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  1) The effects of mouthpiece use on cortisol levels during an intensive resistive bout of exercise
The effects of mouthpiece use on gas exchange parameters during steady-state exercise in college-aged men and women

Dena P. Garner, PhD; Wesley D. Dudgeon, PhD; Timothy P. Scheett, PhD; Erica J. McDivitt, MS

ABSTRACT

Background. The authors conducted a study to assess the effects of custom-fitted mouthpieces on gas exchange parameters, including voluntary oxygen consumption (VO2), voluntary oxygen consumption per kilogram of body weight (VO2/kg) and voluntary carbon dioxide production (VCO2).

Methods. Sixteen physically fit college students aged 18 through 21 years performed two 10-minute treadmill runs (6.5 miles per hour, 0 percent grade) for each of three treatment conditions (mouthpiece, no mouthpiece and nose breathing). The authors assigned the conditions randomly for each participant and for each session. They assessed gas exchange parameters by using a metabolic measurement system.

Results. The authors used analysis of variance to compare all variables. They set the significance level at α = .05 and used a Tukey post hoc analysis of treatment means to identify differences between groups. The results showed significant improvements (P < .05) in VO2, VO2/kg and VCO2 in the mouthpiece condition.

Conclusions. The study findings show that use of a custom-fitted mouthpiece resulted in improved specific gas exchange parameters. The authors are pursuing further studies to explain the mechanisms involved in the improved endurance performance exhibited with mouthpiece use.

Clinical Implications. Dental care professionals have an obligation to understand the increasing research evidence in support of mouthpiece use during exercise and athletic activity and to educate their patients.

Key Words. Mouthpiece; mouthguard; gas exchange; exercise; voluntary oxygen consumption; carbon dioxide.
players assumed that their performance would improve, the psychosomatic effect may have caused the reported improvements in muscular strength.

In an effort to measure breathing outcomes with a mouthguard, Francis and Brasher conducted a study composed of 10 participants to assess the physiological effects of mouthguard use during five minutes of low-intensity and high-intensity exercise on a cycle ergometer. They found that during the higher-intensity exercise, those wearing a mouthguard exhibited improvement in expiratory volume, with significant decreases in ventilation (Ve).

Expanding on the work of Francis and Brasher, Garner and McDivitt conducted a study to determine the effects of mouthpiece use during endurance exercise. In their study, 24 participants ran at 75 to 85 percent of maximal heart rate (HR) for 30 minutes on two occasions. The investigators assigned mouthpiece use randomly to enable them to determine the effects of mouthpiece use on lactate levels before, during and immediately after the protocol. Outcomes from this study demonstrated that mouthpiece use had a positive effect on blood lactate levels, which were significantly lower (22.7 percent) at 30 minutes (4.01 millimoles per liter with mouthpiece use versus 4.92 mmol/L with no mouthpiece use). The results of which showed that lactate levels were 18.1 percent lower after a 30-minute run in the mouthpiece condition versus that in the no-mouthpiece condition (4.41 mmol/L versus 5.21 mmol/L, respectively). The study results also showed that mouthpiece use had a significant effect on airway area in 10 participants, as measured by computed axial tomography. Specifically, both width and diameter measurements were 9 percent greater in participants who wore a mouthpiece, with the difference in width measurement being statistically significant.

Because we discovered both anatomical and physiological changes associated with mouthpiece use during exercise, our goal was to elucidate specific mechanisms involved with this phenomenon. Consequently, we conducted an investigation to examine possible gas exchange differences associated with wearing a mouthpiece during steady-state exercise. The novel aspect of our research was the use of a custom-fitted, unobtrusive mouthpiece rather than the bulky mouthguard used in the study by Francis and Brasher.

Therefore, the purpose of this study was to assess the effects of a custom-fitted mandibular mouthpiece on gas exchange parameters in healthy, college-aged participants.

**PARTICIPANTS AND METHODS**

We recruited 16 participants (13 men and three women) aged 18 through 21 years (mean ± standard deviation [SD] age, 21.2 ± 0.75 years) for this study. Participants’ mean (± SD) height and body mass were 176.37 ± 7.3 centimeters and 75.20 ± 12.96 kilograms, respectively. The men were physically active and had participated in university-mandated physical exercise, which consisted of a minimum of two cardiovascular and two resistance exercise sessions per week. The three women were college athletes, of whom two were on the track and field team and one was on the soccer team. All participants reported that they had refrained from physical exercise the day of testing and were free of injury or illness.

The institutional review board of The Citadel, Charleston, S.C., approved the study. All participants provided oral and written consent before participating in the study; we asked them whether they understood all of the study's methods and procedures; and we informed them of their right to drop out of the study at any time.

**Dental impressions.** Before testing, a dentist made impression molds of each participant's lower teeth. We then sent the molds to the Bite Tech laboratory (Danica Beach, Fla.) for fabrication of custom-fitted mandibular mouthpieces (Under Armour Performance Mouthpiece, Under Armour, Baltimore, in cooperation with Bite Tech, Minneapolis) (Figure 1).

**Treadmill runs.** Participants performed two 10-minute treadmill runs for each of the three treatment conditions assessed in this study: mouthpiece, no mouthpiece and nose breathing. We assigned the conditions randomly for each participant and for each session. We tested each condition on a separate day; thus, participants were required to come to the human performance laboratory on three occasions. For both of the 10-minute runs on each day of testing, we

asked participants to run at 6.5 miles per hour with 0 percent grade so that we could analyze respiratory gas levels during steady-state exercise. Before the first run on each test day, participants warmed up by running on the treadmill for five minutes at 5.0 mph and 0 percent grade. They then immediately began a 10-minute run at 6.5 mph and 0 percent grade. Afterward, the participants cooled down with three minutes of walking at 3.0 mph and seven minutes of seated rest.

The second trial of each day was the same as the first trial, minus the five-minute warm-up. We scheduled conditions two to three days apart during which participants were allowed to participate in their normal physical fitness routine, but we did not allow them to exercise on the day of testing.

One of us (E.J.M.) attached a face mask to each participant for each condition and adjusted it until she detected no air leaks. We used a metabolic cart (ParvoMedics, Sandy, Utah) to measure voluntary oxygen consumption (VO₂), voluntary oxygen consumption per kilogram of body mass (VO₂/kg) and voluntary carbon dioxide production (VCO₂). VO₂ is defined as the amount of oxygen in liters that the body uses per minute during aerobic exercise.7 VO₂/kg is the amount of oxygen in milliliters that a person consumes per minute relative to body mass. VCO₂ is the expired byproduct of metabolism that occurs during aerobic exercise and is measured in liters per minute. In addition to VO₂, VO₂/kg and VCO₂, we measured participants’ respiratory rate (RR) (number of breaths per minute), tidal volume (Vₜ) (amount of air inspired and expired per breath), Ve (total volume of inspired and expired air per minute) and HR by using the metabolic cart.

We measured these parameters every five seconds and averaged the measurements for each minute of the 10-minute run for all three conditions. On all test days, we calibrated the metabolic cart according to the manufacturer’s specifications. For the mouthpiece condition (group 1), we asked participants to bite down on the custom-fitted mouthpiece and breathe through their mouths while their noses were clamped with a metal clamp attached to the face mask. For the no-mouthpiece condition (group 2), we asked participants to breathe through their open mouths while their noses were clamped. For the nose-breathing condition (group 3), we taped participants’ mouths shut, which forced them to breathe through their noses.

**Statistical analysis.** One of us (T.P.S.) entered all data into a spreadsheet (Excel, Microsoft, Redmond, Wash.) for data management and exported the data (SigmaStat 3.5, Systat, Point Richmond, Calif.) for statistical analysis. For each of the three conditions, we grouped and averaged measurements for both trials for each participant to yield mean values, which we used for the statistical analysis. We used analysis of variance (ANOVA) to compare variables (HR, RR, Vₜ, Ve, VCO₂, VO₂ and VO₂/kg). We set the significance level at α = .05 and used a Tukey post hoc analysis of treatment means to identify differences between groups. For nonparametric data, we performed a Kruskal-Wallis ANOVA on ranks and used the Dunn method for post hoc analysis. All values are expressed as mean ± SD. We did not perform any ancillary analyses.

