Influence of Maxillary Mouthguards on Physiological Parameters

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ABSTRACT

BOURDIN, M., I. BRUNET-PATRU, P.-E. HAGER, Y. ALLARD, J.-P. HAGER, J.-R. LACOUR, and B. MOYEN. Influence of Maxillary Mouthguards on Physiological Parameters. *Med. Sci. Sports Exerc.*, Vol. 38, No. 8, pp. 1500–1504, 2006. **Introduction:** The purpose of this study was to test the influence of two types of maxillary mouthguards (a self-adapted and a custom-made model: SA and CM, respectively) on various physiological parameters generally associated with performance in team sports. **Methods:** Nineteen trained male subjects participating in team sports were tested. Visual reaction time, explosive power, ventilation at rest, and ventilation and oxygen consumption during submaximal and maximal exercise were measured in three randomized conditions: normal, with SA mouthguards, or with CM mouthguards. **Results:** Wearing SA or CM mouthguards did not significantly alter any of the measured parameters compared with the normal condition. **Conclusions:** Wearing a maxillary mouthguard does not affect the main physiological parameters generally associated with team sport performance. These results provide additional support to the policy of encouraging athletes to wear individually fitted maxillary mouthguards. **Key Words:** CONTACT SPORTS, VENTILATION, OXYGEN CONSUMPTION, EXPLOSIVE POWER

Some athletes competing in contact sports wear dental mouthguards to reduce the risk of orofacial trauma. The mouthguards are worn over the teeth and absorb energy from blows to the mouth and jaw, thus minimizing the occurrence and severity of dental and oral injuries (6,14,17,22).

Intraoral sports mouthguards have been classified into three main categories: stock mouthguards, self-adapted (SA) or "boil and bite" mouthguards, and custom-made (CM) mouthguards. The third category can be divided into vacuum and pressure-laminated CM mouthguards (18). CM mouthguards are made using an impression of the individual's teeth to fit the individual according to specifications provided by a dental professional. These devices show optimal comfort and wearability (8,23) and are the best protection against orofacial injury (4,18). CM mouthguards are, however, more expensive than the other types. Consequently, many athletes tend to choose SA mouthguards because they are less expensive than the CM type and fit better than stock mouthguards.

Although mouthguards have been shown to protect against orofacial injury, many players do not wear them

during training and competition. The major reasons cited by the athletes for this are discomfort and difficulty in verbal communication and breathing (12). Surprisingly, data concerning the impact of mouthguards on breathing, particularly during exercise, are scarce. It has been demonstrated that mouthguards significantly alter airflow dynamics and ventilation (1,7,11,16) and oxygen consumption ($\dot{V}O_2$) in high-intensity exercise (7,11).

There is a belief on the part of some dentists working in the field of sports that jaw repositioning can increase muscle strength (14). Some players testify to "feeling stronger and being more relaxed" when wearing a mouthguard (9). According to the review by Gelb et al. (13), a mandibular orthopedic repositioning appliance (MORA) increases the isometric strength of the muscles around the neck and head in subjects with temporomandibular disorder and/or occlusal problems. However, there have been few studies of the effect of increasing the vertical dimension on muscle strength in dynamic exercise in normal subjects. Some studies, reviewed by Forgione et al. (10), examined the effect of vertical dimension increase in subjects with normal occlusion. The results were conflicting, probably because most of these studies were flawed in their scientific design (13). Moreover, they mostly measured strength during isometric or isokinetic exercises, whereas muscular performance in contact sports is mainly ballistic.

The present study sought to investigate the influence of two types of mouthguards (SA and CM) on various parameters generally associated with performance in team sports. Three questions were addressed: 1) Does the discomfort associated with wearing a mouthguard affect information processing by decreasing attention? 2) How do mouthguards affect airflow dynamics at rest and ventilation and $\dot{V}O_2$ during submaximal

and maximal exercise? 3) Does wearing a mouthguard during explosive exercise increase strength and power by increasing the vertical dimension of the jaw?

