo at submaximal loads, rest periods, and training volume which is total work performed represented as the product of total repetitions performed and the resistance load (6).

The principle of variation, or periodization, involves the systematic manipulation of one or more training variable over time in order to maintain a challenging and effective training stimulus and prevent adaptation plateauing (6). While variation can be achieved by manipulating any combination of training variables, it has been shown that variation of training volume and intensity is most effective for long term progression (81). The concept of periodization was developed based on the studies of general adaptation syndrome by Hans Selye (76). Periodization is the progressive cycling of various aspects of training in order to optimize performance and recovery (37). Several periodization models have been studied, but the most common model for athletes in traditional sports is linear periodization. Linear periodization is characterized by high initial training volumes and low intensities, and as training progresses, volume decreases as intensity increases (37). The goal of this periodization model is to elicit “peak” performance of a distinct fitness variable, such as strength or power, for a specific and often small window of time (37).

The principle of specificity is one of the most well-understood, thoroughly investigated, and widely known principles of fitness training (68,75). Summarized by the acronym S.A.I.D., which stands for specific adaptations to imposed demands, specificity is the idea that the body’s neuromuscular system will adapt, unambiguously, to the demands placed upon it. Various factors are involved in the physiological adaptations of resistance training. Those factors include the
muscle actions involved (26), speed of movement (21,23), range of motion (62), muscle groups trained (65), and intensity and volume of training (73).

The specific way in which these factors are manipulated affects the resistance training adaptation outcomes. There are four primary resistance training adaptation outcomes: muscular endurance, muscular hypertrophy, muscular strength, and muscular power. In the sports and activities that require the generation of high levels of force over relatively short periods of time, the primary outcomes of interest for the purpose of improving performance are muscular strength and power.

Muscular strength is defined as the maximum force a muscle or muscle group can generate at a specified or determined velocity (63) while muscular power is the product of force production and movement velocity (59). Muscular force production and movement velocity are not mutually exclusive of each other in terms of muscle action. For concentric muscle actions, as movement velocity increases, the muscular force produced decreases and vice versa. Therefore, the maximal expression of muscular power is achieved via the optimum combination of force production and movement velocity (78).

Maximal force production and power are necessary in the movements of sport, manual labor, and activities of daily living. Because of this, both muscular strength and power are especially important human performance testing variables and resistance training objectives (6). In fact, in many such activities, power has been shown to be the primary determinant of performance (53). Training to maximize strength and power involves the purposeful manipulation of training program variables such as exercise selection, intensity, and repetition velocity (6).
Several studies have demonstrated improved power performance following traditional, heavy resistance training (3,50,65) primarily due to the dependence of power production on muscular force. However, it is believed that heavy resistance training could lead to decreased power output over time unless accompanied by explosive movements (11). The inclusion of whole body, explosive exercises in a training regimen has proven effective at improving power production (84). It is recommended that these explosive movements be performed early in a given training session, and sequenced based on complexity (6).

Exercise loading, or intensity, is a variable of considerable importance for the maximization of force production and power improvement. High intensity (85-100% of 1RM) resistance training is necessary for improving force production while sub-maximally loaded (0-60% of 1RM) exercises performed at high movement velocities is required for improving power (6). Because training at any intensity can improve muscle force and power production, subsequently shifting the force-velocity curve up and to the right, training should encompass a range of intensities (59). In the interest of specificity, importance should be placed on intensities that match the demands of the sport or activity of interest (59). Consideration should also be given to training with the intent of moving with maximal velocity regardless of exercise load as it has been shown to impact the training adaptation outcome (10).
Mouthpieces as Ergogenic Aids

The use of a protective mouthpiece, also called a mouthguard, for injury prevention in sports such as football, field hockey, ice hockey, and lacrosse is a recommended (2) and required practice (69) which can be traced back to the 19th century when a British dentist, Woolf Krause, fitted boxers’ teeth with strips of tree bark before fights for protection against dental injury (72). Dr. Krause’s son, Phillip Krause, a former boxer and also a practicing dentist, is credited with making the first re-usable protective mouthpiece for himself and others, including the first professional boxer to wear a mouthpiece, Ted “Kid” Lewis, circa 1920 (72). In the 1940’s and 1950’s, up to 50% of all American football injuries were dental related (61). Research on the protective benefits of mouthpieces began in the 1950’s for the American Dental Association (2) and by 1962 all high school football players were required to wear a protective mouthpiece. In 1973, the NCAA made the use of a protective mouthpiece a requirement for football players at the collegiate level. Dental injuries have declined dramatically since the introduction of the protective mouthpiece, more than a century ago (61).

Stenger (80) reported the first performance improvements attributed to the use of physiologically fitted mouthpieces worn by concussed and injured University of Notre Dame football players. Symptoms of concussion such as headaches, loss of equilibrium and propensity to sustain additional concussions were reduced or eliminated when they were fitted with a mouthpiece to correct the mal-occluded jaw position commonly associated with temporomandibular joint (TMJ) disorder or TMD.

Smith (79) examined the hypothesis that adequate oral muscular strength and proper jaw position would exhibit a positive relationship with the overall muscular strength of the body. Following a dental history questionnaire related to the TMJ and an oral orthopedic examination,
Smith fitted 47 athletes from the Philadelphia Eagles football team with wax mouthpieces designed to bring the jaw into a proper, vertically occluded position, and tested isometric as well as isokinetic deltoid strength, with and without the mouthpiece.

Isometric shoulder abduction strength was subjectively assessed by the researcher manually resisting the participant efforts to abduct the arm. Participants were deemed to have performed better when both the participant and researcher mutually agreed that a difference in strength was present. Of the 47 players tested, 22 performed better during the isometric strength assessment with the wax mouthpiece when compared to without.

Isokinetic shoulder abduction strength was measured via the use of a Cybex II Dynamometer. This more objective measure revealed more conservative results with only four players performing better in the assessment with the use of the wax mouthpiece. Although no proper statistical analysis of data was conducted, Smith concluded that a positive correlation between jaw posture and the ability of the tested musculature to provide a strong contraction was present. These findings provide an early indication that the use of a mouthpiece to properly align the jaw has a greater relationship with isometric muscle force production than other types of muscular actions.

Kaufman (57) fitted U.S. Olympic luge athletes with mandibular orthopedic repositioning appliances (MORA). Several athletes who previously experienced headaches due to the G-forces experienced during the event, reported reductions in the severity and frequency of headaches as well as increased strength during the push off at the start of the event. Following these case-study reports, Kauffman conducted research with the C.W. Post College football team examining the effects of a maxillary MORA on measures of physical fitness including strength, jumping ability, and agility over the course of the 1982 season (58). A total of 40 players completed the study,
with 21 being randomly assigned to the MORA group and 19 assigned to a conventional, boil-and-bite mouthpiece group. Of those 40 players, 20 exhibited symptoms of TMJ disorder (10 in each group) while 20 were asymptomatic. For the physical fitness tests completed, strength assessment via bench press performance was significantly improved for the MORA group compared to the conventional mouthpiece group. The findings of this study suggest that strength assessment via the bench press exercise of collegiate football players may be positively influenced by the use of a MORA regardless of TMJ status.

*MORA Research*

The term MORA is attributed to Dr. Harold Gelb whose occlusal splint design (47) is the basis for the MORA design for many of the studies discussed in this review (9,58,86,88). Intended to cover the occlusal surfaces of the posterior teeth, it typically consists of two acrylic segments fabricated to a thickness determined by measuring the vertical dimension of occlusion (VDO). The acrylic segments are connected by a metal lingual bar, and once inserted into the patient’s mouth, is manually adjusted by a trained dentist to achieve the desired position of the mandible.

It is pertinent to note that the other MORA design primarily used in the research discussed in this section has been termed a kinesiologically designed MORA or K-MORA (1,4). This device’s characteristics are determined by a functional criterion such as the patient’s normal VDO during an isometric strength assessment. For the purposes of this review, the terms MORA and K-MORA will be used to differentiate between the two occlusal splint designs. When these two terms are not used in this review, it is because the occlusal splint design characteristics do not meet those described above or are unknown.
Several studies examining the effects of MORAs on performance variables have revealed primarily positive results. Bates (9) reported a 5% increase in muscular power assessed via the vertical jump and a 17.3% increase in isometric grip strength, but no significant improvement in isokinetic strength via the hip sled and bench press assessment in a group of athletes. Williams et al (88) examined arm and leg isokinetic muscle strength bilaterally for 23 athletes under various mandibular position conditions. Although there was variability between muscle groups and mandibular positions in determining optimum muscle strength, results revealed that proper mandibular position had a positive effect on appendage strength. Verban, et al (86) examined the effects of a MORA verses a placebo mouthpiece and the resulting effects on muscular performance during various shoulder joint movements of 20 randomly selected, undergraduate student, volunteers. Significant differences were seen for shoulder extension peak and average torque as well as external rotation average torque in favor of the MORA as compared to the subjects’ normal bite conditions. No significant differences between the placebo mouthpiece and the normal bite condition were reported.

Al-Abasi (4) tested isometric strength of the sternocleidomastoid muscles in subjects exhibiting clinical malocclusion of the jaw. Strength when the jaw was more properly aligned via K-MORA was greater than in their habitual jaw position. Abdul-Jabar (1) examined bilateral, maximum voluntary isometric contraction strength of shoulder, elbow, and knee flexion and extension of females with TMJ dysfunction in three different conditions: biting in habitual occlusion, biting on a K-MORA, and biting on a placebo mouthpiece. Average strength while biting on the K-MORA was significantly greater than either baseline or placebo conditions.

While the research outlined above provides compelling evidence in support of a positive relationship between proper jaw position obtained via the use of a MORA in subjects with some
form of TMJ dysfunction and strength performance of various muscle groups, it has also garnered criticism from others. Moore (67) provided commentary on the subject, stating that due to the inability to attribute TMJ pain to a singular physical defect, it is undeterminable whether the wearing of mouthpieces for the purpose of alleviating TMJ dysfunction is physiologically based or merely a placebo effect. Jakush (56) criticized the lack of statistical analysis in some studies, and poor experimental design in others. He also suspected a placebo effect as the underlying cause of any reported performance improvements, and as such, questioned whether all patients would actually benefit from a repositioning appliance or only those with some degree of TMJ dysfunction.

Greenburg et al (51) tested the use of a MOR A and placebo device compared to no mouthpiece and the resulting effects on shoulder abduction and adduction strength of 14 collegiate basketball players with no clinical or historical TMJ dysfunction. Isokinetic strength was tested using a Cybex II Dynamometer. No differences were found for any testing condition. Burkett & Burnstein (17) performed a similar study examining occlusal splint and placebo device usage compared to control conditions on various measures of appendage strength including bilateral grip strength and endurance, bilateral quadriceps dynamic and static strength, and hamstring dynamic and static strength. Forty five participants, 22 male and 23 female, with no prior knowledge of occlusal splints or their proposed performance benefits volunteered as participants. Analysis of the collected data yielded no significant results.

Proponents of the use of a mouthpiece for performance enhancement have provided their own criticisms as evidence against the utility of studies showing no performance benefits (39,48). In the first review of literature examining mouthpiece use to potentiate performance, Forgione et al (39) cited research conducted on subjects with no apparent mandibular
malocclusions (51), and lack of appropriate physiological methods to design the experimental MORA (17) as reasons no positive results were observed. Gelb et al (48) postulated that many of the challenges to the early literature by various authors was simply because it was reported by clinical dental practitioners, who spend the bulk of their time in training to patient care, as opposed to learning how to conduct suitable research. They also argued that there can be value in clinical application of discovery even in the absence of scientific verification (48).