**RESULTS**

Data from two of the 16 participants were incomplete; thus, results for this study are based on data from 14 participants. As shown in Figures 2 through 4, VO₂, VO₂/kg and VCO₂ were statistically significantly (P < .05) higher in participants in group 1 than in participants in group 2 and 3 during the entire 10-minute trial, and they were higher in participants in group 2 than in participants in group 3. The results showed no differences (P > .05) in Ve, RR or Vₜ between groups 1 and 2; however, as expected, the results for groups 1 and 2 were statistically significantly different (P < .05) from those for group 3 during the entire
10-minute test (Table 3, page 1046), during minutes 1 through 5 (Table 1) and during minutes 6 through 10 (Table 2). Finally, we found no differences in HR at any time points between all three conditions (Tables 1 through 3).

DISCUSSION

Athletes and others have worn mouthpieces during sports as protective devices against dental injuries and concussions. The American Dental Association’s Council on Access, Prevention and Interprofessional Relations and Council on Scientific Affairs concluded that mouthguards provide a protective effect against hard-tissue or soft-tissue damage in the mouth (such as tooth fractures, lip lacerations and mandibular damage). However, increased use of mouthpieces for performance enhancement is a recent trend in sport and exercise. In a study of mouthpiece use during endurance exercise, Garner and McDvitt reported lower lactate levels in participants who wore a mouthpiece compared with levels in those who did not wear a mouthpiece. Thus, the purpose of this study was to explain the lower lactate levels observed with mouthpiece use during exercise by elucidating the oxygen/carbon dioxide differences with mouthpiece use. Increases in VCO₂ would suggest an improved ability to buffer the hydrogen ion associated with lactate, thereby lowering hydrogen in the blood and subsequent lactate levels.

Respiratory gas exchange. To elucidate the potential mechanisms involved with mouthpiece use during exercise, we assessed the patterns of respiratory gas exchange in a mouthpiece condition, a no-mouthpiece condition and a nose-breathing condition. Previous researchers in the area of airway dynamics have reported differences between nasal and mouth breathing during various intensities of exercise. Specifically, these authors found better gas exchange with mouth breathing than with nasal breathing. Consequently, we expected to find lower V₁, VO₂, VO₂/kg, VCO₂ and RR with nasal breathing because these results have been reported in previous research. Specifically, the results showed significant improvements in VCO₂ and oxygen parameters and no significant differences in Ve when participants wore the mouthpiece versus
when they did not wear the mouthpiece during the entire 10-minute test; during minutes 1 through 5; and during minutes 6 through 10. Thus, the improvements in VCO₂ and oxygen parameters cannot be explained by improved Ve with mouthpiece use.

Francis and Brasher⁴ assessed the physiological effects of mouthguard use during five minutes of low- and high-intensity exercise on a cycle ergometer. For the low-intensity cycling, 10 men cycled at 100 watts and seven women cycled at 75 W; for the high-intensity cycling, men cycled at 150 W and women cycled at 125 W.

In comparing our study results with those of Francis and Brasher,⁴ we should note a difference in VO₂ /kg between the two studies. Francis and Brasher⁴ reported a decreased volume of VO₂ /kg with mouthguard use during high-intensity exercise, whereas we measured a significant increase in VO₂ /kg when participants wore the mouthpiece. However, Francis and Brasher⁴ also noted that participants reported a feeling of restricted airflow with mouthguard use, whereas the participants in our study did not report feeling such a restriction. We believe the differences between our study results and those reported by Francis and Brasher⁴ most likely are attributable to the type of mouthpiece worn in each study. In the study by Francis and Brasher,⁴ participants wore one of three different over-the-counter, unfitted maxillary mouthguards, whereas participants in our study wore a custom-fitted mandibular mouthpiece that did not create any obstruction in breathing.

The results of these studies were similar with regard to Ve, VCO₂ and VO₂ parameters with and without mouthguard or mouthpiece use. During the high-intensity protocol, Francis and Brasher⁴ found an improvement in expiratory volume, with decreases in Ve with mouthguard use; these results are similar to those of our study. Francis and Brasher⁴ suggested that when participants wore a mouthguard, they

### TABLE 1

**Data from minutes 1 though 5 of steady-state exercise.**

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>MEAN (± STANDARD DEVIATION) MEASURE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Group 1 (Mouthpiece)</td>
</tr>
<tr>
<td>VCO₂* (L/Minute)</td>
<td>2.00 ± 0.55⁴</td>
</tr>
<tr>
<td>VO₂⁺ (L/Minute)</td>
<td>2.21 ± 0.64⁴</td>
</tr>
<tr>
<td>VO₂/kg‡ (mL*/kg/Minute)</td>
<td>29.1 ± 6.7³</td>
</tr>
<tr>
<td>Ventilation (L/Minute)</td>
<td>49.7 ± 10.8²</td>
</tr>
<tr>
<td>Respiratory Rate (Breaths/Minute)</td>
<td>31 ± 7⁰</td>
</tr>
<tr>
<td>Tidal Volume (L)</td>
<td>2.10 ± 0.61¹</td>
</tr>
<tr>
<td>Heart Rate (Beats/Minute)</td>
<td>157 ± 15</td>
</tr>
</tbody>
</table>

* VCO₂: Voluntary carbon dioxide production.  
† L: Liters.  
‡ Statistically significant difference (P < .05) from group 3 (nose breathing only).  
§ Statistically significant difference (P < .05) from group 1 (mouthpiece).  
¶ VO₂: Voluntary oxygen consumption.  
# VO₂/kg: Voluntary oxygen consumption per kilogram of body weight.  
** mL: Milliliters.

### TABLE 2

**Data from minutes 6 through 10 of steady-state exercise.**

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>MEAN (± STANDARD DEVIATION) MEASURE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Group 1 (Mouthpiece)</td>
</tr>
<tr>
<td>VCO₂* (L/Minute)</td>
<td>2.29 ± 0.59⁴</td>
</tr>
<tr>
<td>VO₂⁺ (L/Minute)</td>
<td>2.43 ± 0.73¹</td>
</tr>
<tr>
<td>VO₂/kg‡ (mL*/kg/Minute)</td>
<td>31.9 ± 7.5³</td>
</tr>
<tr>
<td>Ventilation (L/Minute)</td>
<td>56.9 ± 11.5⁴</td>
</tr>
<tr>
<td>Respiratory Rate (Breaths/Minute)</td>
<td>33 ± 7⁰</td>
</tr>
<tr>
<td>Tidal Volume (L)</td>
<td>2.28 ± 0.63³</td>
</tr>
<tr>
<td>Heart Rate (Beats/Minute)</td>
<td>169 ± 16</td>
</tr>
</tbody>
</table>

* VCO₂: Voluntary carbon dioxide production.  
† L: Liters.  
‡ Statistically significant difference (P < .05) from group 3 (nose breathing only).  
§ Statistically significant difference (P < .05) from group 1 (mouthpiece).  
¶ VO₂: Voluntary oxygen consumption.  
# VO₂/kg: Voluntary oxygen consumption per kilogram of body weight.  
** mL: Milliliters.
TABLE 3

Data from minutes 1 through 10 of steady-state exercise.