METHODS

Subjects

Nineteen trained male subjects volunteered to participate in the study (2 handball players, 1 ice hockey player, and 16 rugby men, 8 of whom were professional). Their height, body mass, and age were (mean ± SD) 180.9 ± 8.7 cm, 91.4 ± 18.6 kg, and 27 ± 4.8 yr, respectively. None presented temporomandibular joint disorder. After being fully informed verbally and in writing of the purposes and potential risks, the subjects gave their written consent to participate in the study, which was conducted in agreement with the recommendations of the local ethics committee of Lyon (registration number 00/029).

Mouthguards

Two different maxillary mouthguards were used: SA and CM. SA was a commercially available thermoplastic product (Rucanor®, Nieuwerkek, The Netherlands). Subjects fitted the product according to the manufacturer's instructions on the package. The CM mouthguard was constructed and fitted by an experienced dental clinician in the odontology department of the Lyon Hospital Service (Hospices Civils de Lyon) according to the methodology developed by Sametsky et al. (19). The mouthguard was made from methylmethacrylate resin (SR-Ivocap, Ivoclar, St. Jorioz, France), heated, and shaped on a stone cast of the maxillary dental arch of each subject. The appliance contained a metal framework to distribute impact force over a larger zone. The occlusion was raised on each side of the mouthguard in the posterior sector (from the canine to the second molar), creating an anterior gap of 2.0 ± 0.5 mm that allowed the player to breathe with his jaws closed.

Experimental Procedure

Each subject participated in three randomized sessions: normal, with the SA mouthguard, and with the CM mouthguard. Sessions were separated by at least 2 d. The subjects were asked to wear the mouthguard for 15 min before the start of the session.

Simple visual reaction time was measured at the start of each session. Next, oral airflow dynamics was measured with the subject breathing orally via a mouthpiece and a nose clip. After a 5-min warm-up on a friction-loaded cycle ergometer (Monark 818E, Stockholm, Sweden), the subjects were asked to perform three maximal cycling sprints of 6 s, separated by at least 4 min of rest. Three friction loads of 0.25, 0.50, and 0.75 N·kg^{-1} body mass were applied to the friction belt. Finally, after a 20-min rest, $\dot{V}O_{2max}$ was determined by a continuous incremental test on the cycle ergometer. Subjects warmed up again for 6 min at work rates ranging between 100 and 150 W (70–75 rpm), then the

work rate was increased by 35 W every 4 min until exhaustion. For each subject and each session, the same friction loads for sprints and the same work rates (and pedaling frequency) for incremental testing were used.

Measurements

Simple reaction time. Random visual stimulus presentation and response recording used a device (EAP, Issy les Moulineaux, France) on which subjects were asked to press a button on a joystick with their preferred hand as quickly as possible when a light came on. Thirty random visual stimuli were recorded. Visual reaction time (ms) was expressed as means and SD.

Oral airflow dynamics. Oral airflow dynamics was measured with a pneumotachograph (Spiroteq, Eolys, Lyon, France). A forced vital capacity test (FVC) was used to determine the influence of the two studied mouthguards on airway resistance. Ventilation measurements for each experimental condition comprised 1-s inspiratory and forced expiratory volumes (FIV1 and FEV1, respectively) and peak flow rate for inspiration and expiration (PIF and PEF, respectively).

Force–velocity measurements. The friction-loaded cycle ergometer (Monark 818E, Stockholm, Sweden) has been previously described (2). The device was equipped with a strain gauge (200 N, bandwidth 500 Hz) to measure the frictional force and with an optical encoder (1969.2 points per meter of displacement, or 11,815 points per pedal revolution) to record flywheel displacement. Force and displacement signals were sampled (200 Hz) and stored on a PC via a 12-bit analog-to-digital interface card (DAS-8, 12 bits, Keithley Metrabyte, Taunton, MA). First- and second-order flywheel displacement derivatives were calculated to obtain flywheel velocity and acceleration. The external force produced was calculated as the sum of the frictional force (given by the strain gauge) and the force necessary to accelerate the flywheel (15). Power, force, and velocity were averaged for the period of each pedal downstroke. After computation, the data from all the sprints were used to plot the force– and power–velocity relationships, respectively, using a linear and a second-order polynomial regression (20). Maximum power (P_{max}) was identified as the apex of the power–velocity relationship. Optimal pedaling rate (V_{opt}) was the pedaling rate at which P_{max} occurred. Optimal force (F_{opt}) was the force at which P_{max} occurred.

