Influence of a Custom-Made Maxillary Mouthguard on Gas Exchange Parameters During Incremental Exercise in Amateur Road Cyclists

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Abstract

Piero, M, Simone, U, Jonathan, M, Maria, S, Giulio, G, Francesco, T, Gabriella, C, Laura, A, Eva, B, Gianni, M, Francesco, C, and Giovanni, G. Influence of a custom-made maxillary mouthguard on gas exchange parameters during incremental exercise in amateur road cyclists. *J Strength Cond Res* 29(3): 672–677, 2015—Mouthguards are frequently used for protection purposes, particularly by athletes competing in contact sports. However, there is increasing evidence supporting their use for improving performance. Studies have focused their use in athletes who do not traditionally use mouthguards and who may be looking for a performance edge. The aim of the current study was to evaluate the influence of a custom-made mouthguard (Parabite Malpezzi, PM) on maximal and submaximal physiological parameters related to performance in road cycling. Ten well-trained amateur road cyclists (34 ± 6 years) performed an incremental cardiopulmonary exercise test to exhaustion on a frictional braked cycle ergometer. Work rate (WR), heart rate, oxygen consumption ($\dot{V}O_2$), carbon dioxide production, and ventilation at the lactate threshold, at the respiratory compensation point (RCP), and at maximal exercise (MAX) were determined in normal conditions (C) and wearing PM. Cycling economy was also evaluated by analyzing the slope of the $\dot{V}O_2$/WR ($\Delta\dot{V}O_2/\Delta WR$, in milliliters per watt per minute) relationship during the test. Wearing the PM compared with C resulted in significant increases in WR at RCP (281 ± 32 vs. 266 ± 19 W, $p = 0.04$) and at MAX (353 ± 44 vs. 339 ± 38 W, $p = 0.004$). The PM also resulted in an average 8% lower $\Delta\dot{V}O_2/\Delta WR$ (9.5 ± 1.1 vs. 10.3 ± 1.1 $ml \cdot W^{-1} \cdot min^{-1}$, $p = 0.06$) but did not significantly modify any of the other measured parameters at LT, RCP and MAX. To the best of our knowledge, this study is the first to evaluate the effects of a dentistry-designed mouthguard on physical performance of road cyclists. These results provide support for cyclists to correct jaw posture that may improve their exercise performance.

Key Words cycling, jaw posture, endurance performance

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29(3)/672–677

Journal of Strength and Conditioning Research

Introduction

Mouthguards are frequently used by athletes to reduce the occurrence and severity of orofacial trauma during training and competition, both in contact (6,20,21,27,28,30) and non-contact sports (1,14,22,23). Some athletes testify to "feeling stronger and being more relaxed" when wearing a mouthguard (13), and there is evidence that jaw repositioning can improve orofacial muscle strength (21). Moreover, several dental studies have reported increased strength, balance, coordination, and performance as a result of changing the maxillomandibulary relationship with mouthguards (18,29,32,33).

Thus, the concept that mouthguards could provide not only protection but also some increment in athletic performance is intriguing for coaches and athletes (16). However, there are currently minimal data available regarding the influence of wearing mouthguards on cardiorespiratory fitness. In addition, studies focusing on athletes who do not traditionally use mouthguards and who may be looking for a performance edge have advocated their use (3). The few studies that have been performed have largely involved athletes of team sports (5,19,30,34) or contact sports (20) and have reported conflicting results (2,9,12,15).

It has been demonstrated that custom-fitted mouthguards may improve maximal aerobic capacity and economy at high exercise intensity in athletes participating in team sports

(5,34). It is unknown whether wearing a mouthguard influences athletic performance during endurance sports such as cycling that are largely determined by maximal oxygen consumption, anaerobic threshold, and cycling economy (9). The determination of the effects of mouthguard use on physiological responses to incremental exercise is relevant for testing and training purposes in cyclists, who do not commonly use mouthguards in training and competition.

The current study addresses the question whether a mouthguard (usually designed for protection from orofacial trauma and jaw repositioning) influences cardiorespiratory parameters of cyclists during incremental exercise testing.

