VOLUNTARY TEETH CLENCHING DURING PHYSICAL EXERCISE IN NATURAL ENVIRONMENT: PREVALENCE AND GENDER DIFFERENCES

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MASTER OF SCIENCE

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ADAM REYNOLDS
B.S., Brigham Young University, 2007
D.M.D., University of Kentucky, 2011

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VOLUNTARY TEETH CLENCHING DURING PHYSICAL EXERCISE IN NATURAL ENVIRONMENT: PREVALENCE AND GENDER DIFFERENCES

Adam Reynolds, Candidate for the Master of Science Degree
University of Missouri-Kansas City, 2103

ABSTRACT

Background/Objectives: Voluntary teeth clenching (VTC) has been researched with respect to performance enhancement, but little evidence has verified its prevalence. This study’s objective was to determine if VTC occurred during exercise in a natural environment. Secondarily, if differences in VTC existed based on gender and exercise type were investigated. Methods: Ambulatory surface electromyography (EMG) recorders were used to measure activities in the masseter and temporalis muscles and detect VTC during leg extension and general weight-lifting exercises in 7 male and 10 female subjects recruited from UMKC soccer teams. All subjects gave informed consent to participate in IRB-approved study protocols. Laboratory surface EMG recording during static and dynamic biting tasks established linear regression relations between EMG:bite-force for each subject. Then subject-specific thresholds for VTC ranging from 5-80% of a 20 N bite-force (T20N) were applied to detect and measure VTC in ambulatory data. Duty factors (DF=time clenching/total recording time, %) were compared for each VTC threshold and gender/exercise/muscle combination by simple test effect. Statistical significance was set at p<.05 with a Bonferroni correction. Results: VTC was shown by all subjects at a threshold of \( \leq 5\% \) T20N, by 47% of subjects at a threshold of 50% T20N, and by 29% of subjects at a
threshold of 80%T20N. Females tended to have a higher DF at all thresholds during weight-lifting (highest DF at 5%T20N: 5.8%), while males tended to have higher DF during leg extensions (highest DF at 5%T20N: 7.1%). Gender differences in DF were significant during weight-lifting at all thresholds except at 80%T20N and during leg extensions at levels ≤25%T20N; and showed larger effect sizes for standardized leg extension compared to general weight-lifting exercises. Conclusions: Low level clenching was common during weight bearing exercises. Prevalence depended on threshold magnitudes defining clenching. There were gender, exercise-type and muscle differences in VTC.
The faculty below, appointed by the Dean of the School of Dentistry have examined a thesis titled “Voluntary Teeth Clenching during Exercise in a Natural Environment: Prevalence and Gender Differences,” presented by Adam K. Reynolds, candidate for the Master of Science degree, and certify that in their opinion it is worthy of acceptance.

Supervisory Committee

Laura Iwasaki, B.S., D.D.S., M.Sc., Ph.D., Committee Chair
Departments of Orthodontics and Dentofacial Orthopedics and Oral and Craniofacial Sciences

Jeffrey Nickel, D.D.S., M.Sc., Ph.D., Committee Chair
Departments of Orthodontics and Dentofacial Orthopedics and Oral and Craniofacial Sciences

Ying Liu, Ph. D.
Research and Graduate Programs Office

Mary P. Walker, D.D.S., Ph.D.
Department of Oral and Craniofacial Sciences
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CHAPTER 1

INTRODUCTION

In 1977, Stenger was the first to investigate how the bite affected strength (Stenger 1977). Since Stenger’s report many authors have published articles on athletic performance enhancement with relation to mouth guards, jaw position or voluntary teeth clenching (VTC). While much of the early research focused on mouth guards and jaw position, recently there has been a greater interest in the effect that VTC has on strength and performance enhancement. One of the difficulties in reviewing the literature about performance enhancement related to VTC is that researchers have used so many different tests for strength and performance that it is necessary to understand the differences between them.

Voluntary Teeth Clenching

While the sustained act of teeth clenching is generally thought of as a parafunctional habit, Okeson (Okeson 1993) has noted that it also can occur in a moment of intense concentration or strenuous exertion. Therefore, it appears that there is an acceptable occurrence of VTC that may have some benefits as well as parafunctional occurrence of VTC that may result in pathologic symptoms of temporomandibular disorder (TMD). Both pathologic and non-pathologic consequences of VTC will be elaborated in the following sub-sections.

Teeth Clenching as a Parafunctional Habit

It is understood that in the normal rest position of the mandible, the maxillary and mandibular teeth do not contact. Contact usually is limited to the relatively brief moments of chewing and swallowing. However, clenching or bruxism can also occur as an unconscious habit with possible detrimental effects including TMD, muscle pain, and could even be
associated with depression (Barbosa Tde et al. 2008; Farella et al. 2010; Manfredini and Lobbezoo 2010). The researchers at the University of Montreal collected data on clenching and sleep bruxism from 7 to 17 year old orthodontic patients through a questionnaire (Carra et al. 2011). While sleep bruxism is often identified when parafunctional habits are spoken of, the results showed that daytime clenching may be just as prevalent. Sleep-related bruxism was reported in 15% of the population and wake-time tooth clenching by 12.4%. Interestingly 67.3% of those who reported sleep bruxism were 12 years old or less. Conversely, over 78% of the group who reported teeth clenching during the day were 13 years old or older. Furthermore, compared to controls, subjects who reported wake-time teeth clenching also reported more temporomandibular joint (TMJ) clicking, jaw muscle fatigue and sleep and behavior complaints. This was different from those subjects who reported sleep-related bruxism who were more at risk of experiencing jaw muscle fatigue, headache, and loud breathing during sleep compared to controls.

Other studies have also investigated the pathologic effects of jaw clenching. Christensen reported (Christensen 1981, 1989) that a subjective sensation of muscle fatigue appeared after about 30 seconds of maximum VTC. After about 60 seconds VTC elicited a mild pain in the masseter and temporalis muscles and by 120 seconds mild pain and complete exhaustion of these elevator muscles were reported. Glaros et al. (Glaros et al. 2000) hypothesized that clenching could lead to TMD pain. Subjects were divided into two groups. One group maintained a clenching state for 20 minutes 5 days/week while the other group maintained a low level of masseteric activity. At the end of the study three of the ten subjects in the clenching group were diagnosed with TMD pain. In a repeat study with similar protocols, similar results were found when two of 14 subjects developed TMD pain due to
increased clenching. Self-reported pain was significantly higher for the clenching group and electromyography (EMG) from the masseter was strongly correlated with pain (Glaros and Burton 2004). At the University of Witwatersrand, researchers enrolled twelve children ages 9-14 years to understand more about clenching and pain. The children were instructed to maintain maximum voluntary clenching until facial pains could no longer be endured. On average, pain onset occurred at 49 seconds and could be endured until 118 seconds. The pains were typically localized in the masseter and temporalis muscles. The authors reported that the pain threshold varied between individuals, but not within individuals (Christensen 1980).

There is also a reported gender difference in jaw pain induced by jaw clenching. Plesh et al. (Plesh et al. 1998) instructed seven male and seven female subjects to perform various clenching tasks. The next day they found that only females presented with an increased overall pain level and significant decrease in pain-free jaw opening. It is therefore evident from a review of the literature that a habit of frequent or prolonged clenching truly can produce unfavorable conditions that lead to pain in children and adults. It is possible female adults may be more prone to developing pain due to clenching habits.

**Voluntary Teeth Clenching as a Non-Parafunctional Habit**

While voluntary teeth clenching has been well researched as a possible mechanism for performance enhancement, there is very little research about its actual prevalence or occurrence during sports and physical activities. Ohkawa et al. (Ohkawa 1994; Ohkawa et al. 1994) performed two similar studies looking at athletes performing common tasks in their respective sports and found clear masticatory muscle EMG occurred in two of the six soccer
players and all 20 of the volleyball and handball players during kicking, spiking and shooting respectively. In a larger study (Ishijima et al. 1991), researchers investigated the prevalence of clenching in 100 young adults during a measurement of back strength. They found that centric clenching occurred in 58% while 11% exhibited eccentric tooth contacts and 31% did not have any tooth contact during strenuous physical exertion.

**Voluntary teeth clenching and performance enhancement.** There are certain advantages in researching the effect of VTC, instead of the effect of mouthguards, on performance enhancement. One of those inherent advantages is that the variable of the design of the mouth guard is removed. There are many different methods to construct a mouth guard. However, jaw clenching is a fairly simple maneuver. The only variables are the amount of clenching itself and the position of the lower jaw during clenching. When patients are instructed to clench their teeth at maximum clenching according to their own definition there is a large variability from person to person in the force of clenching measured by EMG of the masseter muscle. This shows that each person’s definition of clenching is different quantitatively as shown by Glaros and Waghela (Glaros and Waghela 2006). However, these authors did report that there was significant consistency individually for maximum clenching. Below it will be shown that other researchers have also chosen to look beyond strength as a measurement of performance and have also looked at neurological performance as well as biomechanical performance.

**Relation of voluntary teeth clenching and neurophysiological performance.** One of the ways to measure neurological performance is to look at a nerve’s reflex; for example, a monosynaptic reflex. One commonly assessed monosynaptic reflex is the knee-jerk reflex. By tapping on the tendon of the knee a stretch reflex is induced in the muscle spindle
afferents activating sensory fibers called Ia afferent fibers. These Ia afferents run to the spinal cord where they synapse on a motor neuron efferent. If the afferent sensory fiber is successful at activating the efferent motor neuron then the action potential will be carried down the motor neuron to the motor plate and cause a contraction of the muscle. This process is called monosynaptic because there is only one synapse in the reflex: the synapse between the sensory afferent and the motor efferent.

The H-reflex described by Hoffman in the early twentieth century is the same reflex. The only difference is that the muscle spindle is not activated but is bypassed by using a cutaneous stimulation of a mixed peripheral nerve. The sensory afferent is still activated but it is done through electrical stimulation instead of physically perturbing the muscle. The result is still the same monosynaptic reflex and muscle contraction or twitch. When this is measured by EMG this is called an H-reflex. There are certain aspects of the H-reflex that are crucial to understand in order to understand its use in research.

Using electrical stimulation it is possible to activate the efferent motor neuron through two pathways. The first one is the H-reflex, the monosynaptic reflex through stimulation of the afferent sensory neuron that was described above. The second way is that the efferent motor neuron may be excited directly by surface electrical stimulation. When this is measured by EMG this is called the M-wave or muscle wave. It is not a reflex because it is just a direct activation of the motor efferent nerve. In many muscles it is possible to increase slowly the electrical stimulation to get a selective reading for just the H-wave or H-reflex. If the stimulation is increased further the M-wave will also appear. It is also possible to differentiate between the two because after an electrical stimulation if there are two waves then the first wave will be the M-wave. The second wave is the H-wave since there is a
longer latency due to the signal having to travel up the afferent, synapse, and travel back down the efferent nerve.

The H-reflex is very useful in investigating an intervention’s effect on neurophysiology. Many researchers use the H-reflex to investigate the factors that contribute to inhibition or excitability of the synapse between the sensory afferent and motor efferent nerves. Researchers have used the H-reflex to investigate how clenching might affect the excitability of this reflex (Ueno 2006). A change in the latency of the H-wave due to an intervention would show a change in the inhibition of the synapse. This H-wave latency can be measured against the appearance of the M-wave, which should not change. Therefore, since the M-wave only changes with a change in the electrical stimulation, its constancy assures that the change in the H-wave is due to an influence at the spinal cord level and not a change in the electrical stimulation.

Another aspect of the H-wave and M-wave that can be useful is the amplitude or peak. As the electrical stimulation is increased the H-wave will peak at a maximum amplitude and then slowly disappear due to antidromic collision. The H-wave maximum represents the maximum number of motor neurons that reflex would be able to activate. If the electrical stimulation is increased further the M-wave would increase to a maximum and flatten out at that maximum. This represents the entire motor neuron pool and therefore maximum muscle activation. Therefore, if there is an intervention and the H-wave amplitude increases while the M-wave amplitude remains constant then this would show that the intervention has a facilitating effect on the reflex.

In 1996, researchers (Miyahara et al. 1996) measured the H-reflex in the soleus muscle during maximal voluntary teeth clenching, isometric contraction of wrist extensors or
clenching of the fists. They found that the amplitude of the H-reflex increased significantly during teeth clenching and that the effect was greater than during wrist extension or fist clenching. This increase in the amplitude was correlated to the force of teeth clenching as measured by EMG of the masseter muscle. What is more interesting is that the change in the H-reflex started before the onset of EMG activity in the masseter muscle. A few years later another team of researchers that included Miyahara looked at the reciprocal pretibial and soleus muscles (Takada et al. 2000). They wanted to understand if VTC would facilitate one set of muscles and inhibit the other or if it would facilitate both the flexor and opposing extensor muscles at the same time. They found that facilitation onset occurred before EMG activity in the masseter muscle and facilitation and biting force were positively correlated in pretibial muscles as they had seen previously in the soleus muscle. Interestingly, they also found that during stimulation of the pretibial muscles, the amount of reciprocal Ia inhibition of the soleus muscle decreased. This decreased inhibition became more pronounced during VTC. The implication of this result is the hypothesis that VTC helps to contribute to the stabilization of posture rather than the smoothness of movement. This facilitation effect on the pretibial and soleus muscles may not be limited to constant sustained clenching.

Takahashi et al. found that this same nonreciprocal facilitation occurred during mastication of gum. The measured facilitation was tonic and not phasic during the chewing cycles (Takahashi et al. 2001). This raised the question as to whether or not the periodontal mechanoreceptors played a role in the facilitation of the H-reflex in the soleus muscle. While investigating VTC and the soleus muscle, subjects in another study had their anterior teeth (which they were using to clench) locally anesthetized. The results showed that the H-reflex was facilitated the same during VTC whether the teeth were anesthetized or not. The authors
concluded that the periodontal mechanoreceptors did not play a major role in the facilitation of the soleus muscle (Tuncer et al. 2007).