Incremental exercise up to exhaustion. Expired gas was collected during the last 30 s of each stage through a face mask with a low-resistance Hans Rudolph valve 2700 (Kansas City, MO). Subsequent volume determinations were carried out in a balanced Tissot spirometer. The O_2 and CO_2 fractions were determined in a mixing chamber by means of S3A/I Ametek (Pittsburgh, PA) and D-Fend Datex (Helsinki, Finland) analyzers, respectively. The gas analyzers were calibrated with gas mixtures of known composition. HR was recorded continuously by ECG (Cardimax FX-121 Electrocardiograph; Fukuda Denshi, Tokyo, Japan). Blood lactate concentrations

TABLE 1. Force, velocity, and power values for the three experimental conditions.

	Normal	CM	SA
P_{max} (W)	1184.8 ± 225.4	1180.9 ± 246	1187.6 ± 233.6
V_{opt} (m·s⁻¹)	11.88 ± 0.77	11.84 ± 0.74	11.90 ± 0.49
F_{opt} (N)	100.1 ± 20	100.5 ± 23.3	99.9 ± 19.9

Values are expressed as mean ± SD. CM, custom-made mouthguard; SA, self-adapted mouthguard; P_{max}, maximal power; V_{opt}, optimal velocity; F_{opt}, optimal force.

TABLE 2. Submaximal values of ventilation, frequency of respiration, and $\dot{V}O_2$.

		Normal	CM	SA
Stage 1 (N = 15)	$\dot{V}_E$ (L·min⁻¹)	62.2 ± 13.2	60.7 ± 12	60.7 ± 10.4
	f (breaths·min⁻¹)	25.4 ± 5.9	24.7 ± 5.9	23.3 ± 6.8
	$\dot{V}O_2$ (L·min⁻¹)	2.36 ± 0.49	2.36 ± 0.39	2.45 ± 0.38
Stage 2 (N = 15)	$\dot{V}_E$ (L·min⁻¹)	78.8 ± 15.8	76.3 ± 14.43	77.9 ± 17.5
	f (breaths·min⁻¹)	28.7 ± 7.2	28.8 ± 6.2	27.8 ± 8.3
	$\dot{V}O_2$ (Lvmin⁻¹)	3 ± 0.55	2.89 ± 0.43	2.99 ± 0.58
Stage 3 (N = 12)	$\dot{V}_E$ (Lvmin⁻¹)	98.4 ± 23.2	98.7 ± 20.4	100.8 ± 15.6
	f (breaths·min⁻¹)	34.2 ± 9.4	33.6 ± 7.1	32.5 ± 5.9
	$\dot{V}O_2$ (L·min⁻¹)	3.49 ± 0.68	3.5 ± 0.59	3.58 ± 0.57

CM, custom-made mouthguard; SA, self-adapted mouthguard; $\dot{V}_E$, ventilation; f, respiratory frequency; $\dot{V}O_2$, oxygen consumption. Values are expressed as mean ± SD.

([La]$_b$) were measured after completion of the exercise. Fingertip blood samples were diluted in a hemolyzing solution and stored at 5–10°C. The measurements were carried out with a Y.S.I. 2300 lactate analyzer (Yellow Springs Instruments Inc., Yellow Springs, OH). For each stage, respiratory frequency (f) was determined using the spirometer movements by counting the number of expirations during the expired gas collection. The highest $\dot{V}O_2$ measured during exercise was considered the subject's $\dot{V}O_{2max}$, provided the [La]$_b$ concentration measured at the end of this period exceeded 9 mmol·L⁻¹ and RER exceeded 1.1. The maximal aerobic power (P_{amax}) was the exercise intensity corresponding to the reach in $\dot{V}O_{2max}$. At the end of the test, the RPE was recorded according to Borg's scale (5).

