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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 (VO_2), voluntary oxygen consumption per kilogram of body weight (VO_2/kg) and voluntary carbon dioxide production (VCO_2).

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 $\alpha = .05$ and used a Tukey post hoc analysis of treatment means to identify differences between groups. The results showed significant improvements ($P < .05$) in VO_2, VO_2/kg and VCO_2 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.
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Research in the late 1970s and early 1980s indicated that mouthguards may enhance performance during strength and endurance exercise.[1-3] However, the research findings were difficult to interpret because of the subjective methodology used. Garabee[1] reported that endurance athletes felt they recovered more quickly after endurance training and could run at a higher intensity when wearing a mouthpiece than when not wearing a mouthpiece; however, he provided no physiological measures from the study.

Smith[2,3] reported the results of two studies in which football players increased their muscular strength when wearing a mouthguard adjusted kinesiologically versus when they wore an unadjusted mouthguard. The investigator measured the participants' strength by using a stress gauge kinesiometer, which measures the amount of pressure resistance in kilograms of force per unit of time.

The question remains whether Smith informed the athletes before the study that their performance might be affected positively by mouthpiece use during testing. If

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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[4] 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,[4] Garner and McDivitt[5] 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).[5]

This finding was confirmed in another study by Garner and McDivitt,[6] 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.[6]

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. If participants experienced an improvement in endurance outcomes (that is, lowered lactate levels), as previous research findings indicate, then there may have been some association with improved oxygen/carbon dioxide exchange 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.[4]

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

ABBREVIATION KEY. HR: Heart rate. **RR:** Respiratory rate. **VCO_2:** Voluntary carbon dioxide production. **Ve:** Ventilation. **VO_2:** Voluntary oxygen consumption. **VO_2/kg:** Voluntary oxygen consumption per kilogram of body weight. **V_t:** Tidal volume.

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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 (VO_2), voluntary oxygen consumption per kilogram of body mass (VO_2/kg) and voluntary carbon dioxide production (VCO_2). VO_2 is defined as the amount of oxygen in liters that the body uses per minute during aerobic exercise.[7] VO_2/kg is the amount of oxygen in milliliters that a person consumes per minute relative to body mass. VCO_2 is the expired byproduct of metabolism that occurs during aerobic exercise and is measured in liters per minute. In addition to VO_2, VO_2/kg and VCO_2, we measured participants' respiratory rate (RR) (number of breaths per minute), tidal volume (V_t) (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, V_t, Ve, VCO_2, VO_2 and VO_2/kg). We set the significance level at $\alpha = .05$ 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.

Figure 1. Custom-fitted mandibular mouthpiece (Under Armour Performance Mouthpiece, Under Armour, Baltimore, in cooperation with Bite Tech, Minneapolis) worn by college-aged participants in the study. Image reproduced with permission of Under Armour.

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, VO_2, VO_2/kg and VCO_2 were statistically significantly ($P < .05$) higher in participants in group 1 than in participants in groups 2 and 3 during the 10-minute trial, and they were higher in participants in group 2 than in participants in group 3. The results were similar for minutes 1 through 5 (Table 1, page 1045). During minutes 6 through 10, VCO_2, VO_2 and VO_2/kg were significantly ($P < .05$) higher in participants in group 1 than in participants in groups 2 and 3 (Table 2, page 1045). The results showed no differences ($P > .05$) in Ve, RR or V_t 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

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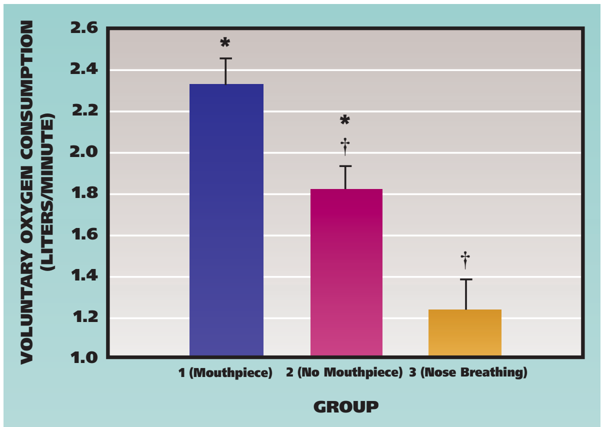

Figure 2. Voluntary oxygen consumption during steady-state exercise. Asterisk indicates statistically significant difference ($P < .05$) from group 3. Dagger indicates statistically significant difference ($P < .05$) from group 1.