The muscles in the leg are not the only place where VTC has been shown to have a facilitating effect. Takahashi et al. also investigated the flexor and extensor carpi radialis muscles. In line with findings in the leg, they found that the H-reflexes of these muscles in the arm were also facilitated by VTC in a force-dependent manner (Takahashi et al. 2003).

There have also been several studies that have looked at H-reflexes in the hand. Many of these studies have also used transcranial magnetic stimulation or brainstem magnetic stimulation in an attempt to determine if VTC not only has an effect on the excitability of motor neurons at the spinal level, but also could affect neuron pathways at a higher level. Transcranial magnetic stimulation (TMS) can run either an anterior medial (AM) or posterior lateral (PL) current to elicit what is called motor evoked potentials (MEPs) that can be measured at a muscle. A similar technique can be used to make MEPs at the brainstem that also can be measured in a muscle. In an effort to determine where along the neural axis that VTC exhibited its effect, Boroojerdi et al. (Boroojerdi et al. 2000) used the above methods to investigate VTC with respect to the tibialis anterior muscle and the right first dorsal interosseus muscle of the hand. They did find that there was an overall enhancement in the motor system excitability for the hand and leg. Furthermore, MEPs that were stimulated at the brainstem level showed facilitation by VTC in both the hand and leg. However, MEPs stimulated at the cortex only showed a change with VTC for the hand muscle. During teeth clenching there was decreased intracortical inhibition for the first dorsal interosseus muscle but not the tibialis anterior muscle (Boroojerdi et al. 2000). The authors hypothesized that the
effect that VTC seems to have at the cortical level could be due to spill over from the face area to the hand area of the motor cortex homunculus.

Sugawara and Kasai (Sugawara and Kasai 2002) investigated changes in MEPs and the H-reflex due to voluntary teeth clenching and the Jendrassik maneuver, another well-known method of producing remote facilitation of neurons where a subject hooks the fingers of both hands and interlocks them together while attempting to pull their hands apart. In this study, Sugawara and Kasai observed facilitation in the MEPs and the H-reflex with VTC in the flexor carpi radialis muscle. This suggests that facilitation for this muscle occurs at the spinal level and also possible unmasking of lateral excitatory projections at the cortical level (Sugawara and Kasai 2002). Takahashi et al. found that the effect of VTC on MEP waves produced by TMS differed among three different muscles of the hand with the PL current, even though it did not differ by brainstem magnetic stimulation. This suggests that the MEP waves induced through TMS truly are from the cortical level and that different muscles in the hand have different properties in regard to cortical control (Takahashi et al. 2006). Therefore the VTC effect at the cortical level is not the same for all muscles in the hand. Another group (Furubayashi et al. 2003) also found that VTC did have an effect on MEPs elicited at the cortex by TMS and MEPs elicited at the brainstem recorded at the first dorsal interosseus muscle. However, if it was varied when they elicited the MEPs in relation to the onset of masseter muscle contraction they saw different responses: VTC affected the MEPs from the cortex in the first 50 ms while it affected the MEPs from the brainstem after 50 ms. Thus Furubayashi and co-authors hypothesized that this showed facilitation by VTC occurs in the hand motor area of the cortex in the early phase and spinal facilitation dominated in the late phase.
Lastly, there have been a few studies that have taken completely different approaches to measuring VTC’s capacity to affect neurophysiology. One group had subjects take a test of arithmetic problems. During part of the test the subjects were instructed to clench rhythmically to investigate whether VTC has an effect on arithmetic performance. There was no difference in scores between times during no tooth contact and clenching conditions (Mizumori et al. 2011). There have also been other studies that have looked into the effect that chewing gum has on cognitive function (Wilkinson et al. 2002; Scholey 2004; Allen et al. 2006; Miles and Johnson 2007; Smith 2010; Onyper et al. 2011). The results are varied with some finding a performance enhancement in memory and others failing to find the same effect. In another recent study (Zhang et al. 2011), subjects unilaterally clenched their jaws while researchers measured systemic and cerebral circulation as well as autonomic nerve activity through heart rate and blood pressure. Zhang and co-authors compared VTC to handgrip exercise and found that VTC showed greater increases in cerebral blood flow in the middle cerebral arteries and a smaller effect than handgrip exercise on cardiac output and sympathetic nervous system activity.

**Relation of voluntary teeth clenching and biomechanical performance.** Just like with research in mouth guards there has also been research to see if VTC has an effect on performance measured biomechanically (Table 1). There are several papers published on VTC and isometric and isokinetic tests of strength. In 1998, Sasaki et al. (Sasaki et al. 1998) investigated the effect of VTC on isometric and isokinetic strength of ankle plantar flexion. They found that VTC did significantly increase the peak torque and the integrated electromyographic activity per second in the isometric test. However, they did not find any effect in the isokinetic test.
There have been many other studies that have also looked at other isokinetic tests, grip force, velocity of a golf swing. One particularly interesting study was done by Yokoyama et al. (Yokoyama et al. 1996). In this study, 12 subjects were separated into two groups based on whether or not they involuntarily clenched during the task. The investigators found that in the non-clenching group isometric elbow flexion strength was no different during clenching or not clenching. However, in the clenching group, elbow flexion strength decreased when subjects were instructed to avoid clenching. The investigators also found that in the clenching group the onset of electromyographic activity in the jaw muscles preceded the activity in the biceps brachial muscles. This suggested to them, that in those who naturally clench their jaws, VTC is a feed-forward mechanism instead of a feedback mechanism.

Takada and colleagues (Takada et al. 2000) hypothesized that VTC’s role may be in the stabilization of posture in the leg muscles and another group investigated this hypothesis (Fujino et al. 2010). In the investigation, subjects stood on a force plate that could measure data in the horizontal plane. The subject’s balance was then disturbed by electrical stimulation of a unilateral lower limb under conditions with and without VTC. The force plate measured the amount of force the subjects placed on the plate in the anterior-posterior and left-right directions as they maintained balance. The results showed that with VTC the maximum force exerted by subjects in the anterior-posterior direction was significantly smaller than when they were not clenching. These results suggest that VTC actually does contribute to maintaining postural stability.

As briefly described previously, in two separate studies Ohkawa et al. (Ohkawa et al. 1994) looked at performance and VTC in a less controlled and more general sports
environment. In the first study they looked at kicking in six soccer players and found that marked activity of four masticatory muscles (bilateral masseter and anterior temporalis muscles) was shown in two of the subjects. In the second study when they looked at volleyball and handball players (20 subjects total) they found marked EMG activity in these same four masticatory muscles during spiking volleyballs and shooting handballs respectively. In both studies the authors reported a positive correlation between masticatory muscle activity and the strength and form of the kick, spike, or shot respectively.
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<th>Significant Results</th>
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<tr>
<td>(Shiau and Chai 1990)</td>
<td>Craniocervical pain (51) Normal (28)</td>
<td>Pinching and grasping force</td>
<td>Yes ($F_{TC} &gt; F_{MN\text{rest}} \geq F_{TC-gauze}$)*</td>
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<tr>
<td>(Ueno 1995)</td>
<td>Normal (12)</td>
<td>Isometric shoulder adduction</td>
<td>Yes</td>
</tr>
<tr>
<td>Kim et al. 1997</td>
<td>Normal (12)</td>
<td>Grip force</td>
<td>Yes</td>
</tr>
<tr>
<td>Kato et al. 1997**</td>
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<td>Back strength</td>
<td>Yes</td>
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<tr>
<td>(Sasaki et al. 1998)</td>
<td>Normal (12)</td>
<td>Isometric and isokinetic (180 degrees/s) ankle plantar flexion</td>
<td>Yes (isometric), No (isokinetic)</td>
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<tr>
<td>Ueno et al. 1999**</td>
<td></td>
<td>Isometric knee extension</td>
<td>Yes</td>
</tr>
<tr>
<td>Sumita et al. 1999**</td>
<td>Normal (9)</td>
<td>Concentric knee extensions (30, 60, 150, 300, 450 degrees/s)</td>
<td>Yes (30 to 150 degrees/s), No (300 and 450 degrees/s)</td>
</tr>
<tr>
<td>(Sumita et al. 2000)</td>
<td>Normal (8)</td>
<td>100 times repeated concentric knee extensions (60 degrees/s)</td>
<td>Yes (until 70 times)</td>
</tr>
<tr>
<td>(Ferrario et al. 2001)</td>
<td>Malocclusion (15) Normal (14)</td>
<td>Endurance time of 80% dumbbell weight-lifting</td>
<td>Yes (both groups)</td>
</tr>
<tr>
<td>(Sato et al. 2001)</td>
<td>Normal (12)</td>
<td>Eccentric knee extensions (30,60,120,240 degrees/s)</td>
<td>Yes (all speeds)</td>
</tr>
<tr>
<td>(Churei et al. 2002)</td>
<td>Normal (8)</td>
<td>Unilateral hand grip</td>
<td>Yes</td>
</tr>
<tr>
<td>(Hiroshi 2003)</td>
<td>Normal (12)</td>
<td>Unilateral hand grip</td>
<td>Yes</td>
</tr>
<tr>
<td>Sato 2003**</td>
<td>10 golfers (10)</td>
<td>Golf swing speed</td>
<td>Yes</td>
</tr>
</tbody>
</table>
**TABLE 1.—Continued**

<table>
<thead>
<tr>
<th>Authors Year</th>
<th>Subjects (number)</th>
<th>Physical Performance Measured</th>
<th>Significant Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yamanaka et al. 2003**</td>
<td>Normal (8) (4 higher % and 4 lower % of fast twitch (FT) fibers)</td>
<td>100 times repeated concentric knee extensions (60 degrees/s)</td>
<td>Yes (higher % of FT fibers), No (lower % of FT fibers)</td>
</tr>
<tr>
<td>(Kyoko et al. 2006)</td>
<td>Normal (10)</td>
<td>Bilateral hand grip</td>
<td>Yes (both hands)</td>
</tr>
</tbody>
</table>

*F_{TC} = force during VTC, F_{MN rest} = force at mandibular rest position, F_{TC-gauze} = force biting on gauze*

**Reference cited in (Ueno 2006) not available**
**Relation between Mouth Guards and VTC**

While some research has been devoted to understanding mouth guards and voluntary teeth clenching in sports dentistry, there has been very little research to address the two factors together. Is it possible that they could have an additive effect? Could VTC have a confounding effect on mouth guard research? None of the studies on mouth guards and performance enhancement reported whether there were instructions to clench or avoid clenching. None of them reported if subjects clenched. Therefore it is difficult to know what, if any, relationship clenching and performance enhancing mouth guards might have. As has already been described above, during back strength tests a significant portion of the subjects clenched while others did not have any teeth contact (Ishijima et al. 1991). Interestingly, in the study previously described by Yokoyama and colleagues, significant differences in strength were only found between clenching and not for those who were initially classified as involuntary clenchers (Yokoyama et al. 1996). Another study investigated the soleus H-reflex during maximum VTC in subjects who wore custom maxillary stabilization appliances (or in other words, mouth guards) of differing materials. These researchers compared the H-reflex of the soleus muscle in five subjects when the mandible was in a rest state, when maximum VTC was performed, and when maximum VTC on hard and soft stabilization appliances were performed. The results showed that there was were no significant differences in soleus H-reflexes in subjects during maximum VTC without an appliance compared to maximum VTC with a hard acrylic occlusal appliance. However, there were significant differences in soleus H reflexes in subjects during maximum VTC compared to during maximum VTC on a soft or very soft stabilization appliance. Clenching on soft and very soft
appliances increased the facilitation of the soleus H-reflex. There was also a positive correlation ($r= 0.67-0.86$) between the soleus H-reflex amplitude and the amount of masseteric EMG activity (Naka et al. 2004). One possibility to explain this relationship could be that the softer appliances allowed the masseter muscle to increase its maximum clenching activity which further affected the H-reflex. Other researchers have also looked at the use of an interocclusal appliance and the activity of muscles via EMG (Visser et al. 1992; Roark et al. 2003). While they did not compare the stiffness of the appliances used, they also found that the activities of the masseter muscle during VTC with the appliance either remained the same or increased compared to VTC without an interocclusal appliance. On the other hand, a different study (Chandu et al. 2004) showed that an interocclusal appliance decreased EMG activity of the master muscles during VTC, however these authors also reported that the use of the appliance increased the measured biting force.

**EMG**

Moyers published the first study describing the use of EMG to study masticatory muscles in 1949 (Moyers 1949). Since then EMG has become a common tool to study the activities of head and neck muscles. Surface EMG has become particularly popular due to the ease of use for the investigator and comfort for the subject. In fact, surface EMG is actually preferred to indwelling electrodes since it has been shown to be more reliable (Soderberg and Knutson 2000).