Statistical Analysis

Results are expressed as means ± SD. A repeated-measures ANOVA design was used to assess the statistical significance of differences between mean values of the different conditions. Scheffé's pairwise multiple comparison t-test was used as a *post hoc* test to compare the three experimental conditions. The level of significance was set at 0.05.

RESULTS

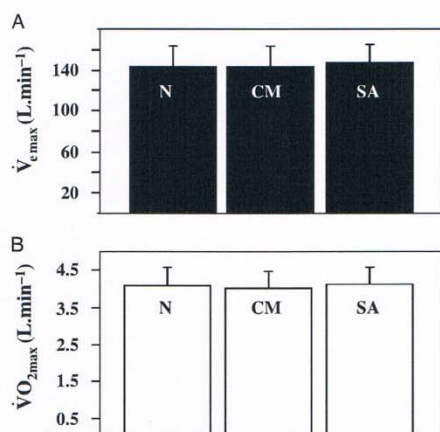**Simple visual reaction time.** No significant difference in visual reaction time was observed between conditions

A

B

FIGURE 1—Comparisons of maximal ventilation ($\dot{V}_{Emax}$) (A) and maximal oxygen uptake ($\dot{V}O_{2max}$) (B) between exercise conditions. Values are means ± SD. N, normal subjects; CM, custom-made mouthguard subjects; SA, self-adapted mouthguard subjects.

(192.8 ± 1.5, 196.5 ± 1.4, and 196.4 ± 1.4 ms for normal, CM, and SA conditions, respectively).

Oral airflow. Mean FIV1 in the CM and SA conditions did not differ from the normal condition (5.25 ± 0.60, 5.37 ± 0.93, and 4.95 ± 0.67 L for normal, CM, and SA subjects, respectively). Neither did mean PIF (7.9 ± 2.3, 7.1 ± 2.1, and 7.7 ± 2 L·s⁻¹ for normal, CM, and SA subjects, respectively). However, the CM PIF values were significantly higher than for SA ($P < 0.01$). Mean FEV1 remained unchanged whatever the experimental condition (4.40 ± 0.70, 4.32 ± 0.62, and 4.20 ± 0.62 L for normal, CM, and SA subjects, respectively), as did mean PEF (9.9 ± 1.5, 9.7 ± 1.1, and 9.3 ± 1.7 L·s⁻¹ for normal, CM, and SA subjects, respectively).

Force–velocity measurements. The results are presented in Table 1. No significant differences between conditions were observed in force, velocity, or power.

Incremental exercise to exhaustion. Only 15 subjects were taken into account for statistical analysis of this test; the expiratory volumes of three subjects were underestimated for one session because of full face mask displacement due to sweating. As can be seen in Figure 1, neither $\dot{V}O_{2max}$ nor maximal ventilation was significantly influenced by CM or SA mouthguards, nor was P_{amax} (286.6 ± 44.5, 283 ± 45.4, and 286.3 ± 44.5 W for normal, CM, and SA subjects, respectively). Maximal f remained unchanged (47.4 ± 8.7, 47.3 ± 9.6, and 47.9 ± 8.5 breaths·min⁻¹ for normal, CM, and SA subjects, respectively), and no significant difference was found for RPE (15.1 ± 2.1, 15.2 ± 1.7, and 15.2 ± 1.6 for normal, CM, and SA subjects, respectively).

The mean values for ventilation, f, and $\dot{V}O_2$, measured for each stage, except the maximal one, are summarized in Table 2. $\dot{V}O_{2max}$ was measured at the third stage of the exercise for three subjects, at the fourth stage for 10 subjects, and at the fifth stage for three. Because fourth-stage values were submaximal for three subjects only, the statistical analysis was not performed. No significant difference was found for the other submaximal stages.

