Physiological effects of wearing mouthguards

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Mouthguards are considered by most authorities to be an essential part of equipment for players participating in body-contact sports. Mouthguards provide excellent dental protection but not all players use them, complaining of breathing difficulties and problems with speaking. Although information exists concerning dental trauma and mouth protector use, there are no reported data that quantify the physiological effects of wearing mouthguards. The purpose of this study was to measure the ventilatory and gas exchange effects of wearing a mouthguard. Ten healthy men and seven women aged 20–36 years (mean(s.d.) 27.2(5.2) years) were used as subjects. Forced expiratory air volume at 1 s (FEV_1) and peak expiratory flow rates (PEF) were measured on each subject while wearing either no mouthguard or one of three different over-the-counter mouthguards including one maxillary (mouthguard 1) and two different bimaxillary guards (mouthguards 2 and 3). To determine the effects of wearing each of the mouthguards during exercise, oxygen consumption ($\dot{V}O_2$) was measured while exercising on a cycle ergometer for 5 min at a light and heavy workload. An ANOVA of repeated measures was used to determine statistical differences. In each case, the wearing of a mouthguard significantly ($P < 0.05$) reduced FEV_1 and PEF in comparison with no mouthguard. FEV_1 was reduced 8% with mouthguard 1, and 12% and 14% with mouthguards 2 and 3 respectively. PEF was reduced by 7, 15 and 15.8% with mouthguards 1, 2 and 3 respectively. The wearing of the different mouthguards did not significantly change $\dot{V}O_2$ while exercising at the lower work level whereas $\dot{V}O_2$ was significantly ($P < 0.05$) reduced at the heavier workload. This surprising reduction in $\dot{V}O_2$ during heavy exercise may be due to a 'pursed-lip' type of breathing which has been shown to decrease CO_2 tension, increase oxygenation and exercise tolerance. It can be concluded that although mouthguards may be perceptably uncomfortable and restrict forced expiratory air flow, they appear to be beneficial in prolonging exercise by improving ventilation and economy.

Keywords: Mouthguards, exercise, ventilation, oxygen consumption

Introduction

Mouthguards are perhaps the most common form of protective equipment now worn in high contact sports. In 1963, the National Federation of State High School Athletic Associations and in 1974, the National Collegiate Athletic Association implemented regulations requiring mandatory mouth protector wear for football players participating in organized games. Since this legislation, dental injuries have almost been eliminated[1-3]. It has been shown that when football players wear mouth protectors, the incidence of dental trauma can be reduced to 0.6 per 100 players[4].

Although mouthguards have been shown to provide excellent dental protection, not all players use them because of complaints of being too uncomfortable, breathing difficulties and problems with speaking[2,5,6]. Many of the complaints about comfort can be attributed to improper design or fit and can easily be corrected by the team dentist by changing to a different type of mouth protector or fabricating a custom-made protector[4].

Although information has been published that describes the types, distribution and changes in dental trauma as a result of wearing mouth protectors, there has been no reported study that quantifies the physiological effects of wearing mouthguards and how this might relate to the complaints of breathing difficulties. Therefore, the purpose of this study was to measure the effects of wearing different types of over-the-counter mouthguards on maximal expiratory air flow parameters and gas exchange variables in order to determine their effect on work and economy of breathing and their possible relationship to the complaints of difficult breathing.

Methods

Subjects

The study population consisted of ten healthy men and seven women aged 20–36 years who were non-smokers and who had no history of any cardiorespiratory problems. Table 1 summarizes the demographic characteristics of these subjects. Participation in the study was strictly voluntary and

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Table 1. Physical characteristics of the 17 subjects

Characteristic	Mean	s.d.	Minimum	Maximum	s.e.m.
Age	27.2	5.2	20	37	1.3
Weight (kg)	72.72	15.59	53.18	104.09	3.90
Height (cm)	175.51	9.65	157.48	190.50	2.31

s.d., Standard deviation; s.e.m., standard error of mean

informed consent was obtained before initiation of the study.

Mouthguards

Three popular, commonly available over-the-counter mouthguards were purchased at a local sporting goods store. Mouthguard 1 (*Figure 1*) consisted of an unfitted, single upper maxillary guard made of a soft rubberized material. Mouthguard 2 (*Figure 2*) was an unfitted bimaxillary guard of the same material and construction as mouthguard 1. Mouthguard 3 (*Figure 3*) was a bimaxillary guard composed of a more rigid vinyl material with a small breathing hole between the upper and lower plates.