**Protective Mouthguard Research**

Recently, research examining mouthpieces designed for injury prevention, commonly called mouthguards, has been conducted to determine what effects, if any, may be present from wearing such devices. Bourdin et al (13) examined the influence of two types of maxillary mouthguards on various physiological parameters of 19 trained male, team sport athletes. The physiological parameters measured were visual reaction time, explosive power via vertical jump, ventilation at rest, as well as ventilation and oxygen consumption during submaximal and maximal exercise. The types of mouthguards examined were self-adapted (SA) or “boil and bite” mouthguards and custom-made (CM) mouthguards which are made using dental impressions and fit specifically to the individual. The research revealed that wearing either type of mouthguard did not significantly affect, either positively or negatively, any of the measured physiological parameters when compared to a controlled, no mouthguard condition. Similarly, von Arx et al (87) examined the use of a CM mouthguard on maximal cycle ergometer exercise capacity and cardiopulmonary parameters at peak workload of 13 male athletes who did not currently practice wearing a mouthguard during competition. The CM mouthguard had no significant impact on maximal exercise capacity, ventilation or oxygen uptake. Duddy et al (25) studied the influence of CM mouthguards in comparison to SA mouthguards on the sport specific performance of 18
male, collegiate varsity crew team members. Results revealed that SA or CM mouthguards did not differ from the control, no mouthguard condition for 1-mile running performance or 1 minute rowing ergometer test. Further, performance of the 3-stroke power test on the cycle ergometer was similar for the CM mouthguard trials in comparison to the control condition. The authors concluded that CM mouthguards can be used when necessary without concern for any negative effects on athletic performance.

In addition to finding no negative impact on performance variables, some authors have reported significant benefits other than injury prevention when a protective mouthguard is used. Francis and Brasher (40) observed decreased VO\textsubscript{2} consumption during heavy cycle ergometer workloads when various protective mouthguards were worn by men and women in comparison to the same workload sans mouthguard. The authors speculated that the improved ventilation and breathing economy may have been due to “pursed lip” breathing as a result of wearing the mouthguard.

Cetin et al (19) examined the influence of CM mouthguards on strength, speed, and anaerobic performance of 21 male and female, highly trained taekwondo athletes. Specifically, significant improvements were observed in peak and average power during the Wingate Anaerobic Test and hamstring isokinetic peak torque as a result of wearing the mouthguard, while no changes were seen in 20 meter sprint time, jumping tests, and isometric hand, leg or back strength. While the authors were pleased to report no detriment to performance of any of the variables assessed, they were hesitant to attribute the improvements in anaerobic power and hamstring strength to the use of the CM mouthguard. The authors expected a potential placebo effect and not merely the implementation of the mouthguard as the underlying reason for
improved anaerobic performance due to the lack of a blinded and placebo controlled
eperimental design.

*Performance Mouthpiece Research*

More recently, research has been conducted on the use of non-injury preventive,
performance mouthpieces on various measures of human performance. These mouthpieces are
generally designed to fit the lower jaw and have small plastic bite plates that would prevent
direct contact of the upper and lower molar teeth when the mouth is closed (see figure 1 below).
More expensive versions of these mouthpieces require a dental image scan and custom fitting by
a dentist, while less expensive, boil-and-bite versions can be purchased via the internet.

![Figure 1. Boil-and-bite (left) and custom made versions of a performance mouthpiece. Images taken from www.bitetech.com](image)

Garner and McDivitt (45) examined the effects of a mouthpiece on airway openings and
lactate levels in college-aged males. Specifically, cross-sectional area of the oropharynx as well
as lactate levels following 30 minutes of endurance exercise was examined under two conditions:
with and without the mouthpiece. Significant increases in mean oropharynx width and diameter
was observed. Lactate levels following exercise were also lower in the mouthpiece condition;
however, the change was not at the level of significance. Another study, also by Garner and
colleagues (44), evaluated the effects of a performance mouthpiece on gas exchange parameters
during steady state exercise. Again, healthy, college-aged men and women participated and results revealed significantly improved VO₂, VO₂/kg, and VCO₂ in the mouthpiece condition in comparison to no mouthpiece and nose breathing conditions.

Arent, et al. (8) reported significant improvements in vertical jump height and peak power during the 30 second, Wingate Anaerobic Power Test when a performance mouthpiece was used by professional and collegiate athletes compared to tests without a mouthpiece in the same participant group. However, submaximal bench press performance and mean power during the Wingate Test were not different between conditions. Another investigation (43) reported significantly reduced salivary cortisol levels in 28 collegiate football players 10 minutes following a 1-hour bout of intense resistance exercise when a performance mouthpiece was utilized in comparison to elevated cortisol levels post exercise when no mouthpiece was used.

In a study by Garner & Miskimin (46), auditory and visual reaction times were examined under performance mouthpiece and no mouthpiece conditions. While a slight improvement in visual reaction time was observed, it was not significant. However, auditory reaction time was significantly lower with the performance mouthpiece in comparison to the no mouthpiece condition. The authors postulated that auditory reaction time may in some way be modulated by improved blood flow and that the use of the mouthpiece reduced stress in the TMJ allowing for increased blood flow to other areas of the head and neck.

Dunn-Lewis et al (27) reported significant improvements in various physical performance tests for 26 highly trained males and 24 highly trained females with the use of a performance mouthpiece in comparison to a regular mouthpiece or no mouthpiece conditions. Specifically, power and force production were significantly higher for the bench throw with the performance mouthpiece. Rate of power development was significantly higher in men during vertical jump
performance when using the performance mouthpiece compared to the other treatment conditions. Additionally, power and force production during the plyo-press power quotient (3PQ) were higher in men for the performance mouthpiece condition over other conditions but not for women.

It is important to note that all studies examining performance mouthpieces discussed to this point have used custom-made mouthpieces that are relatively expensive and require individual fitting by a trained dentist. Allen et al (5) examined the effects of an over the counter, boil-and-bite performance mouthpiece on power and strength in 21 recreationally trained, college-aged males in comparison to no mouthpiece use. While group mean scores for every variable measured was slightly improved during the performance mouthpiece condition, no significant differences were observed. The variables measured were peak force, relative peak force, rate of force development, and jump height during the vertical jump as well as one-repetition maximum bench press performance. The authors proposed a few reasons for the lack of significant performance improvement including variability in the design of the mouthpiece used as well as the training status of the participant sample.

Most of the previous research examining mouthpiece effects has been conducted using custom made versions of the mouthpiece with highly trained athletes at the collegiate or professional level (8,13,19,27,40,86), whereas the mouthpiece in this study was self-adapting and participants were only recreationally trained. Additionally, of the aforementioned studies, only Dunn-Lewis (27) reported that no specific directions to clench the jaw were provided to the participants. The other authors failed to mention specifically whether instructions to clench the jaw or to refrain from clenching were provided. Other authors (28,29) have stated that clenching is a natural occurrence during forceful exertion. Therefore, without knowing what or if directions
were provided to the participants in the presented research, it becomes difficult to attribute any observed performance improvements solely to the mouthpiece treatment.

While it seems plausible that the insertion of a non-injury preventive mouthpiece into the oral cavity would increase the volume area of the cavity via physical separation of the maxilla and mandible which, in turn, could lead to improved breathing economy and improved endurance performance, improvements in other measures of performance are not as easily explained. Some authors have been hesitant to attribute the positive results observed during their research directly to the mouthpiece used in the study (19) and that a placebo effect could not be ruled out as an explanation. Others have attempted to explain the effects through various concepts, with the proposed mechanisms underlying the performance improvements centering around two main theories. The first mechanism offered stems from early research on proper alignment of the TMJ. Jakush (56) stated that improved TMJ position affects proprioceptive function of muscle spindles and Golgi tendon organs leading to improved performance. However, studying this concept, at least 30 years ago was difficult as proponents of this theory believed that the technology needed to perform examinations with the level of control required of scientific research was lacking. Some have even spoken out against this mechanism’s feasibility, stating that defining TMJ dysfunction by a rigid, supposedly ideal standard is flawed and that all joints have an acceptable, normal deviation range (67). The other proposed mechanism for the performance enhancement observed with mouthpiece use focuses on clenching the teeth.
Jaw Clenching, Remote Voluntary Contractions, and Concurrent Activation Potentiation

History provides several anecdotal examples of jaw clenching to perform better in stressful situations including Roman soldiers biting leather straps to improve proficiency in battle, women biting on sticks during childbirth to ease the pain of delivery, and Civil War soldiers biting bullets during battlefield extremity amputation before the development of anesthesia (74). In fact, it has been stated that many people naturally clench their jaw, develop tension in the face and neck, and hold their breath during maximal and near maximal exertion, seemingly to gain an ergogenic advantage (28,29). Empirically, there is considerable evidence that jaw clenching and other remote voluntary contractions (RVC) are capable of eliciting improvements in performance.

Remote voluntary contractions are defined as muscle activation isolated from but synchronized with the activation of a prime mover in an exercise (20). Perhaps the first documented example of an RVC would be the Jendrassik maneuver (JM) which was first described in 1883 by physician Ernő Jendrassik as a method of potentiating tendon reflex response in neurologically impaired patients (89). The maneuver primarily involves the patient clenching the jaw, hooking and interlocking the fingers, then attempting to pull the hands apart as the tendon reflex is invoked.

A number of studies have examined the JM and other RVC effects on various outcome measures, consistently showing a positive relationship. In an attempt to demonstrate age dependent effects of the JM, Burke et al (15) observed increased patellar tendon reflex responses in 15 young adults as well as 15 older adults when the JM was used in comparison to control trials. Dowman and Wolpaw (24) demonstrated significant increases in soleus H-reflex
amplitude, a measure of monosynaptic spinal reflex excitability, when wrist muscle contraction was employed with 15 healthy adults aged 18–40.

Additionally, several studies have demonstrated a positive relationship between jaw clenching and various lower body musculature H-reflex excitability. Miyahara (66) examined soleus H-reflex modulation during voluntary jaw clenching of 11 healthy adult volunteers noting that soleus H-reflex facilitation increased as masseter muscle EMG activity increased and that soleus H-reflex was enhanced more so during voluntary jaw clenching than during the JM. Takahashi et al (82) demonstrated that the pretibial H-reflex was significantly facilitated during mastication and that there were no significant differences in H-reflex facilitation between jaw closing and jaw opening phases of mastication. Hiroshi (55) examined voluntary jaw clenching and the resulting effects on grip force production and rate of force development (RFD) in 14 healthy male subjects. Grip force and RFD were significantly greater when jaw clenching occurred before and during force production assessment.

The observed reflex amplitude increase and greater neural excitability is evidence that RVCs such as jaw clenching may increase voluntary force production of prime movers during physical activity, consequently improving performance acutely and contributing to greater stimuli for adaptation to training over time (28). Collectively, the JM, jaw clenching, and other RVC are techniques to elicit a phenomenon known as concurrent activation potentiation or CAP (28).

Potentiation has typically been described in the literature based on time course of action, such as short-term potentiation (52) and post-activation potentiation (PAP) (85). PAP has been described as acute enhancement of dynamic activity facilitated by preceding activity such as heavy resistance training (34) or whole body vibration (22). The term CAP was first used by
Ebben (28) to describe the ergogenic advantage of increased force production of a muscle group attained through the simultaneous activation of muscle groups remote to the prime movers. Recently, the CAP phenomenon has been demonstrated in several studies (29-32).