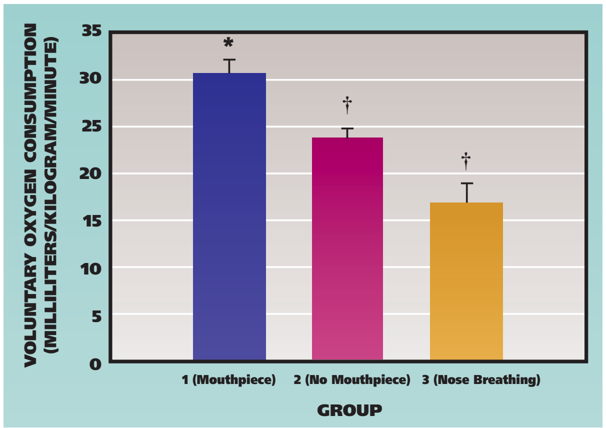

Figure 3. Voluntary oxygen consumption per kilogram of body weight during steady-state exercise. Asterisk indicates statistically significant difference ($P < .05$) from group 3. Dagger indicates statistically significant difference ($P < .05$) from group 1.

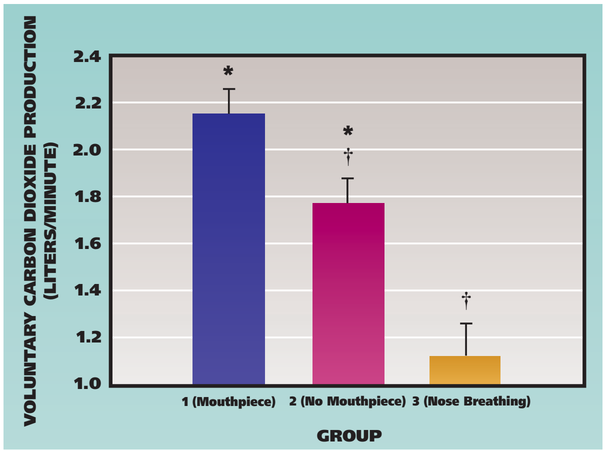

Figure 4. Voluntary carbon dioxide production during steady-state exercise. Asterisk indicates statistically significant difference ($P < .05$) from group 3. Dagger indicates statistically significant difference ($P < .05$) from group 1.

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[8] 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 McDivitt[5,6] 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 VCO_2 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.[9-12] Specifically, these authors found better gas exchange with mouth breathing than with nasal breathing. Consequently, we expected to find lower V_t, VO_2, VO_2/kg, VCO_2 and RR with nasal breathing because these results have been reported in previous research.[9-12]

However, we observed a novel finding when comparing mouth breathing with no mouthpiece use to mouth breathing with mouthpiece use. We had hypothesized that mouth breathing in the no-mouthpiece condition would elicit outcomes similar to those in the mouth-breathing-with-mouthpiece condition; however, this was not the case. Specifically, the results showed significant improvements in VCO_2 and oxygen parameters and no significant differences in Ve when participants wore the mouthpiece versus