Methods

Experimental Approach to the Problem

$\dot{V}O_2$peak, ventilatory threshold (VT), respiratory compensation point (RCP), and the relationship between oxygen uptake and work rate ($\Delta\dot{V}O_2/\Delta WR$) during incremental exercise were investigated in 2 experimental conditions, with and without (C, control) wearing a custom-made mouthguard.

Subjects

Ten well-trained male amateur road cyclists participated in this study (mean [*SD*]: age 34 [6] years; body mass index 22.3 [2.2] $kg \cdot m^{-2}$; height 178 [7] cm; body mass 70 [10] kg). These men were similar in terms of endurance capacity, and continuous training and racing habits for the past 5 consecutive years.

All subjects had been declared eligible for road cycling competition following a medical examination and in accordance with recommendations of the Italian pre-participation athletic screening program. The study protocol was approved by the ethical commission of the University of Ferrara. All participants signed written informed consent after receiving a detailed description of the study design.

Mouthguards

For each athlete, a custom-made mouthguard (Parabite Malpezzi, PM; Bologna, Italy) was designed. First, we obtained precise and complete arch dental impressions using polysiloxane impression material. Second, the impressions were molded in plaster cast using dental arches with type 4 dental stone. Third, an Intraoral Gothic Arch was fashioned, and the values of each gnathological parameter were measured. Fourth, to record the best neuromuscular response, we used a dedicated dentistry electromyograph (Easymyo; TFR Technology, Udine, Italy). With these methods, we were able to certify the values achieved in the normalization clench. The PM was then delivered to the athlete for a 3-week familiarization period. None of the athletes had been using a mouthguard before this study.

Exercise Protocol

As part of the familiarization phase, each subject wore the custom-made mouthguard for at least 2 weeks before testing. Athletes were out of competition (i.e., winter season) but well trained. Each subject participated in 2 randomized testing sessions, with and without wearing the PM, separated by 1 week, at the same time of the day. Subjects were instructed to avoid strenuous or prolonged exercise during the previous 72 hours and maintain their normal sleep and dietary habits, including hydration levels. Exercise tests were performed at the Exercise Physiology Laboratory in the Center of Biomedical Studies applied to Sports of the University of Ferrara, Italy.

Subjects performed incremental ramp exercise tests until exhaustion on a friction-loaded cycle ergometer (Monark 839 E; Stockholm, Sweden) under similar environmental conditions. Subjects were given the same verbal encouragement throughout the test by the same physician and exercise specialist supervising the testing sessions.

The cycle ergometer was modified with a racing saddle and an adjustable stem and pedal system, allowing for a modification of the conventional sitting position during the tests. After 3-minute unloaded warm-up, the test was started at 15 W and the workload was increased by 15 $W \cdot min^{-1}$.

During the tests, subjects were allowed to choose their preferred pedaling cadence between a range of 80–95 rpm. This is known to better simulate actual cycling conditions compared with tests performed at a fixed cadence. Indeed, it has been demonstrated that during actual racing, the preferred pedaling cadence of elite cyclists on flat terrain or individual time trials is 90 rpm (25). The subjects used a pedaling frequency meter to maintain this range of cadences. Tests were terminated when pedaling cadence could not be maintained at 70 rpm. All subjects had previous experience with this type of testing. In these tests, the values obtained were not significantly different. Previous data obtained with this protocol have been reported for gas exchange measurements during incremental exercise and for evaluating mechanical efficiency (26).

Heart rate (HR, in beats per minute) was continuously recorded during the tests by integrated 12-lead

Table 1. Anthropometrics and training characteristics of the subjects examined.*†

Age (y)	34 ± 6
Height (cm)	178 ± 7
Weight (kg)	70 ± 10
BMI ($kg \cdot m^{-2}$)	22 ± 2
Years of competition (y)	21 ± 8
Weekly training volume (km)	331 ± 84
Yearly training volume (km)	13,250 ± 3370

*BMI = body mass index.
†Data are presented as mean ± *SD*.