The first of these studies examined the effects of jaw clenching during the countermovement jump in 14 male and female collegiate track and field athletes. Participants performed jump trials under two experimental conditions: jaw maximally clenched and mouth open (29). During the clenched condition, participants were instructed to bite maximally on a mouthguard during the concentric phase of the jump. Data analysis revealed a significant positive difference for rate of force development and time to peak force during the clenching jump trials when compared to the mouth open trials. Jump height was not affected, however, if clenching was employed during training, the acutely enhanced rate of force development and decreased time to peak force would provide a greater stimulus for training adaptation.

Ebben et al (31), studied the effects of various RVCs on knee extensor torque. Specifically, bilateral gripping, jaw clenching on a mouthguard, and combination RVC conditions including gripping, jaw clenching and modified Valsalva maneuver were reviewed for their effects on knee extensor torque in comparison to non-RVC conditions. Twelve resistance trained males participated and knee extension torque was measured using a Biodex System III dynamometer. Results revealed that gripping alone did not increase performance over the non-RVC condition. However, significantly positive effects were observed for jaw clenching and the various aggregate RVC conditions on knee extension torque over the no RVC condition. Authors stated that quantity and magnitude of RVC may elicit a greater performance outcome for functionally oriented tasks than a single RVC.
The same authors examined RVCs during back squat and jump squat performance of 13 male collegiate athletes from sports including football, track, and hockey (30). Again, CAP was observed. The RVCs used to facilitate CAP were jaw clenching on a mouthguard, gripping and pulling the barbell downward, into the trapezius muscle, and performing a modified Valsalva maneuver. Results revealed significantly increased peak ground reaction forces and rate of force development during the first 100 milliseconds for both the back squat and jump squat trials when RVCs were used as opposed to normal exercise performance. Additionally, rate of force development to peak ground reaction force was significantly increased for the jump squat performance but not the back squat. Jump height was also significantly higher during the RVC condition.

While it appears that CAP can be facilitated via jaw clenching and other RVC, the specific mechanisms of action are not fully understood. Several potential contributing factors, including inhibition of presynaptic inhibition, and motor overflow have been proposed (28).

Early attempts to facilitate the H-reflex via JM were unfruitful, which led researchers to believe tendon reflex modulation by the JM was the result of increased muscle spindle sensitivity (14,71). Recent research has shown that the H-reflex can be facilitated by the JM with correct stimulus intensities (15,18), therefore, changes in peripheral receptor sensitivity is not a factor. Dowman and Wolpaw (24) demonstrated increased soleus H-reflex modulation via the JM without an associated increase in electromyography activity, eliminating changes in motor neuron pool excitability as an explanation. These authors proposed inhibition of presynaptic inhibition or changes in motor neuron excitation threshold resistance as explaining factors. Presynaptic modulation has since been confirmed (89).
In addition to presynaptic modulation, the concept of motor overflow has also been proposed as a potential explanation of the CAP phenomenon. Motor overflow can be defined as involuntary activity in the corresponding muscles of the opposite side of the body during voluntary muscle contractions, as seen in patients with neurological dysfunction (49). Two hypotheses have been proposed to explain motor overflow. The transcallosal facilitation hypothesis states that activation of a cortical region associated with a voluntary movement also activates the opposite hemisphere and homologous muscle or muscles that facilitate that movement, and this is believed to occur via interhemispheric connections (49). The second hypothesis, the transcallosal inhibition theory, states that motor overflow occurs via the removal of inhibition within the ipsilateral corticospinal tract resulting in movements produced by the contralateral hemisphere as the result of overflow (49). Regardless of the specific mechanisms responsible for the CAP phenomenon, facilitation of CAP via RVC can potentially provide an increased stimulus for adaptation when incorporated regularly into strength and power training exercises.
III. METHODOLOGY

Experimental Design and Methodology:

a) Participants:

Thirty six physically active and recreationally trained males, aged 18-30 years, volunteered to participate in this research. The required number of participants was determined via power analysis, with power level set at 0.8 and an effect size of 0.25, using the G*Power statistical software program (35). Participants were considered physically active if they engaged in routine physical activity for a minimum of three days per week for the previous month. Participants had no reported current or past history of TMD, no significant or disabling musculoskeletal, orthopedic, cardiovascular, vestibular, or neurological conditions. Participants also had prior experience performing exercises that are ballistic and explosive in nature, such as the snatch and clean & jerk.

b) Experimental Procedures:

Each participant visited the laboratory on four occasions. The initial visit consisted participant prescreening, obtaining informed consent, basic anthropometric measurement such as height, weight and age, and familiarization of all testing procedures. Each of the remaining testing sessions were approximately one hour in duration and were separated by one week. To account for diurnal variation, all testing times were scheduled within one hour of the previous testing session. The testing conditions, counterbalanced for all participants were as follows: performance mouthpiece with jaw clenched (PMP-C), performance mouthpiece with jaw relaxed (PMP), traditional mouthpiece with jaw clenched (MP-C), traditional mouthpiece with jaw
relaxed (MP), no mouthpiece with jaw clenched (NoMP-C), and no mouthpiece with jaw relaxed (NoMP).

Participants were instructed to maintain a consistent diet and hydration status for the duration of their participation in the study. Participants were asked to refrain from any non-prescription supplementation/drug use throughout the study. The only exception to this request was regarding the use of caffeine, which the participants were asked to maintain consistency with their normal use or nonuse of caffeine. To ensure adequate hydration status for assessment, participants were asked to consume 5-7 milliliters of water per kilogram of body weight four hours prior to each testing session (7). In terms of exercise, participants were asked to refrain from exercise 24 hours prior to a testing session. Finally, participants were asked to maintain their normal sleeping patterns as best as possible throughout their study participation.

To assess total nutritional intake, a three day dietary journal documenting all food and beverage intake for the 72 hours prior to testing was prepared by each participant and submitted prior to the first testing session. Also, single day dietary recalls were reported for each testing day. All diet records were analyzed using the nutrient analysis software, Nutrition Data Systems for Research (NDSR; Minneapolis, MN, version 2009) for total calorie, carbohydrate, and protein intake. Additionally, each participant provided a urine sample on each testing day which was analyzed for specific gravity via dipstick (BTNX Inc; Markham, Ontario, Canada) to ensure proper hydration status. Finally, oral questioning conducted by the primary investigator was used to determine participant adherence to exercise, supplement, and sleep requests.

At the first visit to the laboratory, participants were asked to read and sign an institutionally approved informed consent document and complete the preliminary medical and
participant screening questionnaire. If all inclusion criteria were met, participant anthropometrics were measured and testing protocol familiarization was provided.

During each testing visit to the laboratory, a battery of assessments were administered in the same sequence under two different conditions: jaw maximally clenched, and jaw closed but not clenched. To control for clenching during the non-clenching or “jaw relaxed” conditions, the participants were instructed to breathe through pursed lips which limits the ability to clench the jaw musculature (30). This method is consistent with previously published research (30,31).

Assessment measures included maximal countermovement vertical jump (CMVJ) assessment, maximal isometric force production assessment via the isometric mid-thigh clean pull (MTCP), and muscle activity during both CMVJ and MTCP assessments via surface electromyography (EMG). Prior to the assessment protocol, each participant performed 2 sets of 15 meters of dynamic warm-up movements including jogs, walking lunges, high knees, butt-kickers, and gait swings. Following warm up, participants performed maximum isometric voluntary contractions (MVC) of the selected musculature. Specifically, MVC data was recorded from the gastrocnemius, hamstring, vastus medialis, and erector spinae. This was followed by CMVJ assessment and then MTCP performance. Tests were performed in this sequence in order to mimic the commonly prescribed exercise assessment order of power movements followed by strength movements (38). To determine percent activation of the previously mentioned musculature, surface EMG was collected during both CMVJ and MTCP assessments and compared to the EMG data collected during MVC assessment at the onset of the experimental protocol.

c) Equipment and Assessment Procedures

   i. Vertical Jump Assessment Procedure
Vertical jump performance was recorded using a Vertec® (Sports Imports, Columbus, OH, USA) free standing jump height measurement device. CMVJ assessment procedures were consistent with those described by Semenick (77). The participant was instructed to determine their maximum reach height by standing flat-footed, directly underneath the Vertec device, reaching up with the dominant hand to push forward the highest vane that could be reached. The height of the device was then increased to accommodate a maximal effort CMVJ. The participant was then instructed to perform each CMVJ trial without moving the feet prior to take off, to jump maximally, and to tap the highest vane possible at the apex of the jump. Trials were recorded as the vertical distance, to the nearest one-half inch between the reach height and height of vane tapped during the jump. Each participant was permitted three trials for both the jaw clenched and jaw relaxed conditions. The trial producing the highest value for each condition was used for analysis.

**ii. Isometric Clean Pull Assessment**

Isometric clean pull assessment was facilitated by using a Jones machine (BodyCraft, Inc., Sunbury, OH, USA). The Jones machine was modified so that the bar was fixed and unmovable. A goniometer was used to standardize hip and knee angles to flexed positions of 125 and 140 degrees respectively, with as little variance between participants as the Jones machine adjustments would allow. The participant gripped the bar using a double overhand, closed grip in which the thumb was wrapped around the bar. Additionally, nylon weightlifting straps were used to remove hand size and grip strength as potentially confounding factors. When instructed, the participant exerted maximal force against the fixed barbell for three seconds. Thirty seconds rest was provided between trials to ensure recovery. Three trials were afforded to each participant. The trial producing the highest ground reaction force values from the force
platform for each condition were used for analysis. These procedures are consistent with previously published research (60).

**iii. Instrumentation and Data Processing**

**a. Force Plate**

All jump and clean pull trials were executed from a 600mm x 400mm force platform (Bertec Inc., Columbus OH, USA). Force plate data were recorded at 1000Hz. Ground reaction force (GRF) data was used for the identification of peak force (PF), relative peak force, and calculation of rate of force development (RFD). Relative PF data was determined by dividing the PF by participant body weight and expressed as a function of body weight (nPf).

Derived from the vertical force components of the force-time record during the CMVJ trial of maximal obtained height, RFD was calculated as the slope of the GRF curve over the time interval from 0-200ms relative to the onset of concentric force production. Concentric force production was considered to begin when the vertical force component of the GRF curve exceeded body mass as measured by the force plate.

**b. Electromyography**

Bipolar surface EMG was recorded at 1000Hz during CMVJ and MTCP assessment on the participant’s dominant side during all three testing laboratory visits. Electrodes were placed 3-5cm apart, as measured from the electrode center, at each location with a ground electrode on the tibial head. Proper skin preparation for all electrodes included shaving of the hair and abrasion of the skin around electrode site followed by cleansing with an alcohol swab. Data was recorded from the following muscles: the medial head of the gastrocnemius (MG), medial hamstring (MH), oblique fibers of the vastus medialis (VMO), and erector spinae (ES). Specific electrode placement occurred according to the recommendations found on the Surface
Electromyography for the Non-Invasive Assessment of Muscles website (83). Prior to each assessment of CMVJ and MTCP, participants were asked to perform three MVC for each of the selected musculature. Participants maximally contracted the selected muscles for three seconds, and EMG activity was collected for five seconds including one second prior to and immediately following those contractions. These MVC were analyzed for peak and mean signals respectively, and were used to determine percent activation of the selected musculature during performance of the assessments. EMG data collection was facilitated using an 8-channel electromyography system (Noraxon USA Inc., Scottsdale, AZ, USA and was processed with a 4th order Butterworth bandpass filter (10-300Hz).