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>MEAN (± STANDARD DEVIATION) MEASURE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Group 1 (Mouthpiece)</td>
</tr>
<tr>
<td>Ventilation (L*/Minute)</td>
<td>53.4 ± 11.0†</td>
</tr>
<tr>
<td>Respiratory Rate (Breaths/Minute)</td>
<td>32 ± 7†</td>
</tr>
<tr>
<td>Tidal Volume (L)</td>
<td>2.16 ± 0.62†</td>
</tr>
<tr>
<td>Heart Rate (Beats/Minute)</td>
<td>163 ± 15</td>
</tr>
</tbody>
</table>

* L: Liters.
† Statistically significant difference (P < .05) from group 3 (nose breathing only).
‡ Statistically significant difference (P < .05) from group 1 (mouthpiece).

might have been using a type of breathing called “pursed lip breathing,” which they defined as pursing one’s lips and breathing out deeply. This type of breathing has been linked to improved respiratory measures such as reduced breathing rates and increased Vt in people with respiratory disorders, but it has not been studied extensively in a healthy population.13-15

We propose that a similar, but more plausible, mechanism may have occurred when participants wore the custom-fitted mandibular mouthpiece. We asked participants to bite down on the mouthpiece, which has two wedges (one on either side of the mouthpiece) that create an opening between the maxillary and mandibular teeth (Figure 1). In addition, according to the product description,16 this mouthpiece shifts the mandible down and into a more forward position, which Garner and McDivitt6 reported resulted in increased airway openings.

Genioglossus muscle. We also propose a contribution from a neuromuscular response that occurs when participants bite down on the mouthpiece and breathe through the mouth. What might have occurred, and which some participants reported anecdotally, is that when a participant bit down on the mouthpiece and breathed during steady-state exercise, the tongue moved forward, resulting in a contraction of the genioglossus muscle. The results of extensive research regarding the genioglossus muscle show that contraction of this muscle leads to relaxation of the pharyngeal airway, thereby improving airway dynamics.17-22

Remmers23 reported that the genioglossus may be associated with a reflex that leads to the dilation of the pharyngeal area, thereby aiding in respiration in both humans and animals. Preliminary research in our laboratory has shown differences in electromyographic activity of the genioglossus when one wears a mouthpiece and affects the genioglossus.

Cortisol and epinephrine. We also reported that the use of a custom-fitted mandibular mouthpiece is associated with a decrease in the stress hormone cortisol after high-intensity exercise.24 This finding is consistent with the findings of Hori and colleagues,25 who reported a decrease in corticotrophin-releasing factor levels (stress-induced response of the hypothalamic-pituitary-adrenal axis and a precursor to corticosterone release, the rat equivalent to cortisol in humans) in rats that were allowed to bite down on a wooden stick while experiencing a stressor. If biting down on the mouthpiece results in a decrease in cortisol levels, it stands to reason that it also would affect other stress-related hormones, namely epinephrine. Epinephrine is released quickly in response to a stressor, and one of its many functions is to stimulate the glycolytic process (that is, breaking down of glucose to provide energy) to increase the rate of energy production. Two of the key byproducts of glycolysis are lactate and CO₂. We have shown that use of the custom-fitted mouthpiece decreases lactate production and increases VCO₂ production. We now believe that a decrease in epinephrine release may be the reason for these observed changes; however, more research is needed.

Thus, if an anatomical and neuromuscular improvement in airway dynamics occurs along with a diminished stress response (that is, lower cortisol and epinephrine levels) with mouthpiece use during steady-state exercise, this could explain the improved oxygen and carbon dioxide kinetics, as well as the improvements in lactate production, that the results of our study show.

CONCLUSION

The results of this study show improved airway dynamics in participants who wore a custom-fitted mandibular mouthpiece during steady-state exercise when they breath through the mouth versus when one does not wear a mouthpiece and breathes through the mouth. Thus, the improved airway dynamics we found in our study may be explained in part by anatomical and neuromuscular changes that occur during exercise with custom-fitted mouthpiece use as the mouthpiece
state exercise. The improvements in gas exchange and Ve observed with mouthpiece use may explain the physiological outcomes of improved lactate levels during endurance running, as reported previously. Specifically, improved VCO2 exhalation, as observed with mouthpiece use throughout the 10-minute treadmill protocol, leads to improved buffering of hydrogen ion levels, which, in turn, decreases lactate levels during endurance exercise. This explanation is consistent with the differences in VCO2 observed in this study (21.0 percent higher with mouthpiece use than without mouthpiece use), as well as with differences in lactate levels observed in a previous study (22.7 percent lower with mouthpiece use than that without mouthpiece use). In addition, the improvement in oxygen kinetics during the beginning of the exercise protocol (that is, minutes 1 through 5), as demonstrated by the significantly higher VO2 and VO2/kg levels in participants in group 1 (the mouthpiece condition), also may affect initial oxygen deficit (defined as the amount of oxygen needed for exercise and actual oxygen consumption). At the beginning of exercise, there is a lag of approximately one to two minutes during which oxygen is transported to the skeletal muscles. Therefore, one theory of how the mouthpiece may affect lactate levels is by decreasing the time for oxygen to reach the muscle being exercised, thereby decreasing fatigue during endurance exercise. Further research is needed to fully elucidate the physiological mechanisms involved in improved performance when one wears a custom-fitted mouthpiece.

**Disclosure.** Dr. Garner and Ms. McDivitt received honoraria from Bite Tech, Minneapolis.

The authors thank Michael Engel, DDS (Charleston, S.C.), for making the models of the mouthpiece and Bite Tech Laboratories (Dania Beach, Fla.) for supplying the custom-fitted mouthpieces to each participant.


Limited data suggests mouthpieces may enhance performance. Garabed (1981) cited that runners who wore a mouthpiece reported that they were stronger, less prone to injury and could recover quickly after a running session. Francis and Basher (1991) found that use of a mouthpiece while exercising could increase ventilation, and thereby improve performance. Previous research in our laboratory has suggested that a mouthpiece dampens excessive cortisol during exercise. This finding is similar to what Hori, Yuyama and Tamura (2004) found in corticotrophin-releasing hormone when restrained rats were allowed to bite on a stick.

**PURPOSE:** To investigate the possible correlation between cortisol levels when wearing and not wearing a mouthpiece, the wEdge (Bite-Tech Corp), during two separate exercise protocols.

**METHODS:** Subjects, age 18-24 years old, were asked to complete the same exercise protocol on two separate occasions, 1-2 days apart, with testing taking place at approximately the same time each day. Subjects wore a mouthpiece during 1 testing procedure and repeated the same testing procedure on another day without the use of the mouthpiece. Subjects provided a passive drool sample before and after each exercise bout in order to test salivary cortisol levels. Twenty one (n=21) subjects were asked to complete an exercise protocol on a stationary bike ergometer for 10 minutes at 85%-90% heart rate maximum. A 5 minute warm up was used to reach 90% heart rate maximum. The kilopond level used to achieve this was recorded and used for the second trial.

**RESULTS:** The use of the mouthpiece elicited lower cortisol levels for 11 of the 21 subjects with the remaining subjects seeing no difference in cortisol levels with use of the mouthpiece. In regards to overall mean cortisol levels there was no significant difference post exercise between wearing and not wearing the mouthpiece.

**CONCLUSION:** Possibly due to small numbers in this study, we saw no overall significant differences in cortisol levels with use of the mouthpiece. However, the fact that over half of the subjects saw a lowering effect of cortisol with use of the mouthpiece warrants more research to determine if a mouthpiece has any physiological effects on cortisol levels during exercise.
The Effects Of Mouthpiece Use During Endurance Exercise On Lactate And Cortisol Levels: 2416: Board #61 May 29 9:00 AM - 10:30 AM
Garne, Dena P.; McDivitt, Erica

doi: 10.1249/01.MSS.0000355581.74244.c0

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(No relationships reported)

Protective mouthpieces have been used in a variety of sports to decrease the risk of orofacial injury. However, there is limited research on the physiological effects of mouthpiece use during exercise.

PURPOSE: To investigate the possible effect on lactate and cortisol levels when wearing and not wearing a mouthpiece, the wEdge (Bite-Tech Corp).

METHODS: Subjects (n=24), age 18-24, ran at 75 -85% of their maximal heart rate for 30 minutes on 2 separate trials, being randomly assigned the use of the mouthpiece on 1 of the 2 trials. Lactate levels were assessed before, 15 and 30 minutes during, and post 10 minutes exercise. Subjects provided a passive drool sample before and after each exercise bout to assess salivary cortisol levels.