When investigating clenching and jaw muscle activity it is important to understand which muscles are active during clenching. Rues et al. (Rues et al. 2008) investigated the activities of several jaw muscles during directionally controlled pure vertical clenching and during directionally uncontrolled clenching at different force levels. They compared EMG
activities of several muscles (masseter, anterior temporalis, posterior temporalis, anterior digastric, medial pterygoid and lateral pterygoid) by normalizing the EMG activity as a percentage of the activity from the same muscle during maximum voluntary clenching (MVC%). They reported that during vertical clenching the most active muscles were the anterior temporalis followed, in descending order, by the posterior temporalis, the masseter, and the medial pterygoid. The other muscles showed only weak co-contractions. However, during directionally uncontrolled clenching, which is how a subject clenches without specific instructions, the anterior temporalis, posterior temporalis, masseter, medial pterygoid and digastric muscles showed about the same amount of MVC%. Therefore, according to this research any of these latter muscles of mastication could be considered candidates to use to measure jaw muscle activity during clenching. Farella et al. (Farella et al. 2008) examined masticatory muscle activities in 30 different computer guided oral tasks. They specifically looked at the masseter, anterior temporalis, and suprahyoid muscles. Of these three muscle groups they found that during maximum voluntary clenching the anterior temporalis and masseter showed more activity than the suprahyoid muscles. The authors reported that the maximum EMG amplitudes for the masseter and anterior temporalis muscles were more often found during hard chewing tasks then during maximum clenching tasks. The relative masseter and temporalis activities changed depending on the type of tasks. The masseter muscles were significantly more active than the anterior temporalis muscles during tasks that involved incisal biting, jaw protrusion, laterotrusion, and jaw cupping. On the other hand, the anterior temporalis muscles were significantly more active than the masseter muscles during tasks performed in intercuspal position, during tooth grinding, and during hard chewing on the working side. Venegas et al. (Venegas et al. 2009) showed that there was significantly
more maseter activity during intercuspal clenching than during various eccentric jaw 
grinding movements. Sternocleidomastoid activity was also apparent during intercuspal 
clenching and was also significantly less during eccentric movements. Another group 
(Ciuffolo et al. 2005) investigated maximum voluntary clenching and broadened their 
protocol to include not only the anterior temporalis, masster and digastric, 
sternocleidomastoid, but the cervical, upper trapezius and lower trapezius muscles activities 
as well. As expected the highest levels of EMG were in the masster and anterior temporalis 
muscles. Ciuffolo and co-workers showed that while there were significant increases in the 
root mean squared (RMS) amplitudes of EMG from the sternocleidomastoid and digastric 
muscles during clenching compared to a rest state, there were no significant differences 
between rest and clenching states for RMS amplitudes from the cervical, upper trapezius and 
lower trapezius muscles. In another study (Naeije et al. 1989), anterior temporalis and 
masster EMG were studied at 10, 20, 30, 40, and 50% of maximum clenching. At low levels 
of clenching the temporalis muscle tended to dominate, but at higher levels the masster 
muscle activity was relatively higher.

There are also several factors that can affect EMG from the muscles of mastication 
during VTC. Some of these factors are based on jaw position during clenching. For example, 
it has been reported that temporalis muscle activity decreases with increased vertical 
dimension (Visser et al. 1992). A decrease in muscle activity with increased vertical 
dimension has been shown to occur for the masster muscle as well (Wang et al. 2007). 
Clenching at different positions in a lateral eccentric position can also affect EMG from the 
masster and temporalis muscles (Uchida et al. 2008; Gutierrez et al. 2010). Lobbezzo et al. 
(Lobbezzo and Huddleston Slater 2002) hypothesized that some of the variability in seen in
EMG during subsequent submaximal clenching could be due to differences in mandibular positioning. They found that up to 25% of the variance in the indices that quantify the relative contribution of the jaw closing muscles to the total clenching effort was attributable to mandibular positioning.

Mandibular positioning during clenching is not the only factor that affects EMG from the masticatory muscles. Several other things can affect an EMG reading including, electrode placement over the muscle, subject’s body posture, psychological factors, the training of the operator and interelectrode distance (Castroflorio et al. 2008). Lobbezoo et al. also reported that visual feedback of the EMG activity can also affect muscle activity and which muscles contribute more or less to the clenching (Lobbezoo et al. 1993). However Castroflorio and co-authors have shown that with attention to detail in protocols, surface EMG reproducibility is acceptable and also suggest that increasing the distance between electrodes from the standard 20 to 30 mm may help increase reliability (Castroflorio et al. 2005; Castroflorio et al. 2006). Gonzalez et al. (Gonzalez et al. 2011) investigated the reliability of surface electromyography of the masticatory muscles versus bite force relations using intraclass coefficients (ICCs) ≥0.60 as an indicator to see if these relations could be used as acceptable research tools. They found that for a range of incisor and molar biting positions the ICCs for the ipsilateral and contralateral temporalis muscles were 0.56-0.93 and 0.34-0.91 respectively, while for the masseter muscle were 0.65-0.86 and 0.59-0.88, respectively, and for the suprahyoid muscles were 0.07-0.60 and -0.33-0.67, respectively. They concluded that slopes of the EMG activity versus bite force for a given situation were mostly reliable for the temporalis and masseter but not the suprahyoid muscles.
**Duty Factor**

One method to compare muscle activities measured by EMG is by comparing the duty time or duty factor. The duty factor of a muscle is defined as the amount of time a muscle is active divided by the total amount of recording time. Therefore, if an EMG threshold is set to define what constitutes an active muscle then duty factor (duration of muscle activity/total recording time, %) can be defined for that threshold. This method for quantifying and comparing muscle activity has been used in research successfully in rats, rabbits and most recently in human subjects investigating jaw muscle activities (Kawai et al. 2007; Grunheid et al. 2010; Nickel et al. 2013).

**Gender Differences**

Women and men exhibit a few differences in muscle characteristics and strength. For example, it has been reported in two separate studies that the absolute strength of appendicular extremities of women is about 52-66% and 42.2 to 62.8% that of men (Frontera et al. 1991; Miller et al. 1993). However, it has also been shown that the muscles in the arms and legs in women tend to have a smaller cross sectional area than in men (Kanehisa et al. 1994). Therefore when generally speaking of the appendicular musculature the difference in strength between men and women is usually attributed to an increased muscle mass or to increased muscle fiber size in men compared to women (Frontera et al. 1991; Miller et al. 1993). When strength was adjusted for the cross sectional area of a muscle, a person’s fat-free mass (estimated by hydrostatic weighing), or a person’s muscle mass (estimated by creatine excretion), the gender differences in strength got much smaller or disappeared (Frontera et al. 1991; Miller et al. 1993).
Some of these same gender differences seem to apply to the masseter muscle as well. Waltimo and Kononen (Waltimo and Kononen 1993) reported that the mean maximal bite force in the molar region for men was 847 Newtons and 597 Newtons for women. Tuxen et al. reported (Tuxen et al. 1999) that the greater bite force in men than women was related to the greater diameter and cross sectional area of type II fibers in the masseter muscle. There are also gender differences in clenching. It was reported that at all clenching levels temporalis muscle activity dominated in women while in men it was the opposite with masseter muscle activity being stronger during clenching (Ferrario et al. 1993).

Research on general skeletal muscle fatigue has suggested that there may be evidence that women may have greater fatigue resistance (Hicks et al. 2001). There is further research that extends this thinking to the masticatory muscles as well. In an experiment (Torisu et al. 2006) men and women were asked to sustain low-level clenching for 30 minutes. After this period the visual analog scores for fatigue were significantly higher for men than women. This is interesting considering that after the clenching period the resting masseter EMG appeared to be higher in women than men.

Even though women may exhibit some resistance to muscle fatigue compared to men, as a group they still have more than their fair share of the burden when it comes to temporomandibular disorders (TMDs). Women are 1.5-2 times more likely to be affected by a temporomandibular disorder than men (Maixner et al. 2011) and may be 3 times more likely to experience myofacial pain (MFP) (Velly et al. 2003) Some studies which identify gender as a contributing factor to TMD or MFP also identify self-reported bruxism (Mundt et al. 2005; Casanova-Rosado et al. 2006; Winocur et al. 2006; Nekora-Azak et al. 2010) and self-reported clenching (Velly et al. 2003; Aydin et al. 2004) as increased risk factors.
Comparatively, much of the data on bruxism and TMD are self-reported and actual quantitative studies showed a much lower association between bruxism and TMD (Manfredini and Lobbezoo 2010). One study that did have quantitative data even reported that men had higher mean levels of bruxism (Watanabe et al. 2003). There are no quantitative data that were not self-reported which could be found on clenching habits and gender differences.

As was mentioned earlier, Plesh et al. (Plesh et al. 1998) reported a possible gender difference in jaw pain induced by jaw clenching. As a part of this study protocol seven male and seven female subjects were instructed to perform various clenching tasks. The next day they found that only females presented with an increased overall pain level and significant decrease in pain-free jaw opening compared to their own baseline before clenching tasks. This may be due to gender differences in clenching or pain perception. In a study that tested pain and touch perception after voluntary clenching for 1 minute the results showed several gender differences (Okayasu et al. 2009). Women had higher pain sensitivity after clenching and exhibited a larger increase in the tactile detection threshold.

**Problem Statement**

The objective of this research was to understand jaw musculature function during strenuous exercise in males and females. The main focus will be jaw clenching during exercise measured by activities of the masseter and anterior temporalis muscles through EMG. The primary goal is to establish that VTC does occur during exercise in a subject’s natural environment. Furthermore, the aim is to investigate the prevalence of jaw clenching in males compared to females during exercise both in the laboratory and in a natural environment.
Hypotheses

1. All athletes will exhibit VTC during physical exercise.

2. There will be significant differences in duty factor of VTC between male and female athletes during strenuous physical exercise.
CHAPTER 2

MATERIALS AND METHODS

The protocol for this study was submitted to and approved by the University of Missouri at Kansas City (UMKC) Adult Health Sciences Institutional Review Board (Appendix 1). The study was a pilot study with a convenience sample of subjects comprised of volunteers from the general UMKC student body.

**Experimental Design**

The study was a multifactorial, parallel group, non-blinded, non-therapeutic prospective study. Gender was the primary independent factor in this study. Besides gender the other independent factors were the muscle group (masseter or temporalis), the activity (leg extensions or general weight-lifting exercises), and the threshold values for clenching magnitude. The dependent variable in the study was the duty factor (time of muscle activity/time of recording) of the masseter and temporalis muscles during exercise.

**Subjects**

Subjects were recruited from the UMKC student body and specifically from the UMKC men’s and women’s soccer programs. Invitees were individuals who met the following criteria: 1) were willing to complete all aspects of the study, 2) were relatively symmetrical in terms of the bilateral positions of the dentition and muscles of mastication, 3) anatomy could accommodate the research devices and materials used, 4) all first molar, canine, and incisor teeth were present and 5) no aspect of the medical history contraindicated routine dental procedures. Individuals with: a history of diagnosed musculoskeletal disease (e.g. fibromyalgia, muscular dystrophy) or frank trauma to the TMJ; inability to read;
inability to follow auditory and visual commands; or were not able to meet the inclusion criteria were not included in the study.

**Experimental Protocol**

All subjects participated in a screening visit and two laboratory visits to complete the study before and after ambulatory EMG self-recordings. At the screening visit subjects were recruited and given a written informed consent along with verbal explanations of what was expected to participate in the study. They were also screened for participation by use of the Clinical Exam Form (Appendix 2). If subjects agreed to participate they began by signing the Informed Consent Form (Appendix 3) and Health Insurance and Portability and Accountability Act (HIPAA) form (Appendix 4).

There were two laboratory visits and two field recording sessions. The first laboratory visit was used to perform biting tasks to calibrate EMG recordings for each individual, perform leg exercise tasks while recording EMG data, and instruct the subjects on the use of ambulatory EMG recorders for field recordings. This first visit generally took about an hour and a half. The subject then used the ambulatory EMG recorder to record during two different field sessions on different days. Each of the field sessions had two parts. The first part was for the subject to repeat the leg extension exercises performed in the laboratory and the second part was to record during their usual weight-lifting exercise routine of their choice. The only restriction was no gum chewing. There were no restrictions as to the type of weight-lifting exercises for the second part of the recording session. After the field recordings were completed the subject returned for the second laboratory visit to repeat the
standard biting tasks and leg exercise tasks and return the ambulatory EMG recorder and
data. This second laboratory visit took about one hour to complete.

**Laboratory Visit #1**

**EMG recording during standardized biting tasks.** Patterns of EMG are
characteristic of a given task and unique to the individual (Farella et al. 2008; Gonzalez et al.
2011). Hence, each subject performed a series of calibration tasks during EMG recording in
the laboratory in order to acquire baseline data for analysis of EMG from jaw loading
behaviors recorded in the field sessions. The static and dynamic biting tasks for calibration
were non-fatiguing and employed a custom pre-calibrated bite-force transducer to determine
thresholds of muscle activities (RMS, µV) for processing of field-recorded data. This
permitted a second stage analysis of field recordings to calculate duty factors (duration of
activity/duration of recording period, %) of jaw loading behaviors. Standard protocols were
followed for laboratory EMG (Nickel et al. 2002; Nickel et al. 2003). Each subject’s skin on
the right and left temples and cheeks, and just above one knee and behind one ear was
cleaned with 70% isopropyl alcohol prepackaged wipes¹. These areas received disposable
self-adherent surface EMG electrodes with pre-dispensed conducting gel²: paired for
recording from anterior temporalis and masseter muscles bilaterally and rectus femoris
muscle unilaterally plus a single ground over the mastoid process behind the ear (fig. 1).
Electrode positions were determined by palpating the main muscle belly and placing the pair
of electrodes over the belly in the same direction as the pull of the muscle (fig. 2).

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¹ Alcohol Prep 6818, Kendall Webcoll 15 Hampshire Street Mansfield, MA 02048
² Ambu Neuroline 720, Ambu A/S Baltorpbakken 13 DK-2750 Ballerup Olstykke, Denmark
Figure 1. Subject performing laboratory EMG calibration tasks involved in laboratory visits #1 and #2. Temporalis and masseter bilateral electrodes are shown along with the custom bite-force transducer.