**d) Statistical Analysis**

The study followed a repeated measures design where each participant served as his own control by being exposed to all mouthpiece and clench conditions. Therefore, a 3 x 2 (mouthpiece x clench condition) ANOVA for repeated measures was conducted to analyze each of the dependent performance variables for interaction and main effect significance. Post-hoc analysis for multiple comparisons were performed using a Bonferroni correction to detect condition differences if main effect significance was present. For all statistical analyses, IBM Statistical Package v21 was used and an alpha level of \( p \leq 0.05 \) was set \textit{a priori}. 
IV. MANUSCRIPT 1

Introduction

Clenching of the jaw is a natural occurrence during forceful exertion (28,29). There is considerable research demonstrating a relationship between clenching and improvements in strength and power performance in particular (29-31,55). Hiroshi (55) reported significant increases in force production and rate of force development (RFD) during grip strength assessment of healthy, college-aged males when the jaw was clenched before and during force production. Ebben et al. (29) observed increased RFD and decreased time to peak force during vertical jump assessment of male and female collegiate track and field athletes when the jaw was maximally clenched around a mouth guard.

Clenching the jaw during forceful exertion is one example of a remote voluntary contraction (RVC). RVCs are defined as muscle activation isolated from but synchronized with the activation of a prime mover in an exercise (20). The Jendrassik maneuver may be the first documented example of an RVC (89). Other examples include clenching the jaw, gripping with the fists, and the Valsava maneuver, and all have potential to elicit a phenomenon known as concurrent activation potentiation or CAP (28). The term CAP was first used by Ebben (28) to describe the ergogenic advantage of increased force production of a muscle group attained through the use of RVCs simultaneously with prime mover activation. The phenomenon has been demonstrated in several recent studies (29-31).

The first reported performance improvements attributed to the use of a mouthpiece occurred in 1977 when concussed collegiate football players experienced reduced concussion
symptom frequency and severity following physiological fitting with a mouthpiece designed to correct the mal-occluded jaw position associated with temporomandibular joint (TMJ) disorder (80). The following year, Smith (79) examined the hypothesis that oral strength and proper jaw alignment would exhibit a positive relationship with overall muscular strength of the body, concluding that a positive correlation was present. Early research examined various mouthpieces designed to achieve a more proper jaw alignment with numerous performance variables revealed primarily positive results (1,4,86,88). Williams et al. (88) examined the effect of a mandibular oral repositioning appliance (MORA) on strength of shoulder and knee musculature of 23 male collegiate athletes, concluding that jaw position significantly affects appendage strength. Similarly, Verban et al. (86) examined the effect of a MORA on shoulder strength of a mixed gender sample of college students. Again the MORA yielded higher peak torque for shoulder extension as well as higher average torque for extension and external rotation. Isometric strength of the extremities was improved significantly in females with TMJ disorder with the use of a MORA (1) and sternocleidomastoid isometric strength was improved in 15 subjects exhibiting TMJ symptoms when their maxilla-mandibular relationship was adjusted via the use of a mouthpiece (4).

Recent investigations examining the effect of jaw position and the use of a mouthpiece on various strength and power measures have yielded mixed results (5,8,19,27). Cetin et al. (19) examined the effects of a custom-made mouth guard on various anaerobic variables such as strength, speed, and power in male and female, taekwondo athletes. Although no improvements in 20m sprint time, squat and countermovement vertical jump performance, or isometric strength measures were observed, improved peak and average power during the Wingate anaerobic test and peak hamstring torque were reported in comparison to performance without the mouth
guard. Similarly, Arent et al. (8) reported improved peak power during the Wingate anaerobic test as well as improvements in vertical jump height when a jaw-aligning mouthpiece was worn by professional and collegiate athletes compared to a standard, custom-fitted mouthpiece. There were, however, no observed improvements in bench press endurance performance or mean power during the Wingate anaerobic test.

In both of these studies, it was unclear if participants were provided any instruction in regards to refraining from or intentionally clenching of the jaw around the respective mouthpieces. Therefore, it is not known whether jaw clenching was a potentially confounding factor influencing performance assessment outcomes of these investigations.

Dunn-Lewis et al. (27) investigated the effects of a customized performance mouthpiece compared to an over the counter, boil-and-bite mouthpiece, and no mouthpiece on a battery of assessments in current and former division I collegiate athletes. While no differences in flexibility, balance, speed, or reaction time were observed between treatment conditions, force and power production were higher during the bench throw assessment for the performance mouthpiece condition in both male and female participants. Additionally, other improvements were observed in male participants only under the performance mouthpiece condition, including greater power and force production during the plyo press power quotient assessment and rate of power development during vertical jump performance assessment. Allen et al. (5) examined an over the counter, boil-and-bite version of a performance mouthpiece on vertical jump and bench press performance in recreationally resistance trained, collegiate males. There were no differences for any performance variable when compared to performance without a mouthpiece.

Each of these studies reported specific instructions to the participants to perform normally during assessment, regardless of mouthpiece condition. The idea was that jaw
clenching during performance was unimportant since only the mouthpiece condition would be different between performance assessments. However, without knowing whether participants clenched the jaw, it remains unclear whether improvements in performance can be attributed to jaw alignment via mouthpiece use.

Previous research has differentiated jaw alignment via mouthpiece use and jaw clenching as mutually exclusive factors to explain the observed and reported performance benefits. However, these factors are not mutually exclusive. Many of the jaw alignment studies did not report control of jaw clenching as a potential factor influencing performance. Conversely, several jaw clenching studies utilized mouthpieces to provide participants an object to bite against. No previous investigations have attempted to determine whether any observed performance improvements can be attributed exclusively to jaw clenching, jaw alignment via mouthpiece use, or if the combination of clenching and the presence of a mouthpiece further facilitates performance improvement. As such, this investigation sought to determine whether any observed strength and power performance enhancements may be directly and exclusively attributable to jaw clenching, jaw alignment mouthpiece use, or if clenching and mouthpiece use have a synergistic effect.

**Methods**

*Experimental Approach to the Problem*

This study examined the relationship between jaw clenching, jaw alignment via the use of a performance mouthpiece, and force production performance during maximum countermovement vertical jump (CMVJ) and maximum isometric mid-thigh clean pull (MTCP) assessments in an attempt to determine any observed ergogenic effects attributable to either
clenching, mouthpiece use or the combination of both. A within-subjects design was used in which participants repeated the assessments under each experimental condition.

Experimental testing consisted of 4 laboratory visits. The initial visit consisted of participant prescreening, obtaining informed consent, basic anthropometric measurement, provision of both mouthpieces, and familiarization of all testing procedures. The 3 remaining laboratory visits were data collection sessions lasting approximately one hour in duration and were separated by approximately one week. To account for diurnal variation, all testing times were scheduled within one hour of the time of day of the previous testing session. The experimental conditions, which were counterbalanced for all participants, were as follows: performance mouthpiece (ArmourBite Mouthpiece; Under Armour, Baltimore, MD, USA) with jaw clenched (PMP-C), performance mouthpiece with jaw relaxed (PMP), traditional mouthpiece (Cramer Mouth Guard; Cramer Products Inc, Gardner, KS, USA) with jaw clenched (MP-C), traditional mouthpiece with jaw relaxed (MP), no mouthpiece with jaw clenched (NoMP-C), and no mouthpiece with jaw relaxed (NoMP). Both jaw clenched and jaw relaxed trials for each respective mouthpiece condition were performed within a testing session.

Participants were instructed to maintain a consistent dietary status for the duration of their participation in the study. To ensure no dietary abnormalities, a 3 day dietary journal documenting all food and beverage intake for the 72 hours prior to the initial testing session was prepared by each participant. Two, 24-hour dietary recalls were also reported for both remaining testing days. Participants were also asked to refrain from any non-prescription supplementation/drug use throughout the study. The only exception to this request was regarding the use of caffeine, which the participants were asked to maintain consistency with their normal use or nonuse for the duration of the study. To ensure adequate hydration status for
assessments, participants were asked to consume 5-7 milliliters of water per kilogram of body weight four hours prior to each testing session (7). A urine sample was provided by each participant on each testing day which was analyzed for specific gravity via dipstick (BTNX Inc; Markham, Ontario, Canada) to ensure euhydration status prior to testing. In terms of exercise, participants maintained their normal exercise routines, however, they were asked to refrain from exercise 24 hours prior to a testing session. Finally, participants were asked to maintain their normal sleeping patterns as best as possible throughout their study participation. Oral questioning conducted by the primary investigator was used to determine participant adherence to exercise, nutritional, and sleep requests.

**Subjects**

Thirty six (n = 36) physically active and recreationally resistance trained males, aged 18-30 years, volunteered to participate in this research. Participants were considered physically active if they engaged in routine resistance training exercise for a minimum of three days per week for the previous month. None of the participants (n=36; age, 23 ± 2.8 years; height, 178.54 ± 9.0 cm; body mass, 83.09 ± 7.8 kg) reported current or past history of temporomandibular disorder (TMD), and all were free of injury or illness at the time of testing. Participants also had prior experience performing exercises that are ballistic and explosive in nature, such as the snatch and clean & jerk. All participants signed the University approved Institutional Review Board consent documents.

**Procedures**

During each testing visit to the laboratory, the assessments were administered in the same sequence under two different conditions: jaw maximally clenched, and jaw closed but not clenched. Twenty minutes of quiet rest between the initial and final round of assessments was
provided to each participant to ensure recovery from one experimental condition to the next. These clench conditions were counterbalanced between participants and mouthpiece conditions to control for any potential order effect. To control for clenching during the non-clenching or “jaw relaxed” conditions, the participants were instructed to breathe through pursed lips which limits the ability to clench the jaw musculature (30). This method is consistent with previously published research (30-31).

Prior to the assessment protocol, each participant performed a brief, dynamic warmup which was designed and supervised by National Strength and Conditioning Association, Certified Strength and Conditioning Specialists. Assessment measures in order of occurrence were the maximal CMVJ and assessment of maximal isometric force production via the MTCP. Tests were performed in this sequence in order to mimic the commonly prescribed exercise assessment order of power movements followed by strength movements (38). Specific CMVJ and MTCP assessment procedures are outlined below. All CMVJ and MTCP assessments were executed from a 600mm x 400mm force platform (Bertec Inc., Columbus OH, USA). Force plate data were recorded at 1000Hz. Ground reaction force (GRF) data was used for the identification of peak force (PF), normalized peak force (nPF), and calculation of rate of force development (RFD). Normalized PF data was determined by dividing the PF by participant body weight. RFD was calculated as the slope of the vertical GRF curve over a 200ms time interval relative to the onset of concentric force production. Concentric force production was considered to begin when the vertical force component of the GRF curve exceeded body mass as measured by the force plate.
**Countermovement Vertical Jump Assessment Procedure**

Vertical jump performance was recorded using a Vertec® (Sports Imports, Columbus, OH, USA) free standing jump height measurement device. CMVJ assessment procedures were consistent with those described by Semenick (77). The participant was instructed to determine their maximum reach height by standing flat-footed, directly underneath the Vertec device, reaching up with the dominant hand to push forward the highest vane that could be reached. The height of the device was then increased to accommodate a maximal effort CMVJ. The participant was then instructed to perform each CMVJ trial without moving the feet prior to take off, to jump maximally, and to tap the highest vane possible at the apex of the jump. Trials were recorded as the vertical distance, to the nearest one-half inch between the reach height and height of vane tapped during the jump. Each participant was permitted three trials for both the jaw clenched and jaw relaxed conditions. The trial producing the highest value for each condition was used for analysis.