RESULTS: Lactate data indicated a significant difference between wearing and not wearing the mouthpiece at 30 minutes exercise (p-value = 0.024). Mean lactate levels at 30 minutes with the mouthpiece was 4.01 mmol/L versus 4.92 mmol/L without the mouthpiece. Mean cortisol levels showed no significant difference between wearing and not wearing the mouthpiece (p-value= 0.111). However, there was a trend towards lower mean cortisol levels with use of the mouthpiece (0.1484 ug/dL) versus no mouthpiece (0.2201 ug/dL).

CONCLUSION: This study suggests that use of a mouthpiece may reduce lactate and cortisol increases and thereby improve exercise performance.

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SOUTHEAST REGIONAL CHAPTER

February 12-14, 2009
37th Annual Meeting
Wynfrey Hotel
Birmingham, Alabama

Jointly Sponsored by: The American College of Sports Medicine (ACSM)
and the Southeast Chapter of the American College of Sports Medicine (SEACSM)
The Effect of Mouthpiece Use on Muscular Endurance


Dept. of Health, Exercise and Sport Science, The Citadel, Charleston, SC 29409

There have been many studies on how to improve muscular strength during exercise. Some research suggests that the use of a mouthpiece will increase muscular strength and endurance (Alexander, 1999 and Smith, 1982).

**Purpose:** To test if the influence of wearing a mouthpiece can improve muscular endurance.

**Methods:** Participants took part in a 2 day experiment. On the first day, participants performed their maximum amount of repetitions at 75% of their 1 repetition maximum of the preacher curl exercise and bench press without a mouthpiece. On day 2, participants performed the same exercise with a mouthpiece (The Edge, Bite Tech Corp.). This mouthpiece was specifically fitted to each subject with a boil and bite technique.

**Results:** The use of the Bite-Tech mouthpiece significantly increased muscular endurance in both males and females. The results were run using a dependent t-test using SPSS. Our dependent t-test results had a p-value of .03 for bench press (10% improvement) and a p-value of .004 for preacher curl (17% improvement).

**Conclusion:** The results of this study show that the use of a mouthpiece improves one’s muscular endurance, specifically in the bench press and the preacher curl exercises.

AMERICAN COLLEGE
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SOUTHEAST REGIONAL CHAPTER

February 3-5, 2011
39th Annual Meeting
Hyatt Regency Hotel
Greenville, South Carolina

Jointly Sponsored by: The American College of Sports Medicine (ACSM)
and the Southeast Chapter of the American College of Sports Medicine (SEACSM)
MOUTHPIECE USE INCREASES IN VO2, VCO2 AND VO2/KG DURING STEADY STATE RUNNING

D.P. Garner¹, T.P. Scheett², W.D. Dudgeon¹, E.J. McDivitt¹, and M.A. Rodriguez¹.  (1)Dept of Health, Exercise, and Sport Science, The Citadel, (2) Dept. of Health and Human Performance, Charleston, SC 29409

Emerging research suggests that performance mouthpieces may benefit athletic performance, though the mechanism(s) of action are yet unknown.

Purpose:
The study looked at the effect of a custom fit mouthpiece (MP) on gas exchange during steady state exercise in 13 subjects who completed two 10 minute trials on 2 separate days.

Methods:
The treadmill speed was set at 6.0 mph with 0% elevation and gas exchange parameters were analyzed (ParvoMedics) during each trial. Each subject was instructed to breathe through their mouths during each condition (with and without the MP), with the MP group biting down and breathing while the no MP group breathed through an open mouth. Gas exchange parameters were measured with a mask that fit snugly over the subject’s mouth and nasal area, with the nose being clamped during all trials.

Results:
There was a significant difference in voluntary oxygen consumption per kilogram of body weight (VO2/kg), carbon dioxide (VCO2), and oxygen (VO2) in all conditions with the MP condition eliciting higher VO2/kg, VCO2 and VO2 versus no MP. VO2/kg with a MP was 31.37 ml/kg/min while no MP condition was 23.95 ml/kg/min. VCO2 with the MP was 2.23 l/min while the no MP condition was 1.87 l/min. Finally, VO2 was 2.38 l/min with MP and 1.84 l/min with no MP.

Conclusion:
These results showed improvements in gas exchange with the MP versus no MP and suggests that MP use during endurance exercise may improve performance by improved CO2 removal.

Supported by a grant from Bite Tech Corporation
Mouthpieces have been used for a variety of contact sports to prevent oral-facial injury. In a review of dental trauma literature, Glendor noted that participation in sports is the greatest cause of dental injuries. To minimize injury associated with contact sport participation, the American Dental Association (ADA) recommends the use of mouthguards to protect against dental trauma during contact sports. In addition to the recommendation of the ADA, such sport-governing bodies as the National Alliance of Football Rules Committee have mandated mouthguards for use in high school football in the United States. The 2008-2009 National Athletic Association (NCAA) Sports Medicine Handbook mandates mouthguards for athletes involved with football, field hockey, lacrosse, and ice hockey in order to minimize dental trauma during these sports.

While there is compelling research to support the use of mouthguards to protect against oral-facial injuries during contact sports, there is also research to suggest that mouthpieces may enhance performance. Smith noted that professional football players exhibited greater arm strength with properly fitted mouthguards that resulted in changes in bite patterns. Smith also noted that those players with the most extreme overbite corrected with a mouthguard experienced the greatest increase in strength. Specifically, he observed that with a properly adjusted mouthguard, 66% of the players exhibited significant strength improvements on the isometric deltoid press. He stated that the increase in strength with a properly fitted mouthguard was because of decreased pressure in the temporomandibular joint (TMJ).

Not only has improvement in strength been noted, but Garabee described improvement in 7 runners’ endurance performance with the use of mouthpieces.
and recovery with use of a mouthpiece to promote proper occlusion. He observed that when runners wore a wax bite mouthpiece, there was an increase in mileage: 64 to 100 miles per week in one runner, and 50 to 80-100 miles per week in another. He also noted quicker recovery times and decreased perceived exertion with use of the mouthpiece vs without the mouthpiece. Garabee hypothesized that this improvement was because of decreased stress with mouthpiece use that reduced clenching and grinding of teeth during exercise.

As the research evolved, the possible reasons for improvements in performance were elucidated by Francis and Brasher. In a study of 10 men and 7 women, they found that wearing a mouthpiece during 20 minutes of high intensity cycling resulted in improvements in ventilation (average of 43.13 l/min with mouthpiece vs 50.98 l/min without mouthpiece). They noted that this improvement may be from pursed lips breathing which results in greater oxygen saturation. Ugade and colleagues confirmed that pursed lips breathing resulted in increased oxygen saturation in myotonic muscular dystrophy patients, while Tiep stated that such breathing results in increased tidal volume, carbon dioxide removal, and oxygen saturation.