Figure 2. EMG surface electrodes on anterior thigh.
The custom bite-force transducer (fig. 3) was approximately 8 mm thick and comprised of an electrically-resistive film\(^3\) attached to a stainless steel handle with biting surfaces coated in dental acrylic\(^4\) (used to make orthodontic retainers) and covered with sterile clear plastic film\(^5\). Subjects were asked to perform: 5 static bites and 5 dynamic bites at 4 frequencies. The 5 static and 5 dynamic bites were repeated bilaterally at the left and right first molar position for a total of 50 (10 static and 40 dynamic) bite recordings. Subjects were then instructed to vary the force level between low and moderate for each set of bites at a given position. An investigator held the transducer at the target positions during the biting tasks. Another investigator monitored bite-force and amplified EMG outputs as these were recorded digitally\(^6\) on to tape using specialized software\(^7\) and recorded the tape recording times on the Biting Tasks EMG Log Sheet (Appendix 5).

![Figure 3. Bite-force transducer used to measure the force applied during the various biting tasks for calibration of EMG.](image-url)

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\(^3\) Flexforce®, Tekscan Inc., 307 West First Street South Boston, MA 02127

\(^4\) Triad TruTray, Dentsply Inc., 221 W. Philadelphia St., P.O. Box 872, York, PA 17405

\(^5\) Food Service Film 12”x3000’, Western Plastics, 41995 Remington Ave Temecula, CA 92590

\(^6\) Sony PC-216A 16 Channel Recorder®, Spectris Technologies Inc., 2815 Colonndes Ct Ste A Norcross, GA 30071

\(^7\) PCScan MKII PCIF250NI Real-Time Data Transfer System®, Sony Magnescale America Inc., 34781 Grand River Ave Farmington Hills, MI 48335
**Leg extension exercise tasks.** After the biting tasks were completed the subject conducted some simple leg extension exercises to measure jaw elevator muscle activity during exercise. The surface electrodes just above the knee on the medial belly of the rectus femoris of the quadriceps muscle were used to measure leg muscle EMG as an indicator of the timing of leg muscle activity.

With the EMG electrodes in place, the subject sat at an exercise bench (fig. 4) to do leg extensions. The subject was instructed to start with a low weight that she/he was comfortable with to warm up. This weight and number of repetitions were not recorded. Then the subject was instructed to increase the weight at her/his own discretion until she/he found her/his one repetition max (1RM), which was the maximum weight that could be extended in one repetition. The maximum weight used for any subject was 145 pounds. Subjects were then instructed to start at approximately 20% of 1RM and do as many repetitions as they felt comfortable performing. This exercise was repeated, increasing the weight by approximately 20% of the 1RM until the subject got back or close to the previously established 1RM or 145 pounds. The subject was instructed to take 3-5 minutes of rest between each set, and was given as much time as she/he wanted. The subject was allowed to quit or adjust the weight levels according to her/his comfort at any point. One investigator recorded the tape recording times on a log sheet while the other recorded the weight and repetitions completed in the exercise on a second copy of the same Laboratory Exercise Log (Appendix 6). Recording of the masseter, anterior temporalis and quadriceps muscles via EMG was ongoing through the entire set of exercise tasks.
Preparation and instruction for field recordings. Next each subject was prepared to carry out self-recordings in the field using ambulatory EMG equipment during exercise (fig. 5). This was accomplished through verbal, visual, and written instructions in order to ensure the subject was competent to apply five disposable, single-use surface electrodes\(^8\) to one side of the head and use the portable EMG recorder. For field recordings, the subject was instructed to place one pair of electrodes on the masseter and one pair on the anterior temporalis muscles, and a ground electrode over the mastoid area. They were allowed to choose to record from the right or left side as long as it was consistent between the two sessions. Each subject was asked to make field recordings of activities from 2 muscles (masseter and anterior temporalis) on the same side during two different days of normal

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\(^8\) Pre-Gelled Disposable Surface Electrodes, Alpine Biomed ApS Tonsbakken 16-18 DK-2740 Skovlunde Denmark
weight-lifting routines as prescribed by her/his strength and conditioning coach. The subject was also asked to repeat the same leg extension exercise that she/he performed in the laboratory. Subjects recorded the weights and repetitions as well as the recording times on a Diary Sheet: Exercise Log (Appendix 7). The recordings did not have to be continuous and the subjects could remove and re-apply the electrodes during a session. The dual-channel portable EMG recorder\(^9\) filtered, amplified, and continuously sampled muscle activities at 2 kHz and stored the data on a 512 MB memory card. In between the two activities (leg extensions and normal weight-lifting routine), the subject was instructed to remove the card, store it in a labeled container and load a new card in the portable device. This allowed separation of the data between leg extension exercises and other weight-lifting exercises. At the end of the first laboratory visit each subject was supplied with the portable ambulatory recorder, battery charger, 4 memory cards, a supply of electrodes, alcohol wipes (for cleaning the skin to receive electrodes), hypoallergenic surgical tape\(^{10}\) (to help secure electrodes if indicated), and a diary sheet (to log recording times and exercise routines completed) (Appendix 7). Subjects were each given a manual with illustrated instructions and information about how to contact a study investigator to have questions addressed.

\(^{9}\) EMG Recorder, Clinic for Masticatory Disorders and Complete Dentures, Center for Oral Medicine, Dental and Maxillofacial Surgery, University of Zurich, Plattenstrasse 11, CH-8032 Zürich, Switzerland
\(^{10}\) 3M Transpore Surgical Tape, 3M, 3M Center, St. Paul MN, 55144
Figure 5. The ambulatory EMG recorder used by subjects in the field during leg extension and weight-lifting exercises is shown with four surface electrodes for unilateral recording of masseter and temporalis EMG. A single ground electrode is affixed behind the ear.

Laboratory Visit #2

At this visit the subjects repeated the EMG biting calibration tasks and the leg exercise tasks, as done in laboratory visit #1, and returned EMG recording equipment and any additional supplies. Notations from the recording diaries and data on the memory cards were reviewed and the subject was released. Subjects who completed the study were reimbursed for their travel and time as follows: $25 for the first laboratory visit, $25 for the
second laboratory visit, and $100 for returning usable data from the two self-recording field sessions.

**Data Analysis**

**Behavioral Data Analysis (EMG Recordings)**

The objective of recording and analyzing laboratory behaviors in subjects was to quantify the duty factor (duration of muscle activity/duration of recording period, %) of loading of the mandible by the masseter and temporalis muscles. The occurrence of static and rhythmic masticatory muscle loading of the mandible in the natural environment was quantified with respect to duration and magnitude using portable ambulatory EMG equipment, custom programs in commercial software packages, and subject-specific data from laboratory EMG recorded during the calibration tasks performed at Visits 1 and 2. The behavioral data analysis to quantify duty factors for two jaw muscles (masseter and temporalis) and two field activities (leg extensions and normal weight-lifting exercises) consisted of 3 components:

- Determination of average RMS EMG for a 20 N occlusal force ($T20N_{Ave}$, µV) for each subject using laboratory EMG from calibration biting tasks.
- Processing of field EMG recordings to filter out noise and to identify poor recordings to be excluded.
- Calculation of muscle duty factors during field recordings for thresholds of magnitude.
**Determination of T20N_{Ave}**. The raw data from the laboratory visits were processed by use of a customized software program\(^{11}\) that required several steps. Since each bite-force transducer had unique sensitivity, the program first required the input of the previously determined equation for the specific bite-force transducer (transducer specific calibration curve) which was used during the biting tasks. The raw laboratory data were then sectioned into the static biting tasks and the four dynamic biting tasks at each of the four different frequencies. Next the program asked for the user to define five individual points on the bite-force transducer line in each of the five sections for a total of 25 total data points. The program then used the equation given for the transducer to calculate the biting force in Newtons (N) for the 25 points and gave the four RMS microvolt values (one for each of the masticatory muscles) that corresponded to each of the 25 points. This comma separated value file was then placed in an excel spreadsheet template that created the linear regression for each masticatory muscle for that specific lab visit and right or left side. These linear regressions related the RMS EMG (μV) output from a muscle to biting force (N).

Repeating this sequence to process the raw data yielded 16 linear regression relations for each subject. Specifically this was due to data plotted for four muscles (right and left masseter, right and left temporalis) while biting on each of two sides (left and right), for each of two lab visits.

For each subject the linear regressions were used to calculate the RMS EMG (μV) output for biting at a force of 20 N. These values were defined as the T20N values. Then for each subject the 16 T20N values were split into temporalis and masseter groups. The average for each group was calculated from the eight T20N values. This created a T20N\(_{Ave}\) for the

\(^{11}\) MATLAB version 7.9.0.529 (R2009b) by The MathWorks, Inc.
temporalis muscle and for the masseter muscle for each subject. The data could have been further split up into a T20N_{Ave} for the left and right side, but it was decided to average the two sides since clenching is most often in a centric position and not unilateral as were the bite tests. It was these T20N_{Ave} values that were then used to set the five thresholds for magnitude of EMG activity (5%, 10%, 25%, 50% and 80%•T20N_{Ave}) that were muscle- and individual-specific for analyzing the ambulatory data.

Processing of field EMG recordings. Commercial signal editing software\textsuperscript{12} was used to first view the EMG field recordings completed by subjects during leg extension and weight-lifting exercises. A recording was excluded for one of two reasons. First if a recording had too much noise throughout the recording it was excluded. Secondly, if a muscle recording had absolutely no evidence of electrical activity from muscles it was also excluded. The same signal editing software was then used to filter out any low level noise, in the range of 40 to 20 db. The multiband noise gate function was employed and could be applied to the whole recording if there was a consistent low level noise throughout both channels. Alternatively, the software had the capability to apply a different level of filtration to the separate masseter and temporalis muscle channels or to filter a specific portion of a recording. All recordings were filtered to at least the minimum of 40 db to remove any possible low level noise.

Calculation of duty factors. Software task definers were set-up using the customizable software programs\textsuperscript{13} to calculate duty factors for the selected EMG thresholds of magnitude (5%, 10%, 25%, 50% and 80%•T20N_{Ave}) and duration greater than one

\textsuperscript{12} WavePad Sound Editor Masters Edition version 5.48 by NCH Software
\textsuperscript{13} MATLAB version 7.9.0.529 (R2009b) by The MathWorks, Inc.
second from the processed ambulatory EMG recorded by the subject in the field. That is, the subject- and muscle-specific $T20N_{Ave}$ was applied to calculate duty factors for the magnitude thresholds for the two types of EMG field recordings, during leg extensions and during weight-lifting exercises. The calculated duty factors were used to test for significant differences between the independent factors muscle (masseter, temporalis), gender (male, female), and exercise (leg extension, weight-lifting).

**Statistical Analysis**

Three two-way ANOVAs were used to investigate the interaction between exercise and muscle, between gender and muscle, and between gender and exercise by holding constant gender, exercise and muscle respectively. This was followed-up with a simple T-test to detect whether gender was significant or not by keeping other factors (threshold, exercise and muscle) constant. Similar T-tests were applied to detect if there were significant differences between muscles for a given threshold, gender and exercise and between exercises for a given threshold, gender and muscle. As a next step, a Bonferroni correction was applied ($0.05/4$). The new significance level, $\alpha$, was set at 0.0125.

Effect sizes (using partial Eta squared) and statistical power were also calculated for duty factor with regard to the effect of gender and type of exercise. Lastly, the combination of gender, threshold and exercise that resulted in the smallest effect size was used to calculate the minimum number of subjects that would be required in a future study to find a significant difference with reasonable confidence.
CHAPTER 3

RESULTS

Summary

A total of 17 student athletes were recruited from the women’s and men’s soccer programs at the University of Missouri at Kansas City. There were ten females (subject numbers: 1-5, 10-12, 15) and seven males (subject numbers: 6-9, 13, 14, 17) who participated in the study. The females were all between the ages of 19 to 20 years old and had a mean age of 19 years with a standard deviation of 0 years. The male subjects ranged from 18 to 23 years old and had a mean age of 20 years with a standard deviation of 2 years.

Laboratory EMG Recordings

All of the subjects except subject number 17 completed the two laboratory sessions of standardized biting (figs. 6 and 7) and leg exercise tasks. All subjects, including subject number 17, completed field recordings of the EMG activities of a temporalis and masseter muscle on one side during two sessions of leg extension and weight-lifting exercises. Subject number 17 completed all study protocols except Laboratory Visit #2.
Figure 6. Amplified EMG (mV) and bite-force transducer output (V) versus time (seconds) from subject number 3 during five static biting tasks on left molars during the laboratory visit #1. The top four lines show data from left masseter, left temporalis, right masseter, and right temporalis muscles (in order starting from top). The bottom line shows the bite force transducer output (V) which was converted to units of N using the transducer-specific calibration curve.
Figure 7. Amplified EMG (mV) and bite-force transducer output (V) versus time (seconds) from subject number 5 during a dynamic biting task at different frequencies on left molars during the laboratory visit #1. The top four lines show data from left masseter, left temporalis, right masseter, and right temporalis muscles (in order starting from top). The bottom line shows the bite force transducer output (V) which was converted to units of N using the transducer-specific calibration curve.

**Results from Determination of T20N_{Ave}**

The subjects provided laboratory EMG data that yielded a total of 264 linear regressions relating RMS EMG (μV) to bite force (N) from the static and dynamic biting tasks (fig. 8). That is, 16 linear regression relations from each subject except only 8 regression relations from subject number 17 who completed only the first laboratory visit. Seven of the 264 regression relations were excluded due to inconsistent EMG during the bite tasks. Specifically, “inconsistent” was defined as a laboratory recording that failed to show positive linear relations between EMG and bite-force, and consequently resulted in a
regression with a “flat” slope (see Fig. 8A). Of the remaining 257 relations the $R^2$ values ranged from 0.086 to 0.91 with an average of 0.55 and a standard deviation of 0.19.