**Isometric Mid-Thigh Clean Pull Assessment Procedure**

Isometric clean pull assessment was facilitated by using a Jones machine (BodyCraft, Inc., Sunbury, OH, USA). The Jones machine was modified so that the bar was fixed and unmovable. A goniometer was used to standardize hip and knee angles to flexed positions of 125 and 140 degrees respectively, with as little variance between participants as the Jones machine adjustments would allow. The participant gripped the bar using a double overhand, closed grip in which the thumb was wrapped around the bar. Additionally, nylon weightlifting straps were used to remove hand size and grip strength as potentially limiting factors. When instructed, the participant exerted maximal force against the fixed barbell for three seconds. Thirty seconds rest was provided between trials to ensure recovery. Three trials were afforded to each participant.
The trial producing the highest ground reaction force values from the force platform for each condition were used for analysis. These procedures are consistent with previously published research (60).

**Statistical Analyses**

The study followed a repeated measures design where each participant served as his own control by being exposed to all mouthpiece and clench conditions. Therefore, a 3 x 2 (mouthpiece x clench condition) ANOVA for repeated measures was conducted to analyze each of the dependent performance variables. All analyses were performed with an alpha level of \( p \leq 0.05 \), set a priori. Data were analyzed using IBM Statistics package software, version 22.0 (IBM SPSS Statistics, Armonk, NY, USA). Statistical power (\( d \)) and effect size (\( \eta_p^2 \)) are reported, and all data are expressed as mean ± SE.

**Results**

There were no statistically significant differences in PF, nPF, or RFD observed during CMVJ performance for any treatment condition. The MTCP assessment revealed a significant increase in PF for jaw clenching regardless of the mouthpiece condition (\( p < 0.000, \eta_p^2 = 0.31, d = 0.97 \)). The nPF (\( p < 0.000, \eta_p^2 = 0.32, d = 0.98 \)) and the RFD (\( p = 0.001, \eta_p^2 = 0.27, d = 0.94 \)) were also significantly increased for jaw clenching, regardless of the mouthpiece condition. Data for both the CMVJ and MTCP are presented in Table 1.
Table 1 – Force variables for CMVJ & MTCP. Data are expressed as mean ± standard error. Asterisk (*) indicates a statistically significant difference between clench conditions.

**Discussion**

While several previous studies have examined jaw clenching or jaw alignment via mouthpiece use in efforts to elicit an ergogenic effect, this is the first study to determine whether observed performance improvements can be attributed exclusively to jaw clenching, jaw alignment via mouthpiece use, or if both conditions are necessary to achieve ergogenic effects. Regardless of the presence or type of mouthpiece used, maximum jaw clenching has an ergogenic effect for force production capabilities, specifically in recreationally resistance trained men during an isometric exercise such as the MTCP. These findings are consistent with previously published research examining the effects of RVCs such as jaw clenching on various force production measures (30, 55). Hiroshi (55) examined the effects of jaw clenching on PF and RFD during isometric grip strength performance of a non-athlete population and reported that clenching the jaw resulted in increased grip strength PF by 12.3% and RFD by 15.8%. Similarly, Ebben (30) observed increases in PF and RFD during back squat and jump squat performance of 2.9-32.2% when RVCs including jaw clenching were employed in 13 intercollegiate and recreational male athletes. In this study, maximally clenching the jaw improved PF, and RFD during the MTCP by 3.51% and 8.7% respectively.

Though one investigation of jaw clenching and its impact on CMVJ performance identified improvements in RFD and other variables (29), similar results were not observed in
this research. Participants in the aforementioned study were collegiate track and field athletes while participants in the current study were recreationally resistance trained individuals which provides one possible explanation for the absence of an observed effect on performance. Of note, while no CMVJ performance enhancements were observed in the current study, there was no performance impairment either.

Although several previous investigations reported ergogenic effects for force production variables with a performance mouthpiece for jaw alignment, the differing mouthpiece treatments from the current investigation yielded no such advantages. Arent et al. (8) observed improved peak power during the Wingate anaerobic test as well as improvements in CMVJ height when a performance mouthpiece was worn by professional and collegiate athletes compared to a standard, custom-fitted mouthpiece. Dunn-Lewis et al. (27) saw higher force and power production during the bench throw and plyo press power quotient assessments and increased rate of power development during vertical jump performance assessment when a performance mouthpiece was utilized. In both of these studies, highly trained, professional and collegiate athletes served as participants, and the performance mouthpieces utilized were expensive models requiring specific fitting from a dental practitioner. Similar ergogenic effects were not seen in a recent study involving recreationally resistance trained males and a relatively inexpensive, boil-and-bite performance mouthpiece (5) nor were any advantages from performance mouthpiece utilization observed in this study. This leads these authors to believe that the effects of “optimal” jaw alignment via performance mouthpiece may be limited to the specific training level of the participant group or to the specific brand and model of performance mouthpiece used in those aforementioned investigations. Further, all of the recent studies examining the effects of jaw aligning mouthpieces and their effects on performance have failed to either report or account for
jaw clenching as an outcome influencing variable (8,19,27). As a result, it is possible that the ergogenic effects reported in these studies was, at least in part, due to jaw clenching and not the jaw aligning mouthpiece. Future research should evaluate differences between performance mouthpiece brands as well as both dentistry-fitted and boil-and-bite mouthpiece models while quantifying the amount of jaw clenching during assessment performance. Exploration of the specific mechanisms underlying the CAP phenomenon produced via RVC implementation will also be useful.

Conclusions

This study supports previous research demonstrating that the implementation of remove voluntary contractions (RVC) such as jaw clenching can lead to concurrent activation potentiation (CAP) and a resulting ergogenic effect during activities involving and requiring high levels of force production. As such, strength and conditioning practitioners can encourage athletes and clients to employ RVCs during resistance training sessions to potentially enhance acute force production performance as well as increase the overall training stimulus of the resistance training bout. The use of a jaw aligning performance mouthpiece to aid in force production enhancement does not appear to be justified, specifically in the recreationally trained population.
IV. MANUSCRIPT 2

Introduction

Concurrent activation potentiation (CAP) is defined as the ergogenic advantage of increased force production attained through the use of remote voluntary contractions (RVC) simultaneously with prime mover activation (28). Enhanced neural drive as a result of motor overflow has been proposed as the primary mechanism underlying CAP (29-32). The cortical connection theory of motor overflow states that when one part of the motor cortex is activated, such as during RVC, connections to other areas of the motor cortex are affected (29). This, in turn, would potentially lead to increased activity of the muscles mediated by areas of the motor cortex affected by motor overflow. Motor overflow has been observed in both the neurologically diseased and healthy individuals. Maximum voluntary contractions resulted in involuntary movement of homologous contralateral musculature in participants with Huntington’s disease (49). Additionally, motor overflow has also been demonstrated via potentiated contralateral forearm muscle activity as the result of ipsilateral forearm voluntary movement (12).

Studies examining this mechanism during physical activity are limited and have revealed mixed results (32,41). Ebben et al, (32) examined the effects of RVC on peak force (PF), power, and the activation of various muscles during isokinetic knee extension and flexion. The muscles examined for EMG activity were the prime movers for each movement, the antagonists, and the homologous musculature on the contralateral side of the body. Males exhibited significant improvements in PF and power for both knee extension and flexion, while females had similar improvements during knee extension only. This observed increase in force production was
accompanied by a significant increase in prime mover activation but not in antagonist or
homologous contralateral musculature (32). In a similar study by Garceau et al, (41), PF, rate of
force development (RFD), and muscle activity were examined under RVC and no RVC
conditions for isometric knee extension in males and females. Significant improvements in PF
and RFD were observed under the RVC condition for males only. However, significantly
different prime mover muscle activation did not accompany the improvements in force variables
(41).

Due to the paucity of research examining the effects of RVC such as jaw clenching on
EMG activity, as well as the mixed results of those investigations, it becomes necessary to focus
on the impact of CAP on force variables, for which there is considerable evidence, in an effort to
extrapolate the details underlying the CAP phenomenon. Jaw clenching has been shown to
stimulate CAP and a subsequent improvement in force production variables during a variety of
physical tasks including increased RFD and decreased time to peak force during vertical jump
performance (29), and improved PF and RFD during back squat performance as well as PF,
RFD, and jump height during jump squat performance (30).

The use of jaw-aligning mouthpieces as ergogenic aids have also been investigated.
Smith (79) reported a positive correlation between a properly aligned jaw position via
mouthpiece and the overall muscular strength of the body after subjectively testing the isometric
strength of 47 members of a professional football team exhibiting symptoms of
temporomandibular joint disorder (TMD). Shortly thereafter, several case studies were
completed examining U.S. Olympic luge athletes demonstrating TMD symptoms. When these
athletes were fitted with mandibular orthopedic repositioning appliances (MORA), severity and
frequency of headaches resulting from the G-forces experienced during training and competition
were reduced (57). Additionally, athletes reported increased strength during the push off at the start of the event (57). Subsequent research was conducted with the C.W. Post College football team, examining the effects of the MORA on measures of physical fitness, strength, jumping ability, balance, and agility (58). The findings were positive and in favor of the MORA over the use of a conventional mouthpiece in athletes with TMD symptoms.

The term MORA is attributed to Dr. Harold Gelb whose occlusal splint (47) is the basis for the MORA design. Intended to cover the occlusal surfaces of the posterior teeth, it typically consists of two acrylic segments fabricated to a thickness determined by measuring the vertical dimension of occlusion (VDO) in multiple planes. The acrylic segments are connected by a lingual bar, and once inserted into the patient’s mouth, is manually adjusted by a trained dentist to achieve the desired TMJ alignment and resulting proper mandibular position. This practice of correcting jaw malalignment is referred to as neuromuscular dentistry, and has been shown to improve the force production capabilities of individuals suffering from TMD (1,4,9,86,88).

Recently, neuromuscular dentistry has led to the development of various jaw-aligning mouthpieces for the non-TMD symptomatic population. Typically, dental impressions taken by an orthodontist are used to custom fit the mouthpiece to the individual, which leads to an expensive end product. However, there are boil-and-bite versions available purported to provide similar effects. These products can be designed to fit either the upper or lower jaw, depending on the specific mouthpiece model and individual preference, and have small acrylic bite plates that would inhibit direct contact of the upper and lower molar teeth when the mouth is closed. This changes the temporomandibular joint relationship, pulling the mandible down and slightly forward, which mimics the jaw position achieved with the MORA devices.
Several studies have examined these mouthpieces and their effects on a variety of physiological variables revealing mixed results (43-46). A positive relationship of jaw-aligning mouthpiece use and aerobic endurance exercise performance has been reported due to changes in airway openings (45) and several parameters of respiratory exchange including VO$_2$, VO$_2$/kg, and VCO$_2$ (43). Another investigation reported significant improvements in auditory reaction times when the performance mouthpiece was worn compared to no mouthpiece use (46). Visual reaction time, although slightly improved, was not statistically different (46). Stress hormone response following a vigorous bout of resistance exercise was significantly attenuated when a performance mouthpiece was implemented in comparison to no mouthpiece conditions (44). Researchers examined salivary cortisol levels at various time points during and post-resistance training exercise. While cortisol levels were similar for the duration of the exercise bout for both the mouthpiece and no mouthpiece conditions, cortisol levels at 10 minutes post exercise was significantly lower when the performance mouthpiece was used, suggesting a direct relationship between performance mouthpiece use and post-exercise attenuation of cortisol.