Drawing from the research by Frances and Brasher, the possible reasons for improvements in endurance performance while wearing a mouthpiece provide insight into the physiological mechanisms that may be occurring. In order to first understand if there were improvements in performance, the authors’ laboratory conducted a series of pilot studies primarily to determine if lactate levels were affected by the use of a mouthpiece. If, as Frances and Brasher suggested, there was improvement in ventilation (ie, increased oxygen saturation and removal of carbon dioxide), then there could consequently be an improvement in lactate levels. The authors found that with 24 participants, there was improvement in lactate levels after 30 minutes of running on a treadmill at 85% of maximal heart rate (4.01 mmol/L with mouthpiece vs 4.92 mmol/L without mouthpiece). With this data suggesting a physiological improvement when a mouthpiece is used, the next step was to clarify further the possible reasons for this improvement. Trenouth and Timms found a positive association between the oropharyngeal airway opening and mandibular length, with a narrower opening associated with a shorter mandibular length. They cited previous research that suggested repositioning the mandible in an anterior position, thereby opening airways and promoting respiratory gas exchange to and from the lungs. In the literature associated with sleep apnea (where airway openings are diminished during sleep) and mouthpieces, it can be noted that there is significant improvement in airway openings for patients wearing a mouthpiece (a device that fits like a retainer and forces the lower teeth to relax in a forward position). Kyung and colleagues advanced the mandible forward with an oral appliance in 12 sleep apnea patients and found a reduction of the apnea-hypopnea index from 44.9 (without appliance) to 10.9 (with appliance). Gale and colleagues found a significant improvement in mean airway opening with an anterior mandibular device while patients were supine in a conscious state. Specifically, Gale et al found that in 32 participants, the mean minimal pharyngeal cross-sectional area was increased 28 mm² with the mouthpiece vs without the mouthpiece. Gao and colleagues stated that for their participants, the mandibular advancement was 7.5% with a mouthpiece. They specifically found a significant opening of the oropharynx (P = .0258) and velopharynx areas (P = .006). Zhao et al also found that the velopharynx opening increased significantly with an adjustable mandibular custom mouthpiece, from 3.27 mm² at 0 mm, to 8.45 mm² at 2 mm, 17.73 mm² at 4 mm, 24.45 mm² at 6 mm, and 35.82 mm² at 8 mm. This research suggests that the positioning of the mouthpiece will impact the degree of airway opening, with greater movement of mandible in a forward position resulting in a greater opening of the velopharynx. With the findings of previous studies as well as those in the authors’ laboratory, the hypothesis

THIS PRESENT STUDY SUGGESTS MECHANISMS BY WHICH LACTATE PRODUCTION MAY BE IMPROVED WITH INCREASED AIRWAY OPENINGS, THEREBY IMPROVING OXYGEN KINETICS SUCH AS LOWERED OXYGEN DEFICIT AND/OR IMPROVED BREATHING WORK RATES.
of this study is that there will be increased airway opening and a decrease in lactate levels with the use of a mouthpiece.

**METHODS**

For this pilot study the authors recruited 10 participants to determine if there were differences in airway openings with the use of a mouthpiece and if there were differences in lactate levels after 30 minutes of running. The mouthpiece used was a boil and bite upper mouthpiece which had a greater bite opening distal vs proximal (EDGE, Bite Tech Inc, Minneapolis, MN). Participants were 18–21 years old, male, and from The Citadel. Each participant completed a computed tomography scan (i-CAT 3D Dental Imaging System, Imaging Sciences International, Hatfield, PA) with and without a mouthpiece, and the mean oropharynx area was measured in each. Participants then completed two 30 minute runs on the treadmill at 75%–85% of their maximum heart rate, and lactate levels were assessed at 0, 15, and 30 minutes of the run (Accutrend Lactate Analyzer, Sports Resource Group, Inc, Minneapolis, MN). Participants were randomly assigned a mouthpiece during each running trial and were required to refrain from exercising the day before and the day of testing. If participants failed to cooperate, they were asked to return on a subsequent day when compliance was met.

**RESULTS**

The results of this study displayed a significant increase in mean width value of the oropharynx at 28.27 mm with the mouthpiece vs 25.93 mm without the mouthpiece ($P = .029$) (Figure 1). In addition, the mean value of the diameter was increased with a mouthpiece vs without a mouthpiece (12.17 mm vs 11.21 mm, $P = .096$) (Figure 1). As previous studies had suggested, the difference in lactate levels from pre- to post-exercise was lowered with the mouthpiece vs without a mouthpiece, though not at the level of significance (1.86 mmol/L with mouthpiece vs 2.72 mmol/L without mouthpiece) (Figure 2).

**DISCUSSION**

There is a plethora of research to suggest that the upper airway of patients with sleep apnea is improved with a custom-fit oral device, due specifically to the forward movement of the mandible. Ryan and colleagues found improvement in the cross-sectional area of the velopharynx and in the apnea index with the use of a mandibular advancement oral appliance. Kyung et al also found reduced apnea-hypopnea indices, reducing the average index from 44.9 to 10.9 with an oral appliance.

Research continues to elucidate the degree of forward movement which would be most beneficial. In the research by Zhao and colleagues there was a range of improvement in the airway opening for participants: as the mandible was moved to a more forward position, the opening of the airway increased. It should also be noted that a specific mouthpiece was used for this present study. This particular mouthpiece offered minimal obstruction for the participants as they ran, yet was also designed to bring the mandible to a forward position. The mouthpiece was easy to use and mold to participants, who noticed no impairment in their breathing patterns during use. Further research to understand how different mouthpieces could affect the airway openings is warranted. Such studies should focus on measuring the movement of the mandible with the use of a mouthpiece and how this may affect airway openings in healthy participants.

The results of the study suggest that the use of a mouthpiece increases airway openings in these healthy participants and
Research Update—Lactate Levels

that the use of a mouthpiece while exercising may improve lactate levels. While previous studies with sleep apnea populations indicated improvements in airway openings with the use of a mouthpiece, there were limited data on a younger, healthy population (age 21 +/- 1.1 years). This study, however, is similar in a study by Gao and colleagues\textsuperscript{16} which took magnetic images of 14 healthy Japanese men (age 27.7 +/- 1.9 years). Gao et al\textsuperscript{16} saw improvements in airway opening with a custom-fit oral device that was specifically designed to move the mandible in a more forward position. Their study found significant improvements in the velopharynx ($P = .0006$) and the oropharynx ($P = .0258$), while the current study noted a significant improvement in the oropharynx width ($P = .029$).

Because of the financial costs of obtaining 2 CT scans for each participant, this study was limited in the number of participants. In addition, this was designed as a pilot study to determine: 1) if there were changes in airway openings with a mouthpiece in healthy participants; and 2) if this could translate into lowered lactate levels. The results suggest there may be a link, which could be one possible physiological explanation for performance improvement with a mouthpiece.

It may be surmised that the lack of significant differences in lactate levels in this study may be because of the low number of subjects, even though the trend was lower lactate levels with the mouthpiece vs no mouthpiece. As the authors’ previous study suggested ($N = 24$), lactate levels were significantly lower with a mouthpiece vs without a mouthpiece after 30 minutes of running on a treadmill (4.01 mmol/L mouthpiece vs 4.92 mmol/L no mouthpiece) (Figure 3).

Research has consistently noted the correlation between exercise fatigue and higher lactate levels. As one increases exercise intensity, the glycolytic pathway is highly utilized to meet energy needs. The end product of this pathway is the production of lactic acid. Lactic acid is broken down into lactate and hydrogen ions, and it is this increase of hydrogen ions that is negatively associated with metabolic processes, leading to fatigue.\textsuperscript{19-20} Thus, any mechanism which elicits lowered hydrogen levels resulting from lactic acid should increase an athlete’s time to fatigue. For example, if the pathways used during exercise rely more on oxygen, then lactate levels will be lowered. Yet understanding this link between lowered lactate levels and increased airway openings is a complex issue needing further investigation.\textsuperscript{12}

Previous studies have noted that an improvement in breathing work rates leads to improved exercise time because of reduced oxygen uptake and ventilation.\textsuperscript{21-22} Specifically, if breathing mechanics are improved, then there is a decreased need for oxygen and blood flow by the respiratory muscles which typically require approximately 10% of the oxygen needs during strenuous exercise. Less blood flow to the respiratory muscles suggests an increase of blood flow to the exercising skeletal muscles, which would prolong time to fatigue. Specifically, Harms and colleagues found that when respiratory muscle work was decreased (via a proportional-assist ventilator), time to exercise exhaustion was increased in 76% of the trials by an average of 1.3 minutes (+/-0.4 minutes).\textsuperscript{22}