Amongst all subjects, the slopes of the linear regression relations for either muscle or visit ranged from -0.00001 to 0.004 microvolts/Newton ($\mu$V/N.) The values for the T20N$_{Ave}$ for either muscle ranged from 0.01 $\mu$V to 0.05 $\mu$V (Table 2) with an average and standard deviation ($\pm$ SD) of 0.02 $\pm$ 0.01 for the masseter muscle and 0.02 $\pm$ 0.01 for the temporalis muscle.
## TABLE 2

CALCULATED T20N\textsubscript{Ave} VALUES

<table>
<thead>
<tr>
<th>Subject Number</th>
<th>Muscle</th>
<th>T20N\textsubscript{Ave} ((\mu\text{V}))</th>
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</tr>
<tr>
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</tr>
<tr>
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<td>Temporalis</td>
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</tr>
<tr>
<td>Average</td>
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<td>0.03</td>
</tr>
</tbody>
</table>
Results from Processing of Ambulatory EMG Recordings

Each of the 17 subjects provided 4 field recordings, two during leg extension exercises and two during weight-lifting exercises, for a total of 68 field recording sessions. Each session had a masseter and temporalis recording for a total of 136 individual recordings. Processing techniques as previously described were applied. All of the ambulatory recordings were filtered as needed, and then sections with too much noise or no recording data were excluded (refer to figs. 9-12).

Figure 9. An example of unfiltered ambulatory recording during leg extensions of subject number 4 from the masseter muscle.
Figure 10. The same ambulatory data as figure #9 that has been filtered at 30 db.

Figure 11. An example of noise that would either be cut out if it was only a portion of the recording or the entire channel would be excluded if it was all of the recording time.

Figure 12. An example from subject number 8 where the masseter channel on the bottom has no recording so it was excluded.
As a result, a total of twenty-six recordings were excluded for one of the two reasons stated previously in the methods (see Table 3).

TABLE 3

EXCLUDED AMBULATORY RECORDINGS FOR SUBJECT, EXERCISE, AND REASON (where m. = muscle)

<table>
<thead>
<tr>
<th>Subject Number</th>
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<tr>
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<td>No temporalis m. data</td>
</tr>
<tr>
<td>8</td>
<td>No masseter m. data</td>
</tr>
<tr>
<td>10</td>
<td>No masseter m. data</td>
</tr>
<tr>
<td>14</td>
<td>No data</td>
</tr>
<tr>
<td>15</td>
<td>No masseter m. data</td>
</tr>
<tr>
<td>17</td>
<td>No temporalis m. data</td>
</tr>
</tbody>
</table>

Results from Calculation of Duty Factors

In general, all 17 subjects exhibited ambulatory EMG activity consistent with sustained occlusal contact (“clenching”) during the weight-lifting exercises and 15 out of the 16 subjects exhibited this “clenching” during the leg extension exercises (subject 5 did not have any data during leg extensions). More specifically, when clenching was defined as EMG activity held for at least one second in duration at or above the threshold of 5\% \bullet T_{20N_{Ave}}, all 17 subjects exhibited clenching during exercises in the field. When the threshold was raised to 10\% \bullet T_{20N_{Ave}} 16 subjects exhibited clenching, and at 25\% \bullet T_{20N_{Ave}} then 13 out of the 17 subjects exhibited clenching. At the 50\% \bullet T_{20N_{Ave}} threshold eight out of the 17 subjects showed clenching and at 80\% \bullet T_{20N_{Ave}} five subjects exhibited clenching.
Since some significant main effects and interactions were shown for duty factor at the 5 thresholds by the three two-way ANOVAs, T-tests were utilized to investigate the performance of each factor (muscle, exercise and gender) in different scenarios. For example, the duty factors for genders were compared for each combination of muscle, exercise and threshold. Since there were four comparisons at each threshold level, a Bonferroni correction set the new level of significance at $\alpha=0.0125$ (0.05/4).

**Duty Factor and Comparing Gender**

The results showed that there were significant gender differences in the duty factors from the same muscles at certain thresholds during weight-lifting (fig. 13) and leg extension (fig. 14) exercises. Females tended to have higher mean duty factors in both muscles at all thresholds during weightlifting, while males tended to have higher mean duty factors in both muscles during leg extensions.

When looking at the masseter muscle during weight-lifting exercises, females had mean duty factors (± SD) (from low to high thresholds, respectively) of 5.8 ± 8.5%, 2.1 ± 4.1%, 0.8 ± 2.0%, 0.5 ± 1.8% and 0.3 ± 1.2% compared to 3.1 ± 4.5%, 0.7± 1.5%, 0.02 ± 0.14%, 0.02 ± 0.13% and 0.0 ± 0.0% for males. Females showed a significantly higher duty factor in the masseter muscle at magnitude thresholds of 5%•T20N_{Ave}, 10%•T20N_{Ave}, 25%•T20N_{Ave}, and 50%•T20N_{Ave} (fig. 13). The effect size of these gender comparisons in masseter duty factor during weight-lifting exercises were low-medium and had an Eta squared ($\eta^2$) range of 0.03-0.05 (See Table 4). When looking at the temporalis muscle during weight-lifting exercises, females had mean duty factors (± SD) (from low to high thresholds, respectively) of 5.8 ± 8.9%, 1.7 ± 3.4%, 0.7 ± 1.6%, 0.2 ± 0.59%, and 0.03 ± 0.11% compared to 3.2 ± 4.2%, 0.8 ± 1.6%, 0.03 ± 0.11% for males. That is, the females also
showed larger duty factors in the temporalis muscle compared to males during weight-lifting but differences were only significant at the 25% • T20N_Ave and 50% • T20N_Ave threshold levels. The effect size of these comparisons were low-medium and had an Eta squared (\(\eta^2\)) range of 0.02-0.05 (See Table 4). No males exhibited masseter duty factor at the 80% • T20N_Ave magnitude threshold or temporalis duty factor at or above 50% • T20N_Ave during weight lifting.

While there were also significant differences in duty factors between males and females during the leg-extension exercises, males tended to have higher duty factors for both muscles than females at all thresholds, and gender differences were larger in the temporalis than masseter muscle (fig. 14). Specifically, the mean duty factors (± SD) for the temporalis muscle during leg extension exercises in males (from low to high thresholds, respectively) were 7.1 ± 10.7%, 3.3 ± 5.1%, 1.1 ± 2.5%, 0.8 ± 2.3% and 0.7 ± 2.3% compared to 0.5 ± 3.0%, 0.0 ± 0.0%, 0.0 ± 0.0%, 0.0 ± 0.0%, and 0.0 ± 0.0% in females. Males had significantly higher mean temporalis duty factors compared to females at 5% • T20N_Ave, 10% • T20N_Ave, and 25% • T20N_Ave magnitude thresholds. The relatively large effect size of these gender comparisons had an Eta squared (\(\eta^2\)) range of 0.06-0.21 (See Table 4). The mean duty factors (± SD) for the masseter muscle during leg extension exercises in males (from low to high thresholds, respectively) were 2.6 ± 4.7%, 1.1 ± 2.7%, 0.7 ± 2.2%, 0.7 ± 2.2%, 0.6 ± 0.25% compared to 2.2 ± 6.8%, 0.2 ± 0.9%, 0.0 ± 0.0%, 0.0 ± 0.0%, and 0.0 ± 0.0% in females. The gender difference was only significant for masseter duty factor at the 25% • T20N_Ave threshold. The effect size of those comparisons were low-medium and had an Eta squared (\(\eta^2\)) range of 0.001-0.06 (See Table 4). No females exhibited temporalis duty factors at or
above the 10%•T20N_{Ave} magnitude threshold or masseter duty factors at or above 25%•T20N_{Ave} during leg extension exercises.

Figure 13. Weight-lifting: Gender Comparison of Duty Factor versus Magnitude Threshold. Mean values for genders and muscles are shown as indicated by the key. Vertical lines show standard deviation above the mean. Significant differences (p<0.0125) are indicated by *.
Figure 14. Leg extensions: Gender Comparison of Duty Factor versus Magnitude Threshold. Mean values for genders and muscles are shown as indicated by the key. Vertical lines show standard deviation above the mean. Significant differences (p<0.0125) are indicated by *.

Duty Factor and Comparing Type of Exercise

The differences in duty factors between types of exercises were compared for all the magnitude thresholds for each gender. The duty factors for males tended to be higher during leg extensions compared to weight-lifting but were only significantly higher at the 10% T20N_{Ave}, 25% T20N_{Ave} thresholds in the temporalis muscle (fig. 15). The effect sizes for these comparisons were medium ranging from $\eta^2$ of 0.04-0.09 (See Table 5). There were no significant differences in duty factors between exercise types in the masseter muscle and the effect sizes of these comparisons were relatively small with an Eta squared ($\eta^2$) range of 0.003-0.05 (See Table 5).
For the females in the study, there were significantly higher duty factors at all magnitude thresholds except for >80%●T20N_{Ave} for the weight-lifting exercises compared to the leg extension exercises in both muscles (fig. 16). Particularly large effect sizes were shown for temporalis duty factors in females at magnitude thresholds ≤10%●T20N_{Ave} where Eta squared (η²) was 0.12-0.14 (See Table 5).

**Males: exercise comparison**

Figure 15. Males: exercise comparison. Mean values for exercises and muscles are shown as indicated by the key. Vertical lines show standard deviation above the mean. Significant differences (p<0.0125) are indicated by *. 

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Figure 16. Females: exercise comparison. Mean values for exercises and muscles are shown as indicated by the key. Vertical lines show standard deviation above the mean. Significant differences (p<0.0125) are indicated by *.

**Duty Factor and Comparing Muscles**

For the same type of exercise, males showed a trend towards larger temporalis than masseter duty factors, with the difference being significant at the 10%\(\cdot T20N_{Ave}\) threshold during leg extensions (fig. 15) and a medium effect size for this comparison \((\eta^2 = 0.07)\). Females showed a slight but opposite trend with larger masseter than temporalis duty factors but the differences were not significant (fig. 16).

**Duty Factor and Effect Size**

To confirm that the statistically significant differences in duty factors were due to the differences in gender and type of exercise the effect size and power were calculated (Tables 4 and 5). When looking at the differences between males and females at the various VTC thresholds the range of the Eta squared value was 0.02 to 0.05 for weight-lifting exercises.
and 0.00 to 0.21 for leg exercises (see Table 4). At every threshold level the effect size is larger in leg extensions compared to weight lifting except for the masseter duty factor at the 5% $\bullet T20N_{Ave}$ threshold. The effect sizes are medium to large for both muscles at the threshold levels of 25%$\bullet T20N_{Ave}$ and 50%$\bullet T20N_{Ave}$ as well as for the temporalis at the 5%$\bullet T20N_{Ave}$ threshold.

The effect size for comparing exercise types for masseter and temporalis duty factors at the various VTC thresholds ranged from 0.032 to 0.14 for females and 0.00 to 0.08 for males (see Table 5). The effect sizes were medium to large at thresholds from 10%$\bullet T20N_{Ave}$ -50%$\bullet T20N_{Ave}$ with the exception of at the 10%$\bullet T20N_{Ave}$ threshold in the masseter muscle in males ($\eta^2=0.00$).

Power analyses were done using the smallest effect size and observed power for comparisons of gender and exercise type (See Tables 4 and 5). The results showed that the minimum necessary number of subjects per group to achieve a power of $\geq0.80$ was 17 subjects to investigate the effects of gender and 13 subjects to investigate the effects of exercise type.
### TABLE 4
EFFECT SIZE FOR GENDER

<table>
<thead>
<tr>
<th>Threshold (% • T20N_Ave)</th>
<th>Exercise</th>
<th>Muscle</th>
<th>Effect size (Eta square)</th>
<th>Observed power</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
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### TABLE 5
EFFECT SIZE FOR EXERCISE TYPE

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<tr>
<th>Threshold (% * T20N_{Ave})</th>
<th>Gender</th>
<th>Muscle</th>
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<th>Observed power</th>
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CHAPTER 4

DISCUSSION

The results from this study demonstrate that clenching during exercise may be a common occurrence. Specifically, low level clenching is very common. When the threshold to define clenching is increased to $50\% \cdot T_{20N_{Ave}}$ threshold the prevalence of clenching decreased to 47%. It would seem that Okeson may be correct in his assumption that non-parafunional clenching can and does occur during moments of exertion such as during weight bearing exercises (Okeson 1993). This study also shows that a gender difference may exist in clenching during exercise. However, according to this study the expression of this gender difference may be different depending on the type of activity. The effect sizes showed that up to 21% of the differences in duty factors of clenching could be attributed to gender differences and up to 14% could be due to the type of exercise.

Clenching for this study was defined at multiple different EMG magnitude thresholds. This allowed for the comparison of various levels of clenching during exercise across genders. While other researchers have used a percentage of maximum voluntary clenching, the current method may be more applicable to true clenching practices. It has been reported that a 20 N force is the average load produced when biting through a single cube of unprepared gum on the molar teeth (Iwasaki 1992). Therefore, clenching loads based around 20 N may be more relevant to clenching than a percentage of maximum voluntary clenching since chewing is a more frequent physiologic occurrence compared to maximum clenching. This is a relatively low force when compared to the 133 N required to bite through a 10 mm thick section of a raw carrot (Iwasaki 1992) or the reported mean maximum biting forces in
the molar region for men and women which were 847 N (standard deviation 131 N) and 597 N (standard deviation 94 N) respectively (Waltimo and Kononen 1993).