Studies examining performance mouthpiece use on various measures of force production have also been conducted (5,8,27). Significant improvements in vertical jump height and peak power during the 30 second, Wingate Anaerobic Power Test were reported when a neuromuscular dentistry-based mouthpiece was used by professional and collegiate athletes compared to tests without a mouthpiece in the same participant group, however, submaximal bench press performance and mean power during the Wingate Test were not different between conditions (8). Dunn-Lewis, et al. (27) examined a performance mouthpiece’s effects on a myriad of performance variables in highly trained males and females. Power and force production during the bench throw test were significantly greater in both sexes under the
performance mouthpiece condition. Additionally, significant improvements were reported for the performance mouthpiece condition in males only for force production and power during the Plyo Press Power Quotient assessment and rate of power production during the vertical jump assessment. Other assessments of sprint time, flexibility, visual reaction time, and balance were not significantly different compared to control conditions. Conversely, no improvement in vertical jump performance variables or 1-repetition maximum (1RM) bench press performance were reported with the use of a performance mouthpiece in comparison to no mouthpiece use (5).

Proposed mechanisms underlying jaw realignment via mouthpiece use are varied depending upon the performance outcome of interest. Early practitioners of neuromuscular dentistry proposed improved proprioceptive function of muscle spindles and Golgi tendon organs (56). One proposed mechanism of interest involves improved neuromuscular response due to the performance mouthpiece (44). Increased genioglossus muscle contraction, demonstrated to lead to a relaxation of the pharyngeal airway, was proposed as one explanation for improved gas exchange parameters during treadmill running when a performance mouthpiece was worn compared to no mouthpiece condition (44). These authors also reported increased electromyography activity of the genioglossus muscle when the performance mouthpiece was worn (44). An increase in neuromuscular activity may explain, at least in part, the previously reported improvements in muscle force production (27). However, the effects of performance mouthpiece use on prime mover muscle activation during physical activity have, to the knowledge of the authors, not yet been reported in the literature.

To this point, jaw alignment via mouthpiece use and jaw clenching have been treated as mutually exclusive factors to explain the observed performance benefits. However, these factors have yet to be demonstrated as mutually exclusive. Many of the recent neuromuscular dentistry
mouthpiece studies did not report or control for jaw clenching as a potential confounding factor (5,8,27,43-46). Conversely, the jaw clenching studies utilized mouthpieces to provide participants an item to clench against which may have impacted the reported results (28-32,41). No previous investigations have attempted to determine whether the observed ergogenic effects can be attributed exclusively to jaw clenching, jaw alignment via mouthpiece use, or if the presence of both jaw clenching and a mouthpiece are necessary to facilitate the potentiation effect. Further, reports of jaw clenching and the resulting effects on muscle activation have been inconclusive, and no mouthpiece studies to date have examined muscle activation. Thus, this investigation sought to determine whether any observed improvements in muscle activation may be directly and exclusively attributable to jaw clenching, jaw alignment mouthpiece use, or if clenching and mouthpiece use potentially have a synergistic effect.

**Methods**

This study examined how jaw clenching, jaw alignment via performance mouthpiece, as well as the combination of clenching and performance mouthpiece impacted muscle activation during maximum countermovement vertical jump (CMVJ) and maximum isometric mid-thigh clean pull (MTCP) assessments. A within-subjects design was used in which participants repeated the assessments under each experimental condition.

Experimental testing consisted of four laboratory visits. The initial visit consisted of participant prescreening, obtaining informed consent, basic anthropometric measurement, provision of both mouthpieces, and familiarization of all testing procedures. The three remaining laboratory visits were data collection sessions lasting approximately one hour in duration and were separated by approximately one week. To account for diurnal variation, all testing times
were scheduled within one hour of the time of day of the previous testing session. There were three mouthpiece conditions (performance mouthpiece, traditional mouthpiece, and no mouthpiece) and two jaw musculature conditions (jaw-clenched and jaw relaxed) for a total of six experimental conditions. The experimental conditions, counterbalanced for all participants, were as follows: performance mouthpiece (ArmourBite Mouthpiece; Under Armour, Baltimore, MD, USA) with jaw clenched (PMP-C), performance mouthpiece with jaw relaxed (PMP), traditional mouthpiece (Cramer Mouth Guard; Cramer Products Inc, Gardner, KS, USA) with jaw clenched (MP-C), traditional mouthpiece with jaw relaxed (MP), no mouthpiece with jaw clenched (NoMP-C), and no mouthpiece with jaw relaxed (NoMP). Both jaw clenched and jaw relaxed trials for each respective mouthpiece condition were performed within a testing session.

Subjects

Thirty six (n = 36) physically active and recreationally resistance trained males, aged 18-30 years, completed the research protocol. Participants were considered physically active if they engaged in routine resistance training exercise for a minimum of three days per week for the previous month. None of the participants (n=36; age, 23 ± 2.8 years; height, 178.54 ± 9.0 cm; body mass, 83.09 ± 7.8 kg) reported current or past history of temporomandibular disorder (TMD), and all were free of injury or illness at the time of testing. Participants also had prior experience performing exercises that are ballistic and explosive in nature, such as the snatch and clean & jerk. All participants signed the University approved Institutional Review Board consent documents.

To ensure no dietary abnormalities, a dietary journal documenting all food and beverage intake for the 72 hours prior to the initial testing session was required. Additionally, 24-hour dietary recalls were also reported for both remaining testing days. Participants were also asked to
refrain from any non-prescription supplementation/drug use throughout the study. Caffeine was the only exception to this request. Participants were asked to maintain their normal use or nonuse of caffeine for the duration of the study. To ensure adequate hydration status for assessment, consumption of 5-7 milliliters of water per kilogram of body weight four hours prior to each testing session was prescribed (7). A urine sample was provided by all participants on each testing day which was analyzed for specific gravity via dipstick (BTNX Inc; Markham, Ontario, Canada) to ensure euhydration status prior to testing. Participants maintained their normal exercise routines, however, they were asked to refrain from exercise 24 hours prior to a testing session. Finally, participants were asked to maintain their normal sleeping patterns as best as possible throughout their study participation. Questioning by the primary investigator was conducted each testing day prior to the onset of assessment to determine participant adherence to exercise, nutritional, and sleep requests.

Procedures

During each testing visit to the laboratory, the assessments were administered in the same sequence under two counterbalanced conditions: jaw maximally clenched, and jaw closed but not clenched. Twenty minutes of rest between each round of assessments was provided to ensure recovery from one experimental condition to the next. To control for clenching during the non-clenching or “jaw relaxed” conditions, the participants were instructed to breathe through pursed lips which limits the ability to clench the jaw musculature (30). This method is consistent with previously published research (30,31).

Prior to the assessment protocol, each participant performed a brief, dynamic warmup which was designed and supervised by a National Strength and Conditioning Association, Certified Strength and Conditioning Specialist. Assessment measures in order of occurrence
were the maximal CMVJ and the MTCP. Tests were performed in this sequence in order to mimic the commonly prescribed exercise assessment order of power movements followed by strength movements (38). CMVJ assessment procedures via a Vertec® device (Sports Imports, Columbus, OH, USA) were consistent with previously described methods (77). Similarly, procedures for MTCP assessment were consistent with those previously reported (60). Three testing trials for each assessment under each experimental condition were provided. The trials yielding the best performance were utilized for further analysis.

**Electromyography**

Bipolar surface electromyography (EMG) was recorded at 1000Hz during CMVJ and MTCP assessment on the participants’ dominant side during all three testing laboratory visits. Electrodes (EME Company, Baton Rouge, LA, USA), 5cm in length and 3cm in width were placed 3cm apart, as measured from the electrode center, at each location with a ground electrode on the tibial head. Proper skin preparation for all electrodes included shaving of the hair and abrasion of the skin around electrode site followed by cleansing with an alcohol swab. Data was recorded from the following muscles: the medial head of the gastrocnemius (MG), medial hamstring (MH), oblique fibers of the vastus medialis (VMO), and erector spinae (ES). Specific electrode placement occurred according to the recommendations found on the Surface Electromyography for the Non-Invasive Assessment of Muscles website (83). Prior to each assessment of CMVJ and MTCP, participants were asked to perform three MVC for each of the selected musculature. Participants maximally contracted the selected muscles for three seconds, and EMG activity was collected for five seconds including one second prior to and immediately following those contractions. These MVC were analyzed for peak signals, and were used to determine percent activation of the selected musculature during performance of the assessments.
EMG data collection was facilitated using an 8-channel electromyography system (Noraxon USA Inc., Scottsdale, AZ, USA and was processed with a 4\textsuperscript{th} order Butterworth bandpass filter (10-300Hz).

**Statistical Analyses**

A 3 x 2 (mouthpiece x clench condition) ANOVA for repeated measures was conducted to analyze each of the dependent variables for interaction and main effect significance. In cases where conditions of sphericity were not met, the Greenhouse-Geisser correction estimate was used if $\varepsilon < .75$, and the Huynh-Feldt correction estimate was used if $\varepsilon > .75$. Pair-wise comparisons utilized a Bonferroni confidence interval adjustment. Paired sample t-tests were utilized to determine specific differences when interactions between mouthpiece and clench condition were observed. All analyses were performed with an alpha level of $p \leq 0.05$, set a priori. Data were analyzed using IBM Statistics package software, version 22.0 (IBM SPSS Statistics, Armonk, NY, USA). Statistical power ($d$) and effect size ($\eta_p^2$) are reported, and all data are expressed as mean $\pm$ SE.

**Results**

For all CMVJ and MTCP EMG measures, data are expressed as a percentage of activation relative to MVC EMG signal. For MVC EMG, data represents the peak EMG signal recorded during the trial with greatest muscle activity.

**MVC Data**

Peak EMG signal for all four muscles assessed are presented in Table 2 below. There was main effect significance for clenching ($p = 0.019$, $\eta_p^2 = 0.15$, $d = 0.67$) for gastrocnemius muscle activity only. There was mouthpiece*clench interaction significance for both the gastrocnemius
and erector spinae peak EMG signal. Further analysis revealed that the peak gastrocnemius EMG signal was significantly greater for the MP-C compared to MP condition, and peak erector EMG signal was significantly greater for the NoMP compared to the NoMP-C condition.

<table>
<thead>
<tr>
<th></th>
<th>PMP</th>
<th>PMP-C</th>
<th>MP</th>
<th>MP-C</th>
<th>NoMP</th>
<th>NoMP-C</th>
</tr>
</thead>
<tbody>
<tr>
<td>MG</td>
<td>.570 ± .22mV</td>
<td>.562 ± .24mV</td>
<td>.498 ± .21mV</td>
<td>.604 ± .25mV*</td>
<td>.544 ± .24mV</td>
<td>.589 ± .27mV</td>
</tr>
<tr>
<td>MH</td>
<td>.514 ± .30mV</td>
<td>.518 ± .25mV</td>
<td>.525 ± .29mV</td>
<td>.546 ± .30mV</td>
<td>.515 ± .31mV</td>
<td>.497 ± .29mV</td>
</tr>
<tr>
<td>VMO</td>
<td>.349 ± .19mV</td>
<td>.347 ± .19mV</td>
<td>.307 ± .16mV</td>
<td>.334 ± .18mV</td>
<td>.304 ± .17mV</td>
<td>.328 ± .18mV</td>
</tr>
<tr>
<td>ES</td>
<td>.239 ± .08mV</td>
<td>.241 ± .08mV</td>
<td>.260 ± .12mV</td>
<td>.262 ± .12mV</td>
<td>.290 ± .15mV*</td>
<td>.244 ± .11mV</td>
</tr>
</tbody>
</table>

Table 2 – Peak EMG signal during MVC trials. Data are expressed as mean ± standard deviation. An asterisk (*) indicates a significant difference between clench conditions.