Improvement in respiratory muscle function may not be the only mechanism that occurs during mouthpiece use. An interesting study by Kilding and colleagues\textsuperscript{23} examined response time of oxygen kinetics in endurance runners ($N = 36$) to understand its possible effect on a 5 kilometer time trial. An important finding from their study was that a faster phase II oxygen uptake kinetic response at the onset of moderate intensity exercise resulted in faster 5 kilometer performance. Thus, they concluded that those runners who had a shorter oxygen deficit at the onset of exercise (as indicated by shortened phase II response) could increase time to exhaustion, as indicated by the better 5 kilometer performance. Kilding cited previous work by Casaburi and colleagues\textsuperscript{24} stating a decrease in oxygen deficit at the onset of exercise could result in decreased lactate production, which could potentially improve endurance performance. This present study suggests mechanisms by which lactate production may be improved with increased airway openings, thereby improving oxygen kinetics such as lowered oxygen deficit and/or improved breathing work rates.
CONCLUSION
This study found that the use of a mouthpiece significantly improves airway openings in participants as compared with these same participants who do not wear the mouthpiece. In addition, lactate levels are improved when participants wear the mouthpiece vs when they do not wear the mouthpiece. One explanation for the decrease in lactate levels may be an improvement in oxygen kinetics at the onset of exercise or improvement in breathing work rates which may be prompted by enhanced airway openings with the use of a mouthpiece. Previous research in the field of mouthpiece use and its effect on human performance suggests that mouthpieces improve performance. However, these studies have been unable to elucidate the possible physiological mechanisms for this improvement. This research is novel in the area of human movement because it suggests a possible physiological explanation for the improvement in performance as noted by athletes. Further studies should focus on the reasons for these improvements, noting differences in jaw morphology and airway dynamics for individuals who may benefit from a mouthpiece during exercise and sport.

DISCLOSURE
Dr. Garner has received an honorarium from Bite Tech Inc.

REFERENCES
Effects of Mouthpiece Use on Auditory and Visual Reaction Time in College Males and Females

Dena P. Garner, PhD; and Jenni Miskimin, MS

Abstract: Studies in exercise science have suggested that the use of a mouthpiece can improve performance, and these improvements may be linked to an enhancement in temporomandibular joint (TMJ) positioning. Studies have suggested that by improving TMJ positioning, there is improved blood flow in the area of the TMJ. Changes in TMJ positioning may be improved with an oral device. The purpose of this study was to determine if there were improvements in auditory and visual reaction time with the use of a boil and bite mouthpiece. Using a BIOPAC system, study participants (N = 34) were asked to respond to an auditory signal during 40 trials. In the visual reaction time test, participants (N = 13) were assessed on how quickly they responded to a computer cue for a total of 30 trials. Auditory results showed a significant improvement with the use of a mouthpiece (241.44 ms) vs without a mouthpiece (249.94 ms). Visual results showed that participants performed slightly better with the mouthpiece (285.55 ms) vs without the mouthpiece (287.55 ms). These findings suggest that the use of mouthpiece positively affects visual and auditory reaction time, which is a vital aspect to optimal sport and exercise performance. Future studies should continue to shed light on possible reasons for the improvements in auditory and visual reaction time with the use of a mouthpiece. In addition, future studies should further illuminate what, if any, connection these improvements have with enhanced TMJ positioning.

Reaction time is the period that occurs between a stimulus and the initiation of muscle response and can be assessed as simple reaction time, choice reaction time, and discriminate reaction time. Signals to any sensory system in a variety of populations can be ascertained in any of the above situations. For example, Borysiuk evaluated reaction and movement time with tactile, acoustic, and visual stimuli in advanced and novice fencers. He found that the advanced fencers had a significantly improved reaction time with the visual (P < .057) and the tactile (P < .029) stimuli, with no significant differences in the acoustic stimuli between novice and advanced fencers. However, the mean reaction and movement times with all three stimuli were lower in experienced fencers vs the beginners. Borysiuk found fencing training improved reaction times in people with advanced fencing skills, thereby explaining improved performance.

Many studies in exercise science have suggested that the use of a mouthpiece can improve performance, which may be related to an enhancement in temporomandibular joint positioning. Without proper temporomandibular joint positioning, nerves and arteries within the joint may become occluded, resulting in strain in nearby tissues, thereby reducing blood flow. By neutralizing the temporomandibular joint with a mouthpiece, patients have reported to their dentists reduced pain in the jaw, head, and neck areas, along with increased physical strength. This improvement in strength may be linked to improved blood flow and oxygen kinetics associated with reduced stress in the temporomandibular joint, thereby producing improved blood flow to the exercising skeletal muscles.

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Several studies have shown that mouthpieces result in improved strength and endurance. Specifically, Fuchs found the isometric strength of the upper and lower body in 40 females was improved when participants wore a wax bite between the upper and lower teeth, resulting in a 3-mm vertical dimension. The greatest improvement with the wax bite was in isometric strength, with an increase of 8% in the left arm, 4.5% in the right arm, 6.3% in the left foot, and 11% in the left foot. Alexander confirmed this finding when she tested the EDGE mouthpiece (Bite Tech Inc, Minneapolis, MN) in 61 male and female participants and found 74% had improved grip strength when using the mouthpiece.

The authors found that muscular endurance improved significantly with the use of the mouthpiece vs not using one. Specifically, they determined mean bench press repetitions increased 11% while preacher curl repetitions increased 17% when participants used the mouthpiece compared with non-use ($P = .03$ bench press; $P = .004$ preacher curl). Thus, based on the indicative data that a mouthpiece improves exercise outcomes, this study’s goal was to further elucidate the possible benefits of wearing a mouthpiece in regard to athletic performance, specifically improved reaction time.

**METHODS**

The research involved assessments of visual and auditory reaction times. There were 34 participants for the auditory arm and 13 for the visual. Ages ranged from 18 years to 21 years, with participants recruited from The Citadel’s student body. The study was approved by the school’s internal review board, and all participants signed consent forms.

BIOPAC Systems (BIOPAC Systems Inc, Goleta, CA) equipment was used to gauge auditory reaction time. The BSL-SS10L push button hand switch (BIOPAC Systems Inc), BSL-OUT1 headphones (BIOPAC Systems Inc), and Windows 95/98/NT 4.0/2000 (Microsoft Corp, Redmond, WA) were employed. Each participant sat in a relaxed position with closed eyes and held the hand switch with the dominant hand, with the thumb in position to press the button. They were instructed to press this button when the headphones emitted a sound. Everyone underwent four segments, with 10 trials each. Segments one and two included a stimulus at pseudo-random intervals (1 to 10 seconds) while segments three and four used a stimulus at fixed intervals (every 4 seconds).

The visual test used a MS-DOS-based Motor Learning Activity Software System developed at Texas A&M University. This system uses Hick’s Law, which states that reaction time increases as a function of a binary logarithm ($\log_2 n$), in which “$n$” is the number of equally likely possibilities. Specifically, the participant was asked to place his or her fingers on letters on a computer keyboard that corresponded to the same letters that were displayed on the computer screen. Above each letter on the computer screen were four large circles. The program proceeded through three sets of 10 trials. During the first trial, a line would appear over one circle with the letter beneath it. After a pseudo-random amount of time (1-10 seconds), the circle became white, at which point participants were to respond as quickly as possible by striking the corresponding letter on the keyboard. During the second set of 10 trials, the line would appear over two circles,

**BY NEUTRALIZING THE TEMPOROMANDIBULAR JOINT WITH A MOUTHPIECE, PATIENTS HAVE REPORTED TO THEIR DENTISTS REDUCED PAIN IN THE JAW, HEAD, AND NECK AREAS, ALONG WITH INCREASED PHYSICAL STRENGTH.**

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but only one circle became white, and participants were to strike as quickly as possible the corresponding letter on the keyboard. For the final set of 10 trials, a line appeared over all four circles, one circle turned white after a pseudo-random amount of time, and participants were to respond as quickly as possible by striking the corresponding key on the keyboard. Participants completed two sets of the outlined Hick’s Law test for a total of 60 trials.