It has been shown that when both position and angle of biting forces are controlled during biting tasks a very reliable linear regression between RMS EMG and bite force results (Gonzalez et al. 2011). However, unlike the methods employed by Gonzalez et al., the method employed in this study of static and dynamic biting tasks did not control for the angle of tooth tipping moments. Therefore, the methods used in this study have not yet been verified as reproducible and reliable. Although bite-force position was targeted to molar biting, some inconsistency in positioning of the transducer was possible, especially if the subject’s occlusion resulted in non-vertical bite-forces that caused tooth tipping moments. This likely could result in lower coefficients of determination ($R^2$ values) found in the current study compared to other studies where both position and angle of bite-forces were controlled for molar biting (Uchida et al. 2008; Gonzalez et al. 2011). Gonzalez et al. showed that various slopes resulted when biting position was controlled but direction of the force was varied at several different buccal and lingual angles to the long axis of a molar. Nevertheless, the current methods demonstrated generally well-behaved linear regression relations where only 7/264 relations were excluded as “inconsistent”. The data to compare the linear regressions created from the first and second laboratory biting tasks exist from this study. These data have not been analyzed yet to determine reproducibility and reliability from visit to visit.

It is difficult to know how helpful controlling position of the mandible during the biting tasks would be. This is because in a study that attempts to “monitor” clenching in a natural environment it is almost impossible to know the mandibular position during
clenching, unless a customized intraoral appliance was made and used by subjects during exercise to ensure clenching to a desired occlusal relationship. Even such an appliance could affect “natural” clenching. As mentioned above it has been reported that during exercise 58% of subjects clenched in centric occlusion and 11% exhibited eccentric tooth contacts (Ishijima et al. 1998). This is one of the challenges innate to the study of “monitoring” clenching in a natural environment.

There are just a few studies that have explored whether or not clenching occurs during exercise naturally. Ohkawa et al. (Ohkawa 1994; Ohkawa et al. 1994) looked at common activities in soccer, volleyball and handball. They reported clear masticatory muscle EMG signals during these activities in 22 of the total 26 subjects (or 85%). Ishijima et al. (Ishijima et al. 1991) found that 69% of their subjects exhibited clenching during a back weight lifting exercise. Lastly, Yokoyama et al. reported that in a group of 12 male subjects only eight (67%) showed clenching during exercise (Yokoyama et al. 1996). It was shown in this study that at very low levels clenching is a very common phenomenon with 100% of the subjects exhibiting clenching at some point in either type of exercise activity. However, at higher magnitude thresholds the percentage of those who showed clenching decreased to 29%. Therefore the range shown in this study of 29% to 100% encompasses all the reported results from the previous studies cited above. It seems that the prevalence of clenching may be highly dependent on the definition of clenching and that people who clench may vary in intensity. Unfortunately, it is difficult to further compare this study to the studies done by Ohkawa et al., Ishijima et al., or Yokoyama et al. since the reports of their work are written in Japanese with English abstracts. Even though surface EMG was used in each of these studies it is not clear exactly how clenching was defined.
There have been several studies to look at gender differences in pain perception, maximum force during voluntary clenching, and self-reported bruxism (Waltimo and Kononen 1993; Plesh et al. 1998; Tuxen et al. 1999; Mundt et al. 2005; Casanova-Rosado et al. 2006; Okayasu et al. 2009; Nekora-Azak et al. 2010). However, no study could be found that has quantifiable data on gender differences in clenching. Therefore, this is the first known study that has attempted to explore the possible gender differences in clenching with quantifiable data. In addition, it is the first study to look at gender differences in clenching during exercise. There are known gender differences in biomechanical physiology (Swedan 2001). According to Swedan, (Swedan 2001) females generally have less absolute strength and typically smaller muscle fiber size than men. However, research is split between whether or not there is a difference in the number of muscle fibers in men and women. However, in males individual muscle fibers are larger. When strength is divided by muscle mass females and males have a similar relative strength. Males typically have larger shoulder girdles and females typically have a wider pelvis which results in a lower center of gravity in females. This lower center of gravity in females could help in certain exercises making it easier to maintain balance. This could be a factor in the gender difference in VTC since it has been hypothesized that VTC may help contribute to stabilization and balance (Takada et al. 2000). There was not a lot of research found on gender differences in stabilization and balance but a few articles do report a possible gender difference (Wolfson et al. 1994; Golomer et al. 1997; Schultz et al. 1997). It has also been reported that females have greater flexibility than males (Swedan 2001) which, depending on the exercise, could also contribute to a gender difference in stabilization and balance during an exercise motion.
This is also the first study to explore the possibility that there may be differences in clenching based on the type of activity. Previous research suggests possible theories about why results from this study show that the activity could affect clenching measured by duty factor or clenching intensity. One theory is that since VTC helps to facilitate reciprocal muscles in the leg VTC may help contribute to stabilization and balance (Takada et al. 2000). This theory seems to have been supported when subjects who clenched were able to maintain posture and balance better than “non-clenchers” as measured by a force plate they were standing on after having their balance disturbed (Fujino et al. 2010). It is possible that different exercises may require differing levels of stabilization or balance which could elicit varying expression of VTC. Also it appears that VTC can have varying effects on different muscles due to the properties of the muscle (Boroojerdi et al. 2000; Takahashi et al. 2006). If the type of exercise truly does have an effect on the amount or level of clenching then it would have to be a consideration in any future study and may be a factor that needs to be controlled. As part of this study a more standardized leg extension exercise was done after the biting tasks in the laboratory and these data have yet to be analyzed but may help to further investigate this question. That is, it would be possible with the data collected through this study to explore the question of whether or not the amount of load in the exercise is related to the duty factor or the magnitude of clenching. The data gathered during the laboratory leg extension exercises included the amount of weight and the number of repetitions completed. In the future these data should be processed and analyzed.

In the current study, to allow for the most natural environment to monitor clenching, very little restraints were put on the field recording sessions during weight-lifting exercises. Subjects were told they could do weight-lifting exercises of upper body or lower body or a
combination of both. The only restriction was to avoid chewing gum. Obviously, this introduces possible confounding factors due to individual choice of exercises. Anecdotally, most subjects did a combination of both upper and lower body exercises; however this was not true for all. The other type of the ambulatory recording session was the more standardized leg extension exercises, and this also showed a gender difference in clenching. When comparing gender the effect size for the more standardized leg extensions were greater than the effect size for weight-lifting exercises at each muscle and threshold except for at the 5% threshold in the masseter muscle.

There were a few advantages to having all the subjects be collegiate-level soccer players from the UMKC men’s and women’s soccer teams. All the subjects were concurrently participating in a regular strength and conditioning program. The hope was that this would decrease the possible confounding factor of having volunteers who did not exercise with weights regularly and who might consequently experience stress or nervousness in the protocol. It was also hoped that recruiting subjects from the same sport meant that both subject groups would be involved with similar training regimens, exercises, and environments within and between gender groups. All subjects did use the same exercise facility for their field recordings. However, it is possible that this could also have been a confounding factor. For example, in this study females had permission from their coach to do the weight-lifting field recording during their scheduled workouts (which some of them did) while the males had to do all of their weight-lifting recordings outside of regular workouts on their own time (all subjects did the leg extension field recordings outside of regular workouts).
The relatively small sample sizes may appear to have magnified some of the above-mentioned factors. When a power analysis was done using the smallest effect size of 0.001, that resulted from the comparison of masseter duty factor between genders during leg extensions, the necessary number of subjects per group to achieve a power of 0.828 was 17 subjects. Therefore, this pilot study could potentially be improved by increasing the number of subjects.

There are several limitations to this study, some of which have already been mentioned, such as controlling for jaw position and standardizing exercises. Another limitation with this type of study is the inability to control for “how strenuous” the exercise is for the individual. In other words, it is almost impossible to control how much a subject is “pushing themselves” in the activity. The leg extension exercise instruction was to continue doing repetitions until the subject could not do any more. This instruction was subjective and may have been influenced by other factors such as external distractions, emotional stress, fatigue or depression. There was no instruction given on how strenuous the exercise should be in the weight-lifting exercise. The only instruction was to perform a session like the subjects were already accustomed to doing with their strength and conditioning coaches. Another possible confounding factor that was not addressed in this study is the possibility of varying degrees of external or internal psychological stress or depression. For example, if several of the females or males in the study were in the middle of midterms during the course of this study this could contribute to increased stress and clenching and possibly bias results. Another challenge with the current study is the possibility that EMG activity may be due to noise or include crosstalk from nearby facial expression muscles. As described it was attempted to clean up the data by filtering or excluding data that had noise. However, there is
still the possibility that some noise persisted or that EMG data were from muscles other than
the masticatory muscles of interest. Also there is the possibility that a learning or
accommodation effect exists between the first laboratory or field recording to the second
sessions. Lastly, ideally it would be important to verify that the EMG activity measured was
a result of tooth contact during clenching. Verifying this was not attempted in this study.
However, during the leg extensions during the laboratory visits (these data were not analyzed
in this report) visual confirmation of tooth contact was seen in some of the subjects.
Therefore, this study could be improved upon if the limitations could be addressed by:

1. Controlling for jaw position during biting tasks and during exercise.
2. Attempting to better standardize the exercise and its “intensity.”
3. Accounting for other external and internal stress and psychological states during the
   study through a concurrent survey.
4. Verifying that EMG activity was due to tooth contact during clenching.

One possible confounding factor for this study that was addressed is that during
swallowing teeth may contact with concurrent EMG muscle activity. However, we defined
duty factor as any EMG activity over a certain threshold that was sustained continuously for
at least one second. It has been reported that swallows typically last about one second. Also,
an average human swallows about 1000 times a day. If each of those swallows lasts a second
that would result in a duty factor of about 1% due to swallowing (Proffit et al. 2007). The
duty factors in this study at low levels of clenching were much higher than this. Furthermore,
it would be feasible to guess that swallowing might occur less during exercise than at rest.
Therefore, even though swallowing is still a potential confounder, the methodologies of this
research have attempted to account for that confounder.
Since this study was a pilot study in a novel area of research there are many questions still to be answered. One of those questions is investigating clenching events at different duration thresholds. In this study results have been divided into thresholds of intensity described by bite-force. A duration threshold could also be applied to the data which could divide the factor into clenching events that were sustained over 1, 2, 5, or 10 seconds. These data have been collected but have not been analyzed. For example, further investigation of the laboratory visit data to determine when clenching occurs relative to the exercise is indicated. There is a report that suggests that masticatory muscle EMG activity begins before EMG activity in the muscle performing exercise (Yokoyama et al. 1996). If this is the case, a feed-forward mechanism is suggested as opposed to a feed-back mechanism for clenching. Looking further into VTC phenomena and exercise, it could be useful to standardize the exercise activities and control for how strenuous the activity is to determine if the gender differences in clenching still occur.
CHAPTER 5
CONCLUSION

This pilot study has explored a novel area of research investigating possible gender differences of voluntary teeth clenching during exercise. The first hypothesis that clenching does occur during exercise was confirmed because all of the 17 subjects exhibited low level clenching during exercise and around half of the subjects exhibited moderate level clenching at or over 50%\textbullet T20N_{Ave}.

The second hypothesis that there would be a gender difference in clenching was also verified. For each of the exercise types there was a significant difference in the clenching defined by a difference in the duty factor for the genders. The females showed higher duty factors at four out of five clenching magnitudes for weight-lifting exercises in at least one of the muscles. Males showed higher duty factors at lower magnitudes of clenching for leg extensions in at least one of the muscles investigated.

An unexpected finding was that there was also significant differences within gender groups when the types of exercises were compared. Females had higher duty factors in weight-lifting exercises than leg extensions at all but the highest clenching magnitude. On the other hand, males had higher duty factors during leg extensions than during weight-lifting exercises the 10%\textbullet T20N_{Ave} and 25%\textbullet T20N_{Ave} magnitudes of clenching.
LITERATURE CITED


Hiroshi C. [relation between teeth clenching and grip force production characteristics]. Kokubyo Gakkai Zasshi 2003;70:82-8.


Shiau YY, Chai HM. Body posture and hand strength of patients with temporomandibular disorder. Cranio 1990;8:244-51.


APPENDIX 1

IRB APPROVAL
July 6, 2012

Laura Iwasaki, DDS, MSc, Ph.D.
UMKC - School of Dentistry
Dentofacial Orthopedics
Kansas City, MO 64108

Approval Date: 07/02/2012
Expiration Date: 07/01/2013
Review Type: Expedited Category #4

RE: AHSIRB Protocol #: 12-54e, entitled: "Voluntary Teeth Clenching During Exercise: Prevalence and Gender Differences"

Dear Dr. Iwasaki,

The above referenced study, and your participation as a principal investigator, was reviewed and approved by a member of the Adult Health Sciences Institutional Review Board on 07/02/2012. You are granted permission to conduct your study as described in your application.

The approval includes the following:
- Application Submitted on 06/15/2012
- Flyer Submitted on 06/15/2012
- Clinical Exam Form Submitted on 06/15/2012
- VTC Instructions Submitted on 06/15/2012
- Study Participation Payment Form Submitted on 06/15/2012
- Exercise Log Submitted on 06/15/2012
- Consent Form Version Dated: 06/09/2012
All subjects must be consented on a copy of the stamped AHSIRB approved consent form

The ability to conduct this study will expire on or before 07/01/2013 unless a request for continuing review is received and approved. If you intend to continue conduct of this study, it is your responsibility to provide a Research Progress Report prior to the expiration of approval.

There are 5 stipulations of approval:
1) No subjects may be involved in any study procedure prior to the IRB approval date or after the expiration date. (PIs and sponsors are responsible for initiating Continuing Review proceedings).
2) All unanticipated or serious adverse events must be reported to the IRB.
3) All protocol modifications must be IRB approved prior to implementation unless they are intended to reduce risk. This includes any change of investigator.
4) All protocol deviations must be reported to the IRB.
5) All recruitment materials and methods must be approved by the IRB prior to being used.

Please contact the administrative office of the AHSIRB (email: umkcAHSIRB@umkc.edu; phone: 816-235-5927) if you have questions.
Thank you,

AHSIRB Administrative Office

PLEASE NOTE:
If you are using a signed consent form, a AHSIRB stamped approved version will follow via a separate email.