CMVJ EMG Data

There was significant main effects for mouthpiece and clench conditions for the MG, MH, and VMO but not ES muscle activity. Data illustrating these findings are found in Tables 3 and 4 respectively. A significant mouthpiece*clench interaction was also observed for muscle activity of all four muscles of interest. Post-hoc analysis of this interaction revealed that the MP-C condition elicited significantly greater percentages of muscle activation than the MP condition for all four muscles.
<table>
<thead>
<tr>
<th></th>
<th>PMP</th>
<th>MP</th>
<th>NoMP</th>
</tr>
</thead>
<tbody>
<tr>
<td>MG</td>
<td>76.88 ± 3.18 %</td>
<td>48.44 ± 3.55 %*</td>
<td>74.55 ± 3.83 %</td>
</tr>
<tr>
<td>MH</td>
<td>90.82 ± 7.13 %</td>
<td>76.32 ± 6.48 %*</td>
<td>96.21 ± 9.01 %</td>
</tr>
<tr>
<td>VMO</td>
<td>246.99 ± 19.34 %</td>
<td>153.54 ± 12.11 %*</td>
<td>233.19 ± 21.46 %</td>
</tr>
<tr>
<td>ES</td>
<td>146.61 ± 13.07 %</td>
<td>150.297 ± 13.22 %</td>
<td>155.86 ± 23.50 %</td>
</tr>
</tbody>
</table>

Table 3 – Percentage of muscle activation during CMVJ relative to MVC – MP Conditions. Data are expressed as mean ± standard error. An asterisk (*) indicates a significant difference (p < 0.05) relative to the other mouthpiece conditions.

<table>
<thead>
<tr>
<th></th>
<th>Jaw Clenched</th>
<th>Jaw Relaxed</th>
</tr>
</thead>
<tbody>
<tr>
<td>MG</td>
<td>76.36 ± 3.09 %*</td>
<td>56.89 ± 2.64 %</td>
</tr>
<tr>
<td>MH</td>
<td>97.27 ± 6.42 %*</td>
<td>78.29 ± 6.61 %</td>
</tr>
<tr>
<td>VMO</td>
<td>236.48 ± 16.31 %*</td>
<td>186.00 ± 14.29 %</td>
</tr>
<tr>
<td>ES</td>
<td>156.20 ± 13.34 %</td>
<td>145.65 ± 13.73 %</td>
</tr>
</tbody>
</table>

Table 4 – Percentage of muscle activation during CMVJ relative to MVC – Clench Conditions. Data are expressed as mean ± standard error. An asterisk (*) indicates a significant difference (p < 0.05) between clench conditions.

**MTCP EMG Data**

MTCP EMG data are represented in Tables 5 and 6. There were no significant interaction or main effects for percent activation of any muscle for any treatment condition.
<table>
<thead>
<tr>
<th></th>
<th>PMP</th>
<th>MP</th>
<th>NoMP</th>
</tr>
</thead>
<tbody>
<tr>
<td>MG</td>
<td>20.14 ± 2.09 %</td>
<td>20.67 ± 2.08 %</td>
<td>19.57 ± 1.96 %</td>
</tr>
<tr>
<td>MH</td>
<td>42.20 ± 4.11 %</td>
<td>47.55 ± 6.51 %</td>
<td>49.48 ± 5.17 %</td>
</tr>
<tr>
<td>VMO</td>
<td>73.39 ± 6.83 %</td>
<td>73.46 ± 7.05 %</td>
<td>76.32 ± 8.18 %</td>
</tr>
<tr>
<td>ES</td>
<td>125.54 ± 7.66 %</td>
<td>126.81 ± 7.86 %</td>
<td>124.27 ± 8.86 %</td>
</tr>
</tbody>
</table>

Table 5 – Percentage of muscle activation during MTCP relative to MVC – MP Conditions. Data are expressed as mean ± standard error.

<table>
<thead>
<tr>
<th></th>
<th>Jaw Clenched</th>
<th>Jaw Relaxed</th>
</tr>
</thead>
<tbody>
<tr>
<td>MG</td>
<td>20.45 ± 1.77 %</td>
<td>19.80 ± 2.01 %</td>
</tr>
<tr>
<td>MH</td>
<td>48.97 ± 5.47 %</td>
<td>43.84 ± 3.93 %</td>
</tr>
<tr>
<td>VMO</td>
<td>74.23 ± 6.17 %</td>
<td>74.55 ± 7.27 %</td>
</tr>
<tr>
<td>ES</td>
<td>126.20 ± 6.74 %</td>
<td>124.88 ± 7.75 %</td>
</tr>
</tbody>
</table>

Table 6 – Percentage of muscle activation during MTCP relative to MVC – Clench Conditions. Data are expressed as mean ± standard error.

Discussion

The aim of this investigation was to determine whether changes in muscle activity would be observed as the result of using a performance mouthpiece or incorporating jaw clenching as an RVC during the performance of a maximum CMVJ assessment and an isometric MTCP assessment. Additionally, the authors sought to determine whether the observed changes could be attributed exclusively to jaw clenching, jaw alignment via mouthpiece use, or if both conditions are necessary to achieve ergogenic effects.

Mouthpiece Conditions

There was no difference in percent activation between PMP and NoMP conditions during CMVJ and MTCP performance for any of the four muscles examined. While performance
improvements such as improved respiratory exchange parameters (Garner et al, 2011a), increased vertical jump height and anaerobic power (Arent et al, 2010), and improved force production variables (Dunn-Lewis et al, 2012) have been attributed to the use of a performance mouthpiece, increased relative muscle activation does not appear to be among them.

Interestingly, percent activation for the MG, MH, and VMO was significantly lower during the MP condition compared to the PMP and NoMP conditions. This is an important finding considering the recommended and requisite usage of similar mouthpieces during sports such as lacrosse and American football (2,69). Although important in providing safety and protection of the teeth and mouth from potential injury during competition, many athletes have negative perceptions of mouthpieces due to breathing and verbal communication difficulties (36). Additionally, some athletes suspect that mouthpieces have detrimental effects on performance (13,42). Upon the completion of the current investigation, participants were polled regarding their preference of the mouthpiece conditions in the study. The responses reflect similar discontent with the MP used compared to the PMP and NoMP. Thirty one of 36 participants indicated a preference for either PMP or NoMP conditions over the MP condition, with the most common reason given being discomfort in the MP condition. Of the five participants who indicated a preference for the MP condition, all cited familiarity from previous participation in sports requiring such mouthpieces as the reason for their preference. It is possible that the MP condition, being unfamiliar and uncomfortable to the majority of the participants, created an awkward and distracting performance environment, leading to the observed detriment in muscle activation.
Jaw Clenching Conditions

Clenching the jaw elicited significantly greater percent activation of the MG, MH, and VMO but not the ES, compared to the non-clench condition during CMVJ performance. Erector spinae activity was not different between clench conditions. Ebben (28) defined CAP as the ergogenic advantage of increased prime mover performance as the result of simultaneous RVC such as clenching the jaw, clenching the fists, and a modified Valsalva maneuver, and touted CAP as the reason for improved force production variables during various physical activities (29-32). Considering this definition, the current findings are logical. For the CMVJ, the MG, MH, and VMO would be considered prime movers. The ES, although active during the CMVJ, would not be considered a prime mover for this activity, and as such, should not be expected to be potentiated during CMVJ performance. A previous study investigating muscle activity during isokinetic knee extension and flexion revealed significantly higher muscle activity for prime mover musculature when RVC including jaw clenching were utilized (32). Muscle activity of the movement antagonist as well as homologous contralateral musculature was not changed. These findings, as well as the findings of the current investigation, support the specificity of CAP to the prime movers involved in the activity of interest.

In contrast, jaw clenching failed to lead to a significant change in muscle activity in comparison to the non-clench condition for any muscle examined during performance of the isometric MTCP. These findings are consistent with previous research as well (41). Muscle activity during isometric knee extension with the incorporation of jaw clenching as well as other RVC was no different than isometric knee extension without RVC (41). Although muscle activity was not significantly different between RVC and no RVC conditions, PF and RFD were significantly improved under RVC conditions (41). Increased neural drive as a result of
functional cortical connections and motor overflow has been proposed as the primary mechanism underlying CAP (28-32). The findings of the current study, coupled with those reported by Garceau et al, (41), suggest that any observed CAP performance improvement during isometric activity would not be due to increased neural drive but other mechanisms not yet known. As stated previously, this investigation sought to discern whether jaw clenching or jaw alignment via performance mouthpiece use was exclusively responsible for any observed changes in muscle activity and was not designed to determine specific mechanisms leading to those changes. Future research should attempt to reveal those mechanisms. It is important to note that while the current results do not support motor overflow as the underlying mechanism of CAP during isometric activity, it does not negate it either.

Previous research has demonstrated that aggregate RVC elicited CAP to a greater extent than isolated RVC (31). During isometric knee extension, mean and peak torque values were significantly improved when a single RVC was utilized, however, conditions that combined multiple RVC led to knee extensor torque values greater than the single RVC condition (31). The current study was concerned specifically with jaw clenching as a viable RVC for eliciting the ergogenic advantage of CAP. As such, other examples of RVC, such as the Valsalva maneuver, were not incorporated. All participants in the current investigation were given instructions to breathe as normally as possible during the performance assessments, in an attempt to control for the potential CAP effects of holding the breath. It is possible that, with the incorporation of additional RVC such as the Valsalva maneuver, CAP may have been stimulated to a greater degree, and in turn increased muscle activity to the level of significance.
Conclusions

This is the first study to determine whether observed improvements in muscle activation can be attributed exclusively to jaw clenching, jaw alignment via mouthpiece use, or if both conditions are necessary to achieve ergogenic effects. Jaw clenching, regardless of mouthpiece condition, improved muscle activation during countermovement vertical jump compared to non-clench conditions.

Although muscle activation was greater during vertical jump assessment for performance mouthpiece and no mouthpiece conditions over the use of a traditional mouthpiece, the performance mouthpiece did not lead to improved muscle activation in comparison to no mouthpiece use. No changes were observed in isometric mid-thigh clean pull muscle activation for any mouthpiece or clench condition. These findings support jaw clenching as a viable technique to elicit concurrent activation potentiation of prime mover muscle activity during dynamic but not isometric physical activity. Future studies should attempt to uncover the specific mechanisms leading to CAP and improved performance during isometric muscle actions.
LIST OF REFERENCES

2. ADA council on access, prevention and interprofessional relations; ADA council on scientific affairs. Using mouthguards to reduce the incidence and severity of sports-related oral injuries. *Journal of the American Dental Association* 137: 1712-1720, 2006.