TABLE 2. Physiological variables at maximal effort recorded during the exercise tests with (PM) and without (C) mouth guard.*†

Maximal variables	C	PM	p
$\dot{V}O_2$peak ($L \cdot min^{-1}$)	4.044 ± 0.557	4.053 ± 0.421	0.928
$\dot{V}O_2$peak ($ml \cdot kg^{-1} \cdot min^{-1}$)	57.8 ± 6,5	58.1 ± 5.8	0.838
Wmax (W)	339 ± 38	353 ± 44	0.004‡
HRmax ($b \cdot min^{-1}$)	180 ± 6	182 ± 8	0.379
SBP (mm Hg)	173 ± 13	175 ± 14	0.771
DBP (mm Hg)	73 ± 9	74 ± 11	0.823
VEmax ($L \cdot min^{-1}$)	140 ± 23	141 ± 22	0.525
RF ($f \cdot min^{-1}$)	48 ± 6	50 ± 4	0.283
TV (L)	2.992 ± 0.442	2.957 ± 0.420	0.731
RERmax ($\dot{V}CO_2/\dot{V}O_2$, $L \cdot min^{-1}$)	1.17 ± 0.07	1.20 ± 0.04	0.201
Perceived effort (RPE 6–20 scale)	20 ± 1	20 ± 1	0.726

*HR = heart rate; SBP = systolic blood pressure; DBP = diastolic blood pressure; VE = minute ventilation; RF = respiratory frequency, TV = tidal volume, RER = respiratory exchange ratio; RPE = rate of perceived exertion.
†Data are presented as mean ± *SD*.
‡Statistically significant at $p < 0.01$.

calibration of the gas analyzers using gases of known oxygen, carbon dioxide, and nitrogen concentrations. The data were averaged for 15-second intervals and smoothed using a width of 10 seconds. Data from the first 2 minutes were excluded to avoid the influence of early $\dot{V}O_2$ kinetics (11). $\dot{V}O_2$peak was calculated as the highest $\dot{V}O_2$ obtained over a 15-second averaging period. The VT was mathematically determined using the V-slope method described by Beaver et al. (4). Respiratory compensation point was also identified using the criterion of an increase in both $VE/\dot{V}O_2$ and $VE/\dot{V}CO_2$ and a decrease in $PETCO_2$ (24). Respiratory compensation point was detected by 2 independent

electrocardiogram. Expired gas was collected through a Rudolph face mask. Gas exchange data were collected continuously breath-by-breath using a metabolic cart (Quark b2; Cosmed, Rome, Italy) to determine oxygen uptake ($\dot{V}O_2$, in liters per minute and milliliters per kilogram per minute), carbon dioxide output ($\dot{V}CO_2$, in liters per minute), pulmonary ventilation (VE, in liters per minute), ventilatory equivalents for oxygen ($VE/\dot{V}O_2$, in liters per minute) and carbon dioxide ($VE/\dot{V}CO_2$), and end-tidal partial pressures of oxygen and carbon dioxide ($PETCO_2$). Calibration of the system was performed immediately before each test by using a 3-L syringe to calibrate the turbine, and a 2-point

observers. If there was disagreement, the opinion of a third investigator was sought. The power output (in watt) corresponding to VT (WVT), RCP (WRCP), and maximal effort (Wmax) were calculated.

Cycling efficiency was calculated by analyzing the slope of the $\dot{V}O_2$/WR relationship ($\Delta\dot{V}O_2/\Delta WR$). It has been demonstrated that gross efficiency (9,10) in trained cyclists was generally similar for all WRs evaluated when cycling at 50–90% of $\dot{V}O_2$peak and 80–90 rpm (10,31).

Statistical Analyses

Paired *t*-tests were used to evaluate differences between exercise test responses while wearing and not wearing the PM device. All data were reported as mean ± *SD*. MedCalc 12.0 statistical software (Mariakerke, Belgium) was used to perform all analyses. The level of significance was set at $p \leq 0.05$.