DISCUSSION

The main finding of the present study was that neither ventilation nor $\dot{V}O_2$ were significantly altered by wearing

either an SA or a CM maxillary mouthguard. This was observed in both submaximal and maximal exercises. This lack of significant impact of maxillary mouthguards on ventilation and $\dot{V}O_2$ for submaximal work rates is in line with the previous study by Francis and Brasher (11) and the recent study by Delaney and Montgomery (7). However, both of these studies found that, at high exercise intensity, ventilation and $\dot{V}O_2$ were significantly decreased by wearing a mouthguard. In contrast, in the present study, neither $\dot{V}O_{2max}$, Pa_{max}, nor RPE measured at the end of maximal exercise were modified by wearing CM or SA mouthguards. Likewise, the experimental condition did not significantly affect FEV1 or PEF, whereas in the study by Francis and Brasher (11), these parameters showed a significant decrease. A possible explanation for these discrepancies is that the types of mouthguard used were not the same. In the study of Francis and Brasher (11), three types of stock mouthguard were tested. In the study by Delaney and Montgomery (7), an SA bimaxillary mouthguard was used. The stock mouthguards were bulky, and with a bimaxillary SA mouthguard, the mouth should be closed for retention. Consequently, the stock and bimaxillary SA mouthguards presumably altered airflow dynamics, particularly at high ventilation levels. Amis et al. (1) studied the effect of two types of CM mouthguard on the airflow dynamics of oral breathing at rest and concluded that although the mouthguards did obstruct the oral breathing route, the effect was mainly felt at rest and when the degree of mouth opening was restricted (by the test device, in the case of FVC, or by bimaxillary SA mouthguards). The results of the present study reinforce this hypothesis because wearing CM or SA mouthguards did not impair airflow dynamics. Surprisingly, the results demonstrated that both FIV1 and PIF were higher with CM mouthguards, although significantly so only when compared with SA mouthguards. A possible explanation could be found in the CM mouthguard study by Amis et al. (1), who suggested that mouthguards could alter the nature of the flow regimen in the oral cavity, making airflow somewhat less turbulent.

From the present results, it could be concluded that CM or SA maxillary mouthguards do not alter the breathing pattern or the work rate/$\dot{V}O_2$ ratio. Nevertheless, this conclusion should be made with caution regarding SA mouthguards. The results for airflow dynamics at rest demonstrate that volume and flow values tended to be lower in the SA mouthguard than in the CM mouthguard and normal conditions. This trend could be attributable to some subjects' SA mouthguard not being well fitted, with deficient retention. The trend for airflow dynamics to be altered with SA mouthguard at rest was not confirmed

during exercise. A possible explanation would be that SA mouthguard retention was enhanced during cycling by the pressure of the mask on the face. From the present and previous studies, it could be concluded that a mouthguard will not alter ventilation either at rest or during exercise as long as it is not bulky and has proper retention.

Another argument put forward by players against the extensive use of mouthguards is based on discomfort. Athletes, especially those playing in team sports, have many decisions to make quickly (21). It was hypothesized that discomfort would modify information processing by decreasing attention, as quantified by visual reaction time. However, the mean values of visual reaction time were not significantly altered by wearing the maxillary mouthguard. This result suggests that discomfort due to maxillary mouthguards is moderate at rest.

Force, velocity, and power output measured during explosive exercise were not significantly altered by wearing a mouthguard. To the best of our knowledge, only one study (3) explored the influence of increase in the vertical dimension of occlusion on explosive performance in athletes without occlusion problems. The authors observed that performance in the vertical jump was significantly increased by 5% when wearing a bite positioner (increase in vertical dimension of around 2–3 mm), but with no significant increase in lower-limb strength. This discrepancy could be related to the nonrandomized experimental conditions (systematically, first without and second with a MORA), subjects improving their vertical jump performance by improved coordination. Our present results did not corroborate the hypothesis that increasing the vertical jaw dimension in subjects without occlusion problems with maxillary mouthguards would increase strength during explosive exercise.

In summary, the present results demonstrate that wearing CM or SA mouthguards does not significantly influence the main physiological parameters generally associated with team sport performance; they did not alter ventilation or attention and did not increase explosive force and power. These findings provide an additional argument for medical staff and coaches to encourage athletes to wear individually fitted maxillary mouthguards, such as CM and SA models (which could be further adapted by a dentist). From the point of view of effective protection, CM mouthguards with a hard insert in particular should be recommended for use in sports with a high risk of orofacial injury (4).

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