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TABLE 1

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

VARIABLE	MEAN (± STANDARD DEVIATION) MEASURE		
	Group 1 (Mouthpiece)	Group 2 (No Mouthpiece)	Group 3 (Nose Breathing Only)
VCO_2[*] (L[†]/Minute)	2.00 ± 0.55[‡]	1.66 ± 0.49[‡§]	1.02 ± 0.53
VO_2[¶] (L/Minute)	2.21 ± 0.64[‡]	1.73 ± 0.54[‡§]	1.12 ± 0.57
VO_2/kg[#] (mL[**]/kg/Minute)	29.1 ± 6.7[‡]	22.5 ± 4.8[‡§]	15.2 ± 7.3
Ventilation (L/Minute)	49.7 ± 10.8[‡]	50.4 ± 12.1[‡]	29.8 ± 8.5
Respiratory Rate (Breaths/Minute)	31 ± 7[‡]	32 ± 8[‡]	25 ± 6
Tidal Volume (L)	2.10 ± 0.61[‡]	2.09 ± 0.59[‡]	1.60 ± 0.59
Heart Rate (Beats/Minute)	157 ± 15	156 ± 15	154 ± 11

[*] VCO_2: 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).
[¶] VO_2: Voluntary oxygen consumption.
[#] VO_2/kg: Voluntary oxygen consumption per kilogram of body weight.
[**] mL: Milliliters.

TABLE 2

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

VARIABLE	MEAN (± STANDARD DEVIATION) MEASURE		
	Group 1 (Mouthpiece)	Group 2 (No Mouthpiece)	Group 3 (Nose Breathing Only)
VCO_2[*] (L[†]/Minute)	2.29 ± 0.59[‡]	1.88 ± 0.54[‡§]	1.19 ± 0.64
VO_2[¶] (L/Minute)	2.43 ± 0.73[‡]	1.90 ± 0.60[‡§]	1.31 ± 0.74
VO_2/kg[#] (mL[**]/kg/Minute)	31.9 ± 7.5[‡]	24.8 ± 5.8[§]	18.0 ± 10.5
Ventilation (L/Minute)	56.9 ± 11.5[‡]	58.3 ± 13.7[‡]	34.3 ± 11.0
Respiratory Rate (Breaths/Minute)	33 ± 7[‡]	35 ± 8[‡]	28 ± 8
Tidal Volume (L)	2.28 ± 0.63[‡]	2.25 ± 0.63‡	1.68 ± 0.66
Heart Rate (Beats/Minute)	169 ± 16	167 ± 16	169 ± 10

[*] VCO_2: 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).
[¶] VO_2: Voluntary oxygen consumption.
[#] VO_2/kg: Voluntary oxygen consumption per kilogram of body weight.
[**] mL: Milliliters.

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 VCO_2 and oxygen parameters cannot be explained by improved Ve with mouthpiece use.

Francis and Brasher[4] 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 VO_2/kg between the two studies. Francis and Brasher[4] reported a decreased volume of VO_2/kg with mouthguard use during high-intensity exercise, whereas we measured a significant increase in VO_2/kg when participants wore the mouthpiece. However, Francis and Brasher[4] 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 Brasher[4] 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, VCO_2 and VO_2 parameters with and without mouthguard or mouthpiece use. During the high-intensity protocol, Francis and Brasher[4] found an improvement in expiratory volume, with decreases in Ve with mouthguard use; these results are similar to those of our study. Francis and Brasher[4] suggested that when participants wore a mouthguard, they

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TABLE 3

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

VARIABLE	MEAN (± STANDARD DEVIATION) MEASURE		
	Group 1 (Mouthpiece)	Group 2 (No Mouthpiece)	Group 3 (Nose Breathing Only)
Ventilation (L*/Minute)	53.4 ± 11.0†	54.6 ± 12.8†	32.3 ± 9.9
Respiratory Rate (Breaths/Minute)	32 ± 7†	34 ± 8†‡	26 ± 7
Tidal Volume (L)	2.16 ± 0.62†	2.14 ± 0.61†	Not applicable
Heart Rate (Beats/Minute)	163 ± 15	162 ± 16	161 ± 11

* 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 V_t 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 McDivitt[6] 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]

Remmers[23] 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 breathes 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 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 CO_2. We have shown that use of the custom-fitted mouthpiece decreases lactate production and increases VCO_2 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-

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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.[5,6] Specifically, improved VCO_2 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 VCO_2 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).[5]

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 VO_2 and VO_2/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[26]). 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.[27] Further research is needed to fully elucidate the physiological mechanisms involved in improved performance when one wears a custom-fitted mouthpiece. ■

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