# VITA

**Charles R. Allen Jr., CSCS**

**Academic Record:**

<table>
<thead>
<tr>
<th>Year</th>
<th>Degree</th>
<th>Institution</th>
<th>Major Area</th>
<th>Concentration Area</th>
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</thead>
<tbody>
<tr>
<td>2002</td>
<td>Bachelor of Science</td>
<td>Coastal Carolina University, Conway, SC</td>
<td>Department of Health, Physical Education &amp; Recreation</td>
<td>Physical Education, K-12</td>
</tr>
<tr>
<td>2004</td>
<td>Master of Science</td>
<td>University of Mississippi, Oxford, MS</td>
<td>Department of Health, Exercise Science &amp; Recreation Mgmt</td>
<td>Exercise Science, Biomechanics</td>
</tr>
<tr>
<td>2015</td>
<td>Doctor of Philosophy</td>
<td>University of Mississippi, Oxford, MS</td>
<td>Department of Health, Exercise Science &amp; Recreation Mgmt</td>
<td>Kinesiology, Sport Biomechanics</td>
</tr>
</tbody>
</table>

**Graduate Research Project:** *The Effects of Reciprocal Inhibition of Hip Flexor Musculature on Acute Abdominal Exercise*

**Dissertation:** *The Effects of Jaw Clenching, Jaw Alignment via Performance Mouthpiece, and the Combination of Both on Power and Force Production*

**Employment History:**

<table>
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<th>Year</th>
<th>Position</th>
<th>Institution</th>
<th>Department</th>
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<tbody>
<tr>
<td>2002-2004</td>
<td>Graduate Assistant</td>
<td>University of Mississippi</td>
<td>Department of Health, Exercise Science, and Recreation Management</td>
</tr>
<tr>
<td>2004-2005</td>
<td>Campus Recreation Intern</td>
<td>University of Mississippi</td>
<td>Department of Campus Recreation</td>
</tr>
<tr>
<td>2005-2007</td>
<td>Coordinator of Campus Recreation</td>
<td>The University of Tampa</td>
<td>Department of Campus Recreation</td>
</tr>
<tr>
<td>2007-2015</td>
<td>Coordinator of Fitness</td>
<td>The University of Mississippi</td>
<td>Department of Campus Recreation</td>
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</table>
2015-present  
**Visiting Instructor of Exercise Science**  
Florida Southern College  
School of Nursing and Health Sciences

**Scholarship:**

**Refereed Journal Publications**


**Manuscripts in Preparation**

**Allen, CR**, Cazas-Moreno, VC, Gdovin, JR, Williams, CC, **Allen, CR**, Fu, YC, & Garner, JC. An applied investigation of the effects of jaw clenching, jaw alignment, and the combination of both on force production and power. *Journal of Strength and Conditioning Research*


**Published Abstracts**


**Presentations (Peer Reviewed)**


**Invited Presentations**


**Book Chapter**


Funding:
Allen, CR
Graduate Student Council Research Grant, Spring 2012
Office of Research and Sponsored Programs, University of Mississippi
Role: Primary Investigator
Funding Request: $1,000.00
Status: Funded

Allen, CR
Exercise Equipment Purchase, Spring 2012
Ole Miss Parents Association
Role: Program Supervisor
Funding Request: $16,520.00
Status: Partially Funded ($8,260.00)

Allen, CR & Dudley TN.
Exercise Equipment Purchase, Spring 2013
Ole Miss Parents Association
Role: Program Supervisor
Funding Request: $39,508.58
Status: Not Funded

Lundahl, J & Allen, CR.
Graduate Student Council Research Grant, Fall 2013
Office of Research and Sponsored Programs, University of Mississippi
Role: Researcher
Funding Request: $1,000.00
Status: Not Funded

Allen, CR
Doctoral Candidate Research Grant, Fall 2014
Department of Health, Exercise Science, and Recreation Management, University of Mississippi
Role: Researcher
Funding Request: $1,090.55
Status: Funded

Curriculum Experience (Professional Classes):
The University of Tampa
Undergraduate Courses
ESC 105 – Biokinetics & Conditioning
ESC 110 – Introduction to Exercise Science and Sport Studies

**University of Mississippi**

*Non-Credit Courses*
- ACE Personal Trainer Certification Prep Course
- Campus Recreation Personal Trainer 15-Hour Supplemental Training Course

*Undergraduate Courses*
- EDHE 105 – The Ole Miss Freshman Year Experience
- EL 124 – Racquetball
- EL 147 – Tennis
- EL 151 – Weightlifting
- ES 346 – Kinesiology
- ES 391 – Trends & Topics in Exercise Science – Guest Lecturer
- ES 402 – Exercise Leadership
- ES 440 – Behavioral Aspects of Exercise – Guest Lecturer
- ES 446 – Biomechanics of Human Movement
- ES 447 – Biomechanics Lab
- HP 191 – Personal & Community Health – Guest Lecturer

**Florida Southern College**
- EXS 2760 – Sports Nutrition and Supplementation
- EXS 2775 – Kinesiology
- EXS 3750 – Essentials of Strength and Conditioning

**Professional and Academic Affiliations:**
- 2004-present National Intramural and Recreational Sports Association
- 2005-present National Strength and Conditioning Association
- 2010; 2013 American College of Sports Medicine
- 2011-2015 Mississippi Chapter of the National Strength & Conditioning Association
- 2015-present Florida Chapter of the National Strength & Conditioning Association
- 2015-present USA Weightlifting

**Certifications:**
- 2005-present NSCA Certified Strength and Conditioning Specialist (CSCS),
- 2005-present ACE Certified Personal Trainer
- 2010-present American Red Cross First Aid, CPR, and AED Instructor Certified
- 2011-present Concept2 Certified Indoor Rowing Instructor
- 2012-present TRX® Group Suspension Training Certified
- 2014-present RealRyder® Indoor Cycling Instructor Certified
- 2014-present CardioPump™ Kettlebell Certification
- 2015-present USAW L1 Weightlifting and Sports Performance Coach Certified

**Service:**

*Departmental:*

*University of Mississippi*
<table>
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<tr>
<th>Year</th>
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<tbody>
<tr>
<td>2010</td>
<td>Campus Recreation, Administrative Assistant Search Committee</td>
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<td>2010-2011</td>
<td>Campus Recreation, Relay for Life Group Fitness Fundraiser</td>
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<td>2011</td>
<td>Campus Recreation, 6th Annual Fight Gone Bad Fitness Competition Site</td>
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<tr>
<td></td>
<td>Coordinator &amp; Team Captain</td>
</tr>
<tr>
<td></td>
<td>• Raised over $2,000 to benefit the Special Operations Warrior</td>
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<tr>
<td></td>
<td>Foundation</td>
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<td>2012</td>
<td>Campus Recreation, Breast Cancer Awareness Fundraiser Event</td>
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<tr>
<td></td>
<td>Coordinator</td>
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<td>2013</td>
<td>Campus Recreation, Turner Recreation Center 1st Floor Renovation</td>
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<td>Committee</td>
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<td>2014-2015</td>
<td>Campus Recreation, Emergency Response Committee</td>
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<td></td>
<td>• Committee Co-Chair</td>
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<td>2015</td>
<td>Campus Recreation, Wellness Committee</td>
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<td></td>
<td>• Committee Co-Chair</td>
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<td>2015</td>
<td>Campus Recreation, Rebel Trail Challenge Race Event Committee</td>
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<td>Florida Southern College</td>
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<td>2015</td>
<td>Athletics, Functional Movement Screening for Men’s &amp; Women’s Tennis</td>
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**Division:**

**University of Mississippi**

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<th>Year</th>
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<tr>
<td>2009</td>
<td>Student Affairs, Resident Life Marketing Coordinator Search Committee</td>
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<tr>
<td>2013</td>
<td>Student Affairs, Health Center Director Search Committee</td>
</tr>
<tr>
<td>2013</td>
<td>Student Affairs, Collaborative Learning and Unlimited Excellence Committee</td>
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<td>2013-2014</td>
<td>Student Affairs, Division Review Committee</td>
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<td>2014-2015</td>
<td>Student Affairs, Incident Response Team, Volunteer/Supply Sub-committee</td>
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<td>2014-2015</td>
<td>Student Affairs, Incident Response Team, Phone Response Sub-committee</td>
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**University:**

**University of Tampa**

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<th>Year</th>
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<tr>
<td>2005-2007</td>
<td>Tampa Wellness Committee</td>
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<td>2005-2007</td>
<td>C.A.R.E. Committee – Coalition for an Alcohol Responsible Environment</td>
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**University of Mississippi**

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<th>Year</th>
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<tr>
<td>2007-2013</td>
<td>University of Mississippi HealthWorks Faculty/Staff Wellness Committee</td>
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<td>2013-2014</td>
<td>Whirlpool Building Renovation Committee</td>
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<td>2014-2015</td>
<td>University of Mississippi RebelWell Wellness Committee</td>
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**Professional:**

<table>
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<th>Year</th>
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<tr>
<td>2010-2012</td>
<td>NIRSA Region II Leadership Team</td>
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<td>• Mississippi State Director</td>
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<td>2012-2013</td>
<td>MS/AL NIRSA Workshop Host Site Committee</td>
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<td>• Committee Chair</td>
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<td>2013</td>
<td>NIRSA Region II Conference Program Committee</td>
</tr>
<tr>
<td>2013-2015</td>
<td>NIRSA Institutional Engagement Coordinator</td>
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<tr>
<td>2014-2015</td>
<td>NSCA Mississippi State Advisory Board Member</td>
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Manuscript Reviewer
2014-present NSCA Coach
2015-present Sports Biomechanics

Sally McDonald Barksdale Honors College – Undergraduate Honors College
2012-2013 Jacob MacGregor – Graduate Mentor
2013-2014 Brandon Turnage – Graduate Mentor
2014-2015 Hannah Hudson – Graduate Mentor
2014-2015 Daniel Hartman – Graduate Mentor

Undergraduate Practicum Supervisor (Applied Biomechanics Laboratory)
Spring 2012 Josh Namin
Spring 2013 Coury Zachary

Undergraduate Practicum Supervisor (Turner Fitness Center)
Fall 2007 Terry-Lynn Crawford
Spring 2012 Jon Lundahl
Spring 2013 Julia Koch
Spring 2015 Caleb Creel
Spring 2015 Jena Ely

Undergraduate Practicum Supervisor (CrossFit 38655)
Spring 2013 Josh Hart
Fall 2013 Matt Reynolds
Spring 2014 Catherine Clark

Letters of Recommendation (Students)
Graduate School:
Abigail Miller (Appalachian State University)
Brandon Miller (University of Mississippi)
James Scott Sharp (University of Southern Mississippi)
Jennifer Hall (Auburn University)
Sarah Smith (University of Mississippi)
Julia Koch (University of Southern Mississippi)
Jennifer Drake (Wake Forest University)
Kimberly Sterner (Arizona State University)
Chelsea Skinner (Rowan University)

Nursing School:
Kathleen Cleary (University of Mississippi)
Robert Kirby (University of Mississippi)

Nutrition/Dietetics Internship:
Heather Jamison (American Dietetic Association)
Sarah Ziha (Oregon Health & Science University)
Physical/Occupational Therapy School:
  Christina Thompson (University of Mississippi Medical Center)
  Tyler Hudgins (University of St. Augustine)
  Kyle Nelson (University of Southern California)
  Katharine Davis (Brenau University)
  Avery Drennen (Hardin-Simmons University)

Professional/Corporate:
  Dylan DeWitt
  Kathy Dunham
  Justin Rakes
  Samantha Hirth
  Nicole Dudley
  Carey Greenwood
  Samantha Jacobs
  Kimberley Sterner

NIRSA Scholarship Foundation:
  Jennifer Hall (J. Michael Dunn Scholarship Winner)
  Julia Koch
  Kimberley Sterner (William Wasson Award Nominee)
  Nicole Dudley (William Wasson Award Nominee)
  Rachel Dybala
  Ryan Gloeckner
  Samantha Hirth (Region II Student Excellence Scholarship Winner)
  Sarah Ziha (Region II Student Excellence Scholarship Winner)

Additional Scholarship Recommendations:
  Haley Berich (CPSDA DuPoint Sports Dietitian Student Scholarship)

Letters of Recommendation (Professionals)
Professional Recognition & Merit
  Dr. John Garner (Thomas A Crowe Outstanding Faculty Award)
  Dr. Melinda Valliant (Thomas A. Crowe Outstanding Alumnus Award)