TABLE 3. Physiological variables at submaximal effort recorded during the exercise tests with (PM) and without (C) mouth guard.*†

Submaximal variables	C	PM	p
VT_{watt} (W)	207 ± 35	204 ± 44	0.824
VT_{watt} (%Wmax)	61 ± 7	59 ± 13	0.490
$VT\dot{V}O_2$ ($L \cdot min^{-1}$)	2.894 ± 0.480	2.892 ± 0.410	0.984
$VT\dot{V}O_2$ (%$\dot{V}O_2$peak)	71 ± 5	71 ± 6	0.924
RCP_{watt} (W)	270 ± 34	288 ± 47	0.013
RCP_{watt} (%Wmax)	80 ± 4	81 ± 4	0.213
$RCP\dot{V}O_2$ ($L \cdot min^{-1}$)	3.437 ± 0.473	3.538 ± 0.381	0.327
$RCP\dot{V}O_2$ (%$\dot{V}O_2$peak)	85 ± 5	87 ± 3	0.184
$\Delta\dot{V}O_2/\Delta WR$ ($ml \cdot min^{-1} \cdot W^{-1}$)	10.3 ± 1.1	9.5 ± 1.1	0.06

*VT = ventilatory threshold; RCP = respiratory compensation point; $\Delta\dot{V}O_2/\Delta WR$ = slope of the oxygen uptake/work rate relationship.
†Data are presented as mean ± *SD*.

RESULTS

Anthropometric and training characteristics of the participant population are presented in Table 1. None of the participants had significant temporomandibular disorders, and all completed the protocol without adverse events. No significant effects associated with breathing, speaking, or concentration while wearing the PM were reported.

The effects of wearing the PM on functional and gas exchange parameters during the tests are presented in Tables 2 and 3. There was a significant difference in power output at maximal effort while wearing the PM compared with C (353 ± 44 vs. 339 ± 38 W, $p = 0.004$). No significant differences were observed for any of the other functional, cardiorespiratory, or metabolic parameters measured at maximal effort. In particular, minute ventilation and oxygen uptake were unchanged during testing with and without PM, suggesting that ventilation was not negatively affected during exercise with the PM. The mean maximal respiratory exchange ratio was not significantly different in the PM and C conditions, indicating that similar maximal efforts were given for both conditions. Similarly, subjects reported exhaustion at the same rate of perceived exertion during exercise with and without PM.

The mean absolute power output at RCP was significantly higher ($p = 0.04$) in the PM condition (281 ± 32 W) compared with C (266 ± 19 W). The mean relative power output values at RCP, expressed in %Wmax, were not different (80 vs. 81%) in the PM and C conditions. Wearing the PM did not significantly modify any of the other measured parameters at RCP and LT.

An improvement in cycling economy was observed wearing PM ($\Delta\dot{V}O_2/\Delta W$ 9.5 ± 1.1 vs. 10.3 ± 1.1 $ml \cdot W^{-1} \cdot min^{-1}$, $p = 0.06$).

Discussion

To the best of our knowledge, this study is the first to evaluate the effects of a dentistry-designed mouthguard on physical performance of road cyclists. In comparison with no-mouthguard fitting, wearing a neuromuscular dentistry-made mouthguard (PM) was associated with significant 4% ($p = 0.004$) and 7% ($p = 0.01$) increases in power output at maximal effort and at the RCP, respectively, in amateur cyclists. In addition, none of the maximal and submaximal cardiorespiratory variables considered were adversely influenced by the PM. In particular, respiratory rate, ventilation, and oxygen uptake at peak effort and at submaximal exercise intensities were not different while wearing or not wearing the PM, suggesting that no ventilatory limitations occurred. In addition, an improvement in cycling economy was observed. There was a tendency toward a difference in cycling economy wearing PM compared with C as documented by an 8% lower $\Delta\dot{V}O_2/\Delta W$ (9.5 ± 1.1 vs. 10.3 ± 1.1 $ml \cdot W^{-1} \cdot min^{-1}$, $p = 0.06$).

These results may have practical implications for coaches and athletes not only to provide dental protection but also to enable high WRs, given the significant improvement in power output at high effort and the lower metabolic cost observed while wearing the PM. The latter could be relevant in cycling because differences in performance between individuals and improvements with training are largely explained by changes in $\dot{V}O_2$peak, anaerobic threshold, and cycling economy (9). In some cases, differences in performance are related to differences in biomechanical economy rather than by $\dot{V}O_2$peak and anaerobic threshold (7,9,17). These findings could be relevant in road cycling where high-intensity exercise is common, both in training and racing conditions.