For both arms of the study, participants completed the trials with and without a mouthpiece (the EDGE boil and bite). This mouthpiece was designed specifically to create a greater bite opening distal vs proximal in the mouth. Assignment of the mouthpiece was random, and participants were not told if any effect, either positive or negative, would result from its use.

RESULTS
Results of the auditory test showed participants (N = 34) performed significantly better with the mouthpiece than without (P = .004). The mean values with the mouthpiece were 241.44 ms vs 249.94 ms without the mouthpiece (Figure 1). Sixty percent were more successful with the mouthpiece. For the visual test, participants (N = 13) performed slightly better with the mouthpiece (P = .681). The mean values with the mouthpiece were 285.55 ms vs 287.55 ms without the mouthpiece. Sixty-two percent of participants were more successful with the mouthpiece (Figure 2).

DISCUSSION
This study indicates the use of a mouthpiece results in improvements in auditory and visual reaction times. The significance found in the auditory assessment suggests that the outcomes were not coincidental. The lack of significance in the visual test may be because of the small number of participants. If more participants were recruited, a trend of a lowered visual reaction time with the mouthpiece may be established.

The question, however, is how the mouthpiece provides such a benefit. Reaction time, specifically with visual and auditory stimuli, is a complicated series of events that begins with the stimulus and ends with the initiation of the movement. For example, reaction time associated with visual stimuli begins with the primary visual cortex from which two processing streams emerge. The first stream entails recognition of objects, while the second involves guiding actions and originates from the posterior parietal cortex. The oculomotor system involves three loops starting from the frontal cortex. The first loop goes through the brainstem, then the thalamus, returning to the cortex. The second loop travels through the caudate nucleus, substantia nigra, and thalamus, back to the cortex. The final loop proceeds through the superior colliculus and thalamus, returning to the cortex, with all three loops cross-communicating.

Auditory reaction time is associated with efficient spiral organ receptors in the middle ear, which transfer sound to the temporal lobes of the cerebral cortex via sensory neurons. It is well known that visual stimulus results in slower reaction times vs auditory stimulus because of the increased number of sensory neurons involved in the visual pathway. Thus, the mechanisms by which a mouthpiece could affect these pathways may be complicated and worthy of further research.

Research claiming a reduction of stress in the temporomandibular joint area with the use of a mouthpiece may be one explanation for the improvement in reaction time. If there is improved blood flow and neural transmission with the use of a mouthpiece that properly aligns

![Figure 2](image-url)
the temporomandibular joint, then blood flow with increased oxygen unloading could be enhanced in other areas of the head and neck, leading to improvements in such events as reaction time. Reaction time with both the auditory and visual cues is a complicated series of events that may in some way be modulated with improved blood flow. Further studies should ascertain whether the physiologic mechanism within each of these systems is affected by proper temporomandibular alignment that occurs with the use of a mouthpiece.

CONCLUSION
This study explored auditory and visual reaction times with and without the use of a mouthpiece. Many sports engage the use of auditory and visual cues and depend on improved reaction times to obtain positive performance outcomes. If these findings are correct, it can be hypothesized that a number of athletes may be able to enhance performance when using a mouthpiece. Further studies are needed for a greater understanding of how mouthpieces affect performance physiologically.

DISCLOSURE
Dr. Garner has received an honorarium from Bite Tech Inc.

REFERENCES
Abstract: Intraoral appliances (mouthguards) have long been used and mandated for several sports, with good results on the reduction of dentition injury. Recently claims have arisen that mouthguards prevent brain injury. This article reviews the data on such claims, the basic science that has been conducted, and how an intraoral appliance may in the future become part of an engineered system to reduce transfer of energy from impacts to specific locations on the head, in an effort to mitigate some types of mild traumatic brain injury.

Intraoral appliances, or mouthguards, designed to protect the dentition have been in use for many years and mandated in most collision sports for some time. These devices have demonstrated some degree of effectiveness in limiting certain types of dental injuries. Recently, research has attempted to demonstrate that mouthguards prevent mild traumatic brain injury (MTBI). This interest stems from growing emphasis on the causes, incidents, and identification of MTBI, as well as potential preventive interventions associated with MTBI. Some of this science is based on acceleration measurements of the empty skull, while some is ascertained from field data. While skull measurement research is of interest, the magnitude of the impact and thus the impulse is necessarily low. Although the data show some attenuation of energy, it is insufficient to make any claims. The field data also fall short of providing proof of any meaningful reduction in MTBI. A more recent controlled study of neurologic impairment and recovery showed no change in outcome with the use of mouthguards.

This lack of data is not unexpected: to understand these issues, the mechanics of MTBI and the use of the term “mouthguard” should be examined. The term “mouthguard” seems to refer to anything from a “buy them by the hundreds” boil and bite device that has little to no functional effect on occlusion, to professionally made custom appliances, which may offer functional occlusion limits with a wide variety of possible mandible positions and which can be made from different materials. While many of these custom appliances have a good track record of dental injury reduction, there is no standard for determining the function of these appliances in MTBI, and they are functionally useless in MTBI prevention. The construction and fit of these custom appliances is as variable as the practitioners and laboratories that create them. In addition, other “in between” devices, which make various safety claims and offer insurance plans, can be purchased at retail and sporting goods stores and are sold by the millions. These devices sometimes use the word “brain” in the product name or include illustrated claims of MTBI reduction or even prevention. Scientific data show these claims to be misleading at best, and fraudulent at worst.

The previously mentioned studies often lack a description of the actual devices employed at the time of data collection; this is particularly true of retrospective cohort studies in which athletes are polled after the fact to see if they were wearing an appliance. The data is of little value, except that it offers no evidence of mitigation in the MTBI event. Other recent data suggest that some appliances may even increase the transferred energy of an impact. In this author’s opinion, medically trained individuals should not believe that a device...
placed between the mandible and the maxilla will somehow mitigate the energy from blows to any location on the head that result in MTBI. At best, placing a simple "boil and bite" appliance in the space between the mandible and maxilla may effectively prevent interdigitation, but it could also provide a slippery surf-
dence for the dentition of the mandible.

Consider typical athletes in contact sports: they are given a helmet, a face protector, a chin cup, and a "boil and bite" mouthguard. They are told repeatedly to "keep their head up" or "hit with the face." What happens when athletes follow these rules? The energy from an impact is transferred from the face protector to the chin cup, then to the mandible, the dentition of which is on that slippery surface. The mandible is then allowed to transfer to the rear with considerable force. The mechanics of this event, while not likely to cause MTBI or dentition injuries, will probably cause mandibular injury. This type of event can also endanger the delicate areas of the intercondylar space, perhaps leading to basilar skull fractures or penetration of the glenoid fossa. As this is not a typical consideration for which the athlete is examined, and the problem may not present clinically for years, the claim for the successful prevention of dentition injury persists. From an engineering or biomechanics point of view, one of the basics of any intervention is to understand how it will impact the surrounding tissues and structures. In this case, the simple mechanics of the above impact scenario makes the potential for injury obvious.

**MECHANICS OF THE MTBI**

To understand MTBI, and any role a mouthguard may play in the prevention of such injury, the mechanics of the MTBI should be examined. While the pathophysiology is only now being understood, the mechanism of tissue distortion that triggers these cascades is better comprehended. The basic mechanical properties of the brain, while a very complex issue, are outlined here for the purposes of this discussion. The brain—within the confines of the cranial vault and protected by the dura mater, pia mater and arachnoid sheath, bathed in cerebral spinal fluid—is divided into approximate halves separated by the falk, a very tough layer that limits the motion of the brain as a unit. Interspersed with the functional grey and white matter is the blood supply. If one could hold the blood supply of the brain intact in one hand, and the grey and white matter with the falk in the other, one would appear to be holding two brains. This intimate and complex system of tissues is at times very different in the way it reacts to impacts and impulses that demand a response from this viscous system.