If a signed copy of this letter is needed, please contact a member of the IRB staff.

This e-mail is an official notification intended only for the use of the recipient(s). If you have received this communication in error, please return it to the sender immediately and delete any copy of it from your computer system.
APPENDIX 2

CLINICAL EXAM FORM
Voluntary teeth clenching during physical exercise: prevalence and gender differences

Clinical Exam

ID#: ________

<table>
<thead>
<tr>
<th>Yes/No</th>
<th>Feature</th>
<th>Explanation/Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Right-left facial symmetry</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Number of missing teeth</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Missing teeth: X</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Restorations: ●</td>
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<tr>
<td></td>
<td></td>
<td>1 2 3 4 5 6 7 8 9</td>
</tr>
<tr>
<td></td>
<td>20 21 22 23 24 25 26 27 28 29</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Last dental check-up: _______</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Intra-oral anatomy – acceptable?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>➤ Periodontal condition</td>
<td></td>
</tr>
<tr>
<td></td>
<td>➤ Vestibular depth</td>
<td></td>
</tr>
<tr>
<td></td>
<td>TMJ</td>
<td></td>
</tr>
<tr>
<td></td>
<td>➤ Right pain: <strong>Observed</strong> Reported</td>
<td></td>
</tr>
<tr>
<td></td>
<td>➤ Left pain: <strong>Observed</strong> Reported</td>
<td></td>
</tr>
<tr>
<td></td>
<td>TMJ</td>
<td></td>
</tr>
<tr>
<td></td>
<td>➤ R. crepitus: <strong>Observed</strong> Reported</td>
<td></td>
</tr>
<tr>
<td></td>
<td>➤ L. crepitus: <strong>Observed</strong> Reported</td>
<td></td>
</tr>
</tbody>
</table>

Medical History:

- Musculoskeletal disease
  (e.g. fibromyalgia, muscular dystrophy)
- History of frank trauma to TMJ
- Other

Notes:
The HIPAA Privacy Rule protects the privacy of personal health information (PHI) contained in your medical records. HIPAA now requires researchers, except in specific circumstances, to get written permission from study participants before using or disclosing their health information for a research study. The University of Missouri – Kansas City has to obtain this separate Authorization from you so it can use your personal health information for the medical research outlined in the Informed Consent Form.

<table>
<thead>
<tr>
<th>Investigators</th>
<th>Investigator response (all boxes must be filled in)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Principal Investigator (PI) Name</strong></td>
<td>Dr. Laura Iwasaki</td>
</tr>
<tr>
<td><strong>Title of Research Study</strong></td>
<td>VOLUNTARY TEETH CLenchING DURING PHYSICAL EXERCISE: PREVALENCE AND GENDER DIFFERENCES</td>
</tr>
<tr>
<td><strong>Description of the information to be collected. The research subjects’ authorization applies to the information described to the right. Only this information may be used and/or disclosed in accordance with this authorization. List what personal health information you (the PI) will collect from the research subject?</strong></td>
<td>- Medical history and dental clinical examination findings  - Laboratory electromyographic (EMG) recordings of 2 jaw muscles (masseter and anterior temporalis) and 1 leg muscle (quadriceps) during biting tasks for calibration and during exercise involving weight lifting.  - Bite-force magnitude measurements during biting tasks using a custom transducer.  - Field EMG recordings of 2 jaw muscles (masseter and anterior temporalis) during exercise involving weight lifting.</td>
</tr>
<tr>
<td><strong>Who may use and/or disclose the information? The research subject authorizes the following persons (or class of persons to the right) to make the authorized use and disclosure of their (PHI).</strong></td>
<td>Drs. Laura Iwasaki, Adam Reynolds, Jeffrey Nickel and study personnel</td>
</tr>
<tr>
<td><strong>Who may receive the information? You authorize the following persons (or class of persons to the right) to receive your (PHI).</strong></td>
<td>• The Institutional Review Board at UMKC  • Federal agencies such as the Office for Human Research Protections</td>
</tr>
<tr>
<td><strong>Purpose of the use or disclosure. Your PHI will be used and/or disclosed as described in the attached consent form. Investigator list to the right the purpose of the research study.</strong></td>
<td>The purpose of this pilot study is to compare the prevalence of clenching in jaw muscles in males and females during exercise.</td>
</tr>
<tr>
<td><strong>Expiration of the Authorization</strong></td>
<td>This authorization does not have an automatic end date. It will stay in your electronic patient file.</td>
</tr>
</tbody>
</table>
Authorization for Use of Protected Health Information

Canceling the authorization
You have the right to cancel this authorization at any time. Your cancellation must be in writing, addressed to the PI listed in the box below. You are aware that even if you cancel this authorization and withdraw from the study, researchers may continue to use and disclose information that was gathered before they received your cancellation.

Dr. Laura Iwasaki
UMKC School of Dentistry
650 East 25th St.
Kansas City, MO 64108

Disclosures outside the research study
Once your health information has been disclosed to anyone outside this study, the information may no longer be protected under this authorization. The researchers (and if applicable, the sponsor) agree to protect your health information by using and disclosing it only as permitted by you in this Authorization and as directed by state and federal law.

Right to refuse to sign the authorization
You have the right not to authorize the use and disclosure of your health information. In such a case you would choose not to sign this document. You understand that refusal to sign the authorization means that you cannot participate in the study.

Suspension of right to access personal health information
You agree that you will not have a right to access your personal health information obtained or created in the course of the research project until the expiration of this authorization.

Authorization for Adults
By signing this Authorization you agree that you have read this Authorization form and that you have been given the opportunity to ask questions. You will be given a signed copy of this Authorization for your records.

Subject Signature ___________________________ Date __________

Subject's Printed Name ___________________________

If questions, contact the Principal Investigator (PI) of this study and/or the Privacy Official at the Institutional Review Board, University of Missouri-Kansas City, 5319 Rockhill Road, Kansas City, MO 64110, 816-235-5370 (Phone).
APPENDIX 4

INFORMED CONSENT FORM
CONSENT FORM FOR PARTICIPATION IN A RESEARCH STUDY

Voluntary Teeth Clenching During Exercise: Prevalence and Gender Differences

Introduction

You are being asked to volunteer for a research study. This study is being conducted at the University of Missouri Kansas City (UMKC) School of Dentistry.

The researchers in charge of this study are Drs. Adam Reynolds, Jeff Nickel, and Laura Iwasaki. While the study will be run by them other qualified persons who work with them may act for them.

The study team is asking you to take part in this research study because you are over 18 years of age and are physically able to participate in weight lifting exercises. Research studies only include people who choose to take part. Please read this consent form carefully and take your time making your decision. The study doctor or staff will go over this consent form with you. Ask him/her to explain anything that you do not understand. Think about it and talk it over with your family and friends before you decide if you want to take part in this research study. This consent form explains what to expect, the risks, discomforts, and likely benefits if you consent to be in the study.

Background

Different people seem to use their muscles differently to do the same task. This research study involves people who regularly do weight-lifting exercises. When you use a muscle, it gives off a small electrical signal. This signal can be recorded by a device. The method is called “electromyography” (or EMG).

Purpose

The purpose of this research study is to learn more about how different muscles are used during exercise. This may help in future to understand more about muscle strength and activities.

You will be one of about 30 subjects in the study at UMKC. About 30 subjects in total will take part across all the places working on this study.

Study Procedures and Treatments

If you decide to participate in this study, there will be a Screening Visit followed by four EMG recording sessions in total. The Screening Visit will be about 30 minutes long and will take place in Room 180 at the UMKC School of Dentistry.

Two of the recording sessions will take place during Lab Visit #1 and Lab Visit #2 in Room 398 at the UMKC School of Dentistry. At Lab Visit #1, EMG will be recorded from four of your jaw muscles and one of your leg muscles while you...
bite on a special instrument and then while you do some leg-raising exercises. At this visit you will also learn how to use a portable EMG device for the two recording sessions you will do on your own. Lab Visit #1 will take about 1.5 to 2 hours. A portable EMG device will be loaned to you and you will be given supplies for the two self-recording sessions. The EMG device is about the size of a mobile phone. During each self-recording session, EMG will be recorded from two of your jaw muscles on the same side while you do a weight-lifting work-out. You will record at two work-outs of at least 0.5 hour each on different days. Lab Visit #2 will take place after the two self-recordings are done. At Lab Visit #2, you will return the portable EMG recording equipment and any extra supplies. Then, EMG will be recorded the same way as at Lab Visit #1 for the same tasks. Lab Visit #2 will take about 1 to 1.5 hour.

If you agree to take part in this study, you will be involved in this study for a total of about 4 to 6 hours. Lab Visits #1 and #2 will be set-up between 2 to 20 days apart at times that work for you and the study investigators.

The following study visits and procedures will occur:

Screening Visit - Room 180, UMKC School of Dentistry (0.5 – 1 hour)
A screening examination will be done by one of the study investigators to see if you can participate in this study. Your mouth, teeth and jaw muscles will be looked at to see if you can participate in this study. If the screening examination shows that you qualify, you will be invited to schedule Lab Visit #1. Lab Visit #1 may follow right away or may be at another time.

During lab visits you will be asked to wear your exercise shorts to permit EMG recording of your leg muscle on one side.

Lab Visit #1 - Room 398, UMKC School of Dentistry (1.5 - 2 hours)
- Rubbing (isopropyl) alcohol wipes will be used to clean the skin on your cheeks and temples on both sides, behind one ear, and on one thigh, just above the knee. In these places, pairs of sticky pads (EMG electrodes) with conducting gel will be placed. This will allow the electrical signals from 5 of your muscles to be recorded and measured.
- With the electrodes in place:
  - You will bite on a plastic-covered stick using low to medium effort. This stick is a device that can measure how hard you are biting. The stick will be held in place by one of the study investigators. You will be asked to hold each bite for a few seconds, 5 times. You will then be asked to bite repeatedly for a few seconds using 4 different speeds. These bites will be done at 2 tooth positions with rest periods in between.
  - You will sit at a weight-lifting bench for some exercises called “leg extension-flexion exercises.” The leg with the electrodes will be used. The exercises involve raising and lowering a weight near your ankle by straightening your leg, then bending your knee. If needed, an investigator
can demonstrate these exercises. You will be directed to do a few of these exercises at a very light weight level to "warm up" your muscles. Then you will do 1 extension-flexion at progressively larger weight levels until you reach the largest weight that you can comfortably lift. This weight will be called your "one repetition maximum" (1RM). Beginning with a low weight level (20% of your 1RM), you will do a set of 12 leg extension-flexion movements. Then the weight level will be increased by 10% and you will repeat the set. This will be repeated until you reach your 1RM or until you choose to stop.

- You will be given written instructions and shown how to use the portable EMG recording device and supplies. This will include how to:
  - Wear 5 EMG electrodes (small sticky disposable pads with connectors)
  - Connect the electrodes to the recorder
  - Turn the recorder on and off
  - Change and store the memory cards for the recordings
  - Arrange and secure the equipment during your work-out
  - Use a diary form
  - Recharge the recorder's batteries between recordings.

- You will be given a supply of disposable electrodes, alcohol wipes, hypo-allergenic tape (to help secure the electrodes in place if needed) and an instruction manual. You will be loaned a recorder with adjustable carrying case, connectors, battery charger, memory cards and diary sheet for between 2 – 20 days. During this time you will make your 2 self-recordings.

Self-recording Session #1, gym of your choice (0.75 -1 hour)
- You will use the recorder, equipment, supplies and diary sheet as instructed during a routine work-out of at least 0.5 hour. This work-out should involve weight-lifting and using your legs.
- The side that you record on will be your choice. On that side, you will do at least one set of 12 leg extension-flexion exercises similar to the ones you did at Lab Visit #1. These will be done near the beginning of your work-out, after you have warmed-up. Then you should carry-on to complete your own typical exercise routine that includes weight-lifting and using your legs.
- You may stop and start recording at any time as needed.
- On the diary sheet you should write down what exercises, how many repetitions, and what weight levels you used.

Self-recording Session #2, gym of your choice (0.75 -1 hour)
- Same as for Self-recording Session #1.

Lab Visit #2 - Room 398, UMKC School of Dentistry (1 - 1.5 hours)
- The recording equipment and any unused supplies will be returned at this visit.
- The self-recordings stored on memory cards and diary sheets will be reviewed.
- EMG recordings during biting and leg exercises, as done for Lab Visit #1, will be repeated.
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If you withdraw early from the study, you will be asked to complete an end of study visit to return the recording equipment and supplies.

When you are done taking part in this study, you will not have access to the recording equipment any longer.

Possible Risks or Side Effects of Taking Part in this Study

- Cleaning of your skin with rubbing (isopropyl) alcohol for the electrodes will cause minor irritation of your skin over your cheeks, temples, behind your ear and on your leg. Skin irritation can be relieved by applying moisturizing cream to these areas after the recording.
- There is potential for minor skin irritation in the areas where hypo-allergenic tape is used to secure the recording equipment.
- Completing the biting tasks is expected to take about 15 minutes per visit. Doing these tasks may cause tiredness or soreness of your jaw muscles but there will be short rests between each task to make this less likely. In susceptible people, the biting tasks may cause headache or jaw joint pain. Tooth damage may occur during the biting tasks if your tooth structure has been weakened by decay, fracture, large fillings, or other unforeseen reason.
- Completing the leg extension-flexion exercises is expected to take about 30 minutes per visit. Doing these exercises may cause temporary tiredness or soreness of the leg muscles, similar to when you exercise on your own. You will be directed to stop the exercises if you feel tired or sore.
- Physical injury, such as straining or pulling a muscle, can occur with any type of weight-lifting or other fitness training exercises with or without EMG recording. Similarly, accidental physical injury can occur during any work-out with or without EMG recording.
- Using the portable EMG recorder may cause frustration during exercise since you are not used to this.