In previous studies in which no significant effects were found with mouthguards for power output at high exercise intensities, it has been suggested that this could be related to open-mouth breathing, which may negate the effects of the mouthguard on occlusion (3). It has also been suggested that there may be suboptimal bite designs for muscular endurance activities that may limit or negate the potential ergogenic effects of a mouthguard and that specific practice may be needed to ensure that athletes benefit from occlusional positioning (3). In our study, cyclists bit down into the PM with no negative effects on ventilation, and positive effects on power output at high intensities.

Our findings are in line with previous studies in team sports athletes (5,12,15) and with tae kwon do athletes (19) at submaximal exercise intensities. However, in contrast to these studies, but similar to the results of Von Arx et al. (34), we observed no influence of the PM on ventilation and oxygen uptake at high exercise intensities. Francis and Brasher (15) studied the physiological effects of different types of mouthguards in healthy young adults exercising on a cycle ergometer for 5 minutes at light and heavy workloads. There were no significant differences in oxygen consumption with the various mouthguards compared with no-mouthguard conditions at lower work levels, whereas, in contrast to our findings, $\dot{V}O_2$ was significantly reduced at heavier workloads. The authors suggested that the reduction in $\dot{V}O_2$ during heavy exercise may be because of a "pursed-lip" style of breathing that has been shown to decrease CO_2 tension, increase oxygenation, and thus exercise tolerance. Although the mouthguards tested restricted forced expiratory airflow, they seemed to be beneficial in prolonging exercise by improving ventilation and economy. Delaney and Montgomery (12) reported no significant differences in ventilation and $\dot{V}O_2$ among female university ice hockey players at submaximal exercise intensities, whereas both parameters were significantly reduced at maximal effort. These discrepancies could be related to the type of mouthguard. In the study by Francis and Brasher (15) and Delaney and Montgomery (12), "stock" mouthguards were tested. These require the mouth to be closed for retention, possibly negatively influencing airflow dynamics, particularly at high ventilation levels. Similar results have been observed by Bourdin et al. (5) using custom-made mouthguards. Thus, our results provide further evidence supporting the concept that custom-made mouthguards do not impair airflow dynamics.

Greater motivation during the testing session wearing the PM should be considered because athletes are often highly motivated to seek a competitive advantage and improve performance. However, a placebo-controlled study was not practical in the current context. In previous studies in which custom-made mouthguards have been compared with standard conditions, conflicting results have been reported. There is good evidence that custom-made mouthguards do not negatively affect endurance performance or ventilatory capacity nor do they interfere with maximal exercise capacity (5,19,34). Improvement in economy during cycle ergometry at higher exercise intensities in healthy men and women have been reported by Francis and Brasher (15), whereas no differences were found by Delaney and Montgomery (12) at submaximal intensities. However, the latter authors demonstrated a decrease in ventilation and oxygen uptake at maximal intensities in university female ice hockey players during treadmill skating.

In conclusion, the present study demonstrates that wearing a PM positively influences some physiological parameters generally associated with cycling performance. In addition, PM did not modify breathing pattern and ventilation. Improvement in cycling economy and power output at high exercise intensities could be relevant during continuous and interval-based training and competition. These findings provide additional evidence for coaches and athletes to advocate the use of individualized mouthguards not only for effective protection but also for improving performance.

Practical Applications

Many athletes, particularly those competing in contact sports, use mouthguards for protection from orofacial injuries. However, other athletes are hesitant to use mouthguards because of uncertainty regarding potential decrements to performance. Studies focusing on athletes who do not traditionally use mouthguards and who may be looking for a performance edge have recently advocated their use. In the current study, the use of a novel custom-made mouthguard (PM) resulted in an increased power output at high-to-maximal exercise intensities and a tendency to improve cycling economy. Other major physiological variables associated with road cycling performance were not hindered by wearing the PM. These findings could be relevant for cyclists involved in either continuous or interval-based training and competition. These results provide support for coaches and athletes to advocate the use of individualized mouthguards not only for orofacial protection but also for improving performance.

Acknowledgments

The authors are grateful to Mr. Andrea Canuti and to TFR Technology (Udine, Italy) for the kind assistance in fabricating the mouthguards. The authors very much appreciate the cooperation and positive propensity of the cyclists involved in the study. This was an independent investigation, and the results of this study do not constitute endorsement of the product by the National Strength and Conditioning Association.

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