As the system is combined of materials with different mechanical properties, the issue of tissue distortion becomes apparent. Imagine shaking this complex, and visualize the neuronal axons of the grey and white matter distorting around the more rigid materials of the falk and blood supply. One can see how tissue distortion can be highly variable based on several factors, not the least of which is the magnitude and direction of the impact or force vector. It also becomes clear that rotational or angular forces are the most likely to invoke problems at low levels. These kinds of insults do not require an actual impact to the head itself but can be the result of rapid non-impact motion. More likely, there is an impact component at either the beginning or the end of the event. Therefore, both linear and rotational forces are at work in almost all events that result in MTBI. For this reason, helmets demonstrate mixed and limited usefulness in the prevention of MTBI and diffuse axonal injury (DAI).

While somewhat over-simplified, the following two scenarios are examples of the complexity of these injuries. In the first, a head relatively not in motion is struck with an object. The impact results in a linear acceleration followed by a rotation, as the head is tethered to the torso and can translate only a short distance. In this case, without a helmet, the person is likely, depending on the impact magnitude, to have a point load, perhaps a skull fracture and significant linear injury prior to the onset of any rotational acceleration. In this kind of event a helmet is indispensable, as it will spread the load area, which reduces the point load, thereby reducing the translation and rotational impulse as well. For this reason helmets have a stellar record of injury reduction and prevention of events such as skull fracture, subdural hematoma, and sudden death.

In the second scenario, the head is in motion: for example when a person falls from a bike, and the head hits the pavement after the shoulder lands. In this case, there is a very high rotational impulse prior to head strike because the linear portion of this event is after the rotational event. Even if a helmet is worn, serious brain damage occurs, limited to the diffuse axonal damage, which is the result of the rotation. The helmet prevents the linear impact from causing immediate death by preventing skull fracture and tissue-destroying linear impact. Although the helmet proved life-saving, the person is seriously injured. The helmet could not protect the brain; the energy that injured the brain is the result of the brain's motion, while the helmet is on the skull.


Literature Review

These events are only two possible examples: there are many other incidents with varying degrees of magnitude. For example, if the helmet is too stiff, the impulse at the end of the rotation may exacerbate the rotational acceleration. A softer helmet may limit the rotational rebound inside the head but may have allowed the point load to take place, still resulting in serious injury, but now more from the linear rather than rotational impact. In the first scenario, a too-soft helmet can result in death.

As a final step in this introduction to MTBI, imagine these scenarios, and others, occurring at much lower impulses, so that the damage is limited to a smaller number of axons (typically farther from the center of rotation). In the case of lower magnitude insult, MTBI can occur. There are standards for the thresholds of more serious brain injuries, but not yet for MTBI. As some MTBIs can occur without head impact, no helmet, and thus no mouthguard, can prevent them.

PREVENTING INJURY

However, there are measures that can be taken to prevent MTBI. There is a point where the right mouthguard can limit some of the forces that might cause MTBI. Based on the above explanation, it is clear that the possibility is limited to blows that occur to or are transferred to the mandible—and only the mandible. A device that 1) interdigitates the upper and lower dentition so the mandible is fixed, 2) separates the upper and lower dentition by providing a physical barrier of deformable material with the appropriate mechanical properties, and 3) wears comfortably, will limit the acceleration of the head in impacts where the mandible is a primary point of load to the head. This device will protect the dentition and the mandible, and will limit the acceleration translated to the head, thus reducing both linear and rotational forces that result from the impact impulse.

While this is all good, it is neither a panacea or a simple process. The mechanical properties of such a device must allow it to work, via deformation, at the right time, for the maximum amount of displacement, while still maintaining interdigitation and remaining comfortable. This is not a small task. A standard must be developed to test various compounds and approaches to determine if this device could perform as needed and further to determine the range of function given the limits of materials and space. However, this author believes, based on ongoing testing, that there is a balance of mechanical properties that will result in a device that, when impacted with reasonable forces, either directly or via a chin cup, will limit head acceleration to a degree that makes this of value. This device will work best when coupled with other devices that limit the impulse, such as deformable face protector systems and chin anchor systems with carefully designed properties, resulting in a system that works in harmony to limit the widest range of impulses while transferring the least amount of acceleration to the head.

CONCLUSION

Should such devices exist, they will be important in the toolbox used to limit MTBI; however they will not be the critical component. Broad claims that such devices prevent concussive remain unsupported, and any claim that the device has some function even when the mandible is not the point of load should be discounted by the knowledgeable practitioner.

DISCLOSURE

Bite Tech Inc. has provided graduate student support in the past.

REFERENCES

A Study on the Effectiveness of a Self-Fit Mandibular Repositioning Appliance on Increasing Human Strength and Endurance Capabilities

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A Study on the Effectiveness of a Self-Fit Mandibular Repositioning Appliance on Increasing Human Strength and Endurance Capabilities

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Major Professor Jack Wasserman  Committee Members John Hungerford, Tyler Kress

Abstract

Years of study and constant anecdotal information dating back to the ancient Romans exists regarding the relationship of mandibular position, occlusion surface changes, and human performance. Such old sayings and practices like "bite the bullet" and the actual act of clenching one's teeth on a stick prior to exertion or in anticipation of pain are but two examples of how this relationship has been intuitively understood by man for some time. Previous scientific works in this area have generally suffered at least one serious shortcoming in data collection, data analysis, test device flaws or lack of control measures. There seem to be emotionally charged efforts to either prove or disprove the apparent relationship between jaw positioning and human performance. It is unclear why there has been so much controversy but the fact that this emotional side taking exists leads to concerns about preconceptions on the part of the previous research teams. In an effort to reach some realistic levels of confidence, this effort has been accomplished in a double blind, placebo controlled, unbiased manner utilizing the tenets of the scientific method throughout. The data indicate that a self-fit, intra-oral device is beneficial in improving grip strength values for both men and women at a confidence level of at least 95 percent. In addition, there is a 96 percent confidence level that a mandibular repositioning appliance is of greater assistance in grip strength tests than a placebo device. Therefore, the results of this research initiative demonstrate that statistically relevant human performance increases are possible by employing a self-fit, intra-oral device in active men and women of all ages.

Recommended Citation


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THE EFFECTS OF ARMOURBITE® MOUTHPIECE USE ON BASEBALL PITCHING VELOCITY

STUDY PERFORMED AT
Rod Dedeaux Research & Baseball Institute
The Effects of ArmourBite® Mouthpiece Use on Baseball Pitching Velocity

House, Tom; Wishmyer, Randy
Performance Mouthpieces, particularly ArmourBite® (Bite-Tech Corp), are becoming more and more prevalent among rotational sports such as baseball. There is limited research to date examining these mouthpieces and any direct effect on pitching velocity (mph).

PURPOSE: To investigate the possible effect on pitching velocity (mph) when wearing and not wearing a mouthpiece, ArmourBite® (Bite-Tech Corp), during several offseason training periods.

METHODS: Subjects, amateur and professional baseball pitchers, were asked to take part in Personal Adaptive Joint Threshold Training, 1 day a week, over a 6 week training period at the Rod Dedeaux Research & Baseball Institute. Subjects would train with 6 differently weighted training baseballs, 2lb., 1lb., 6oz., 5oz. (regulation baseball), 4oz., 2oz., during a training session (6 total). Subjects would alternate throwing with and without ArmourBite® mouthpiece, in 2 pitch increments, while velocity was actively recorded by a standard radar speed gun. Ten (n=10) subjects were asked to complete the training protocol while alternating with and without ArmourBite®. Pitching velocity (mph) of all subjects were recorded for each of the 6 differently weighted training baseballs per session with and without the use of ArmourBite®, and the averages were recorded.

RESULTS: The use of the mouthpiece elicited an average of 2 mph increase in pitching velocity among all subjects for all 6 variously weighted training baseballs, including a 5 oz. weighted baseball (regulation weight).

CONCLUSION: This study suggests that the use of a mouthpiece (ArmourBite®) may be used to directly increase pitching velocity amongst amateur and professional baseball pitchers.

Performed at the Rod Dedeaux Research & Baseball Institute