Possible Benefits for Taking Part in this Study

There are no benefits to you for taking part in this study.

Other people may benefit in the future from the information about how muscles are used that comes from this study.

Costs for Taking Part in this Study

You will not have to pay for any procedures associated with the study. You will be responsible for doctor and or hospital or dental clinic costs as usual except for those directly related to the research study.

Return any EMG equipment lent to you by study personnel. You will be charged a fee of $1000.00 if this equipment is not returned.
Payment for Taking Part in this Study

To compensate you for your time and transportation expenses you will be paid $25 for each Lab Visit that you complete. You will be paid an additional $100 for completion of the 2 self-recording sessions. If you complete the study the total amount you will receive is $150.

After each Lab Visit you will be asked to complete a Study Participant Payment Form. This form will be submitted so that a check for the appropriate amount is made and mailed to you from the UMKC. The Payment Form requires your name, address, and social security number or individual tax identification number. To comply with federal income tax laws, payments to you are reportable income. You should not expect to receive a form 1099 from the UMKC for compensation for taking part in this study.

Alternatives to Study Participation

The alternative is to not take part in the study.

Confidentiality and Access to your Records:

The results of this research may be published or presented for scientific purposes. You will not be named in any reports of the results. Your study or applicable medical and dental records that have your identity in them may be shown to the Institutional Review Board (IRB) (a committee that reviews and approves research studies), or other governing agencies. This is to prove which study procedures you completed and to check the data reported about you. They may also review your medical and dental records for any treatment you received before you agreed to take part in this study. This is to confirm your medical and dental history and that you meet the requirements to be in this study. The study team will keep all information about you confidential as provided by law, but complete confidentiality cannot be guaranteed.

If you leave the study or are removed from the study, the study data collected before you left may still be used along with other data collected as part of the study. For purposes of follow-up studies and if any unexpected events happen, subject identification will be filed at Room 398 of the UMKC School of Dentistry under appropriate security and with access limited to medical and dental research personnel only.

If you sign this consent form you are allowing the study team and these other agencies to see your medical and dental records.

In Case of Injury

The University of Missouri-Kansas City appreciates the participation of people who help it carry out its function of developing knowledge through research. Although it is not the University’s policy to compensate or provide medical treatment for persons who
UMKC AHS IRB #

participate in studies, if you think you have been harmed as a result of participating in this study, please call the investigator, Dr. Adam Reynolds at 816-235-2141.

Contacts for Questions about the Study

You should contact the IRB Administrator of UMKC’s Adult Health Sciences Institutional Review Board at 816-235-5927 if you have any questions, concerns or complaints about your rights as a research subject. You may call the researcher Dr. Adam Reynolds at 816-235-2141 if you have any questions about this study. You may also call him if any problems come up.

Voluntary Participation

Taking part in this research study is voluntary. You are free to stop being in this study at any time and for any reason. If you choose not to be in the study or decide to stop participating, your decision will not affect any care or benefits you are entitled to. The investigators may stop the study or take you out of the study at any time

- if they decide that it is in your best interest to do so,
- if you experience a study-related injury,
- if you need medication/treatment, or
- if you do not comply with the study plan.

They may also remove you from the study for many other administrative or medical reasons. They can do this without your consent.

You have read this Consent Form or it has been read to you. You have been told why this research is being done and what will happen if you take part in the study, including the risks and benefits. You have had the chance to ask questions, and you may ask questions at any time in the future by calling Dr. Adam Reynolds at 816-235-2141. By signing this consent form, you volunteer and consent to take part in this research study. Study staff will give you a copy of this consent form.

Signature (Volunteer Subject) __________________________ Date ______________

Printed Name (Volunteer Subject) __________________________

Signature of person obtaining consent __________________________ Date ______________

Printed Name of Person Obtaining Consent __________________________

Page 6 of 6
Version Date: 6/09/2012 Subject Initials _______
APPENDIX 5

BITING TASKS EMG LOG SHEET
<table>
<thead>
<tr>
<th>Channel #</th>
<th>Location</th>
<th>Amplification</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Left masseter muscle</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Left anterior temporalis muscle</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Right masseter muscle</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Right anterior temporalis muscle</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ground:</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tooth Location</th>
<th>Activity</th>
<th>Tape Start</th>
<th>Tape Stop</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right Molar-Bicuspid</td>
<td>Static Bite #1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right Molar-Bicuspid</td>
<td>Static Bite #2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right Molar-Bicuspid</td>
<td>Static Bite #3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right Molar-Bicuspid</td>
<td>Static Bite #4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right Molar-Bicuspid</td>
<td>Static Bite #5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right Molar-Bicuspid</td>
<td>Static Bite #__</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left Molar-Bicuspid</td>
<td>Static Bite #1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left Molar-Bicuspid</td>
<td>Static Bite #2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left Molar-Bicuspid</td>
<td>Static Bite #3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left Molar-Bicuspid</td>
<td>Static Bite #4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left Molar-Bicuspid</td>
<td>Static Bite #5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left Molar-Bicuspid</td>
<td>Static Bite #__</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right Molar-Bicuspid</td>
<td>5 Bites @ 0.5 Hz</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right Molar-Bicuspid</td>
<td>5 Bites @ 1 Hz</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right Molar-Bicuspid</td>
<td>5 Bites @ 1.5 Hz</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right Molar-Bicuspid</td>
<td>5 Bites @ 2 Hz</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left Molar-Bicuspid</td>
<td>5 Bites @ 0.5 Hz</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left Molar-Bicuspid</td>
<td>5 Bites @ 1 Hz</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left Molar-Bicuspid</td>
<td>5 Bites @ 1.5 Hz</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left Molar-Bicuspid</td>
<td>5 Bites @ 2 Hz</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Additional Notes:
APPENDIX 6

LABORATORY EXERCISE LOG
Voluntary Teeth Clenching During Exercise:
Prevalence and Gender Differences

Subject #: __________
Side of Recording: □ R □ L

LABORATORY LOG

<table>
<thead>
<tr>
<th>Date</th>
<th>Start Time</th>
<th>Stop Time</th>
<th>Location</th>
<th>Tape Time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Weight</th>
<th>Repetitions</th>
<th>Tape time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leg extension-flexion</td>
<td>/12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leg extension-flexion</td>
<td>/12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leg extension-flexion</td>
<td>/12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leg extension-flexion</td>
<td>/12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leg extension-flexion</td>
<td>/12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leg extension-flexion</td>
<td>/12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leg extension-flexion</td>
<td>/12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leg extension-flexion</td>
<td>/12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leg extension-flexion</td>
<td>/12</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Any questions please contact Adam Reynolds at reynolds@umkc.edu or 816-235-2141
APPENDIX 7

DIARY SHEET: EXERCISE LOG
## Exercise Log

<table>
<thead>
<tr>
<th>Date</th>
<th>Start Time</th>
<th>Stop Time</th>
<th>Location</th>
<th>Notes/Card time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Exercise Log Table

- **Exercise**
  - Leg extension-flexion
  - Leg extension-flexion
  - Leg extension-flexion
  - Leg extension-flexion
- **Weight**
  - /12
- **Repetitions**
  - /12

### Notes/Time on Recorder:

- Time on recorder: 

---

Any questions please contact Adam Reynolds at [reynoldsa@umkc.edu](mailto:reynoldsa@umkc.edu) or 816-235-2141
### NAME:
Adam Reynolds

### DATE AND PLACE OF BIRTH
May 25, 1983, Provo, Utah

<table>
<thead>
<tr>
<th>Education</th>
<th>University of Kentucky College of Dentistry</th>
<th>2007 – 2011</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>800 Rose St.  Chandler Medical Center  Lexington, KY 40536</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Class Rank: 2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>GPA: 3.99</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NBDE Part I: 97</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Provo , UT 84602</td>
<td></td>
</tr>
<tr>
<td></td>
<td>GPA: 3.95</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Degree: BS Biology (Magna Cum Laude)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Entrepreneurship/Relevant work experience</th>
<th>Ace</th>
<th>2007 – 2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>I helped a company by developing their DAT prep course. I wrote the 300 page course content and teacher’s manual. I was over all pricing, costs, advertising, content, presentation, and execution of course. We grew from 13 to over 40 students within 1 year. The course is still functioning today.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Entrepreneurship/Relevant work experience</th>
<th>I-Satellite</th>
<th>April-August 2005</th>
</tr>
</thead>
<tbody>
<tr>
<td>Worked successfully on full commission as door to door salesman selling satellite systems</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Entrepreneurship/Relevant work experience</th>
<th>Tutor</th>
<th>2009-2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>University of Kentucky College of Dentistry in various subjects</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Entrepreneurship/Relevant work experience</th>
<th>Lexington Federal Medical Center (Federal Prison)</th>
<th>July 15-August 6 2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Worked as general dentist on inmates</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Business Experience</th>
<th>Shadowing Experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shadowed in many different orthodontic offices during residency</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Business Experience</th>
<th>Business Webinars</th>
</tr>
</thead>
<tbody>
<tr>
<td>Have attended many 1-hour business webinars on own time put on by Ortho 2 during evenings</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Scholarships/Honors/Awards</th>
<th>Pierre Fauchard Academy Award for Academic Excellence</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Recipient-to one graduating senior dental student</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Scholarships/Honors/Awards</th>
<th>American Association of Orthodontics Award</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Recipient- to one graduating senior dental student</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Scholarships/Honors/Awards</th>
<th>AADR Research Fellowship</th>
<th>2010-2011</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Recipient-One of 22 students nationally to receive this fellowship based on submission of a proposed research project (The childhood obesity and skeletal maturation project)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Scholarships/Honors/Awards</th>
<th>ADEA/AADR Academic Career Health Fellowship</th>
<th>2010-2011</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Recipient- One of seven students nationally to receive this fellowship designed to give students experience in teaching, research, and academics.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Scholarships/Honors/Awards</th>
<th>UK Academic Careers Fellowship</th>
<th>2009-2010</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Recipient- Modelled after the ADEA fellowship for students who are interested in academics. One of three dental students to receive this fellowship</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Scholarships/Honors/Awards</th>
<th>Omicron Kappa Upsilon Honorary Dental Society – Outstanding Achievement in the Basic Sciences Award</th>
<th>2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>Award</td>
<td>Recipient</td>
<td>Details</td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>ADA Foundation Dental Student Scholarship</strong></td>
<td>Top overall grade point average in all basic science courses through the first two years of the dental education</td>
<td>2008</td>
</tr>
<tr>
<td><strong>Academic Recruiting Scholarship</strong></td>
<td>1 of 25 students in the nation - minimum GPA of 3.0, nominated by faculty</td>
<td>2007-2011</td>
</tr>
<tr>
<td><strong>UKCD Student Research Fellowship</strong></td>
<td>A financial award based on proposed research. Have received this award twice. (Investigation of Morbidities and Problem-oriented dental attenders)</td>
<td>2008, 2009</td>
</tr>
<tr>
<td><strong>CCTS Mentored Health Sciences Student Award</strong></td>
<td>A financial award based on proposed research. Have received this award three times. (Investigation of Childhood Obesity)</td>
<td>2008, 2009, 2010</td>
</tr>
</tbody>
</table>

**Research**

- **Childhood Obesity’s affect on dental age and skeletal maturation using cervical vertebrae.** (Principle Investigator)
  - Dr. Beeman (Faculty)
  - Received AADR fellowship

- **A patient profile of the Urgent Care Clinic of the University of Kentucky's College of Dentistry.** (Principle Investigator)
  - Dr. Juan Yepes (Faculty), Dr. John Lindroth (Faculty)
  - Published in the Kentucky Medical Journal

- **Investigation of pain and morbidities due to bone harvesting from the iliac crest for cleft palate reconstruction in children.** (PI)
  - Dr. Larry Cunningham (Faculty)
  - Presented a poster at the College Research Day as well as the CCTS Spring Conference

**Volunteer/Extracurricular**

- **Volunteer Youth Basketball Coach and Referee**
  - Hold weekly practices and games for 12-18 year-old boys, also referee in same league
  - Jan-March 2011

- **Mentor and Art Teacher**
  - I mentored and gave art lessons to two boys for an hour each every other Saturday since February of 2009-Jan 2010
  - 2009-2010

- **Various volunteer positions at church**
  - I have served as the executive secretary to the pastor, the Congregation Mission Leader in charge of the proselytizing efforts, a Sunday school teacher and currently as youth minister where I organize activities every Wednesday evening, campouts and teach their Sunday School class
  - 2007 – Present

- **Dean’s Interprofessional Honors Colloquium**
  - 1 of 5 dental students to be invited by Dean to participate in an interprofessional leadership program
  - 2010-2011

- **Project Manager for Serve the City Day**
  - Helped to organize and oversee a project to clean up a creek
  - 2009

- **Mission for the LDS Church**
  - Lived in Brazil, learned Portuguese and talked to people door-to-door for 2 years
  - 2002-2004

**Memberships**

- **AAO**
  - 2011-current

- **OKU**
  - 2011-current

- **ASDA**
  - 2007 – Present
<table>
<thead>
<tr>
<th>Extracurricular/ Hobbies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spending time with my wife and 2 sons</td>
</tr>
<tr>
<td>Louisville marathon- completed my first marathon in April, missed qualifying for Boston by 11min. Finished 60th overall out of 1800</td>
</tr>
<tr>
<td>Sports – Playing soccer weekly, as well as basketball and tennis</td>
</tr>
<tr>
<td>Adventure Race- (did it in November 2009-60 mile race of hiking/biking/canoeing).</td>
</tr>
<tr>
<td>Reading-I have read over 80 books since dental school started for pleasure and leisure.</td>
</tr>
</tbody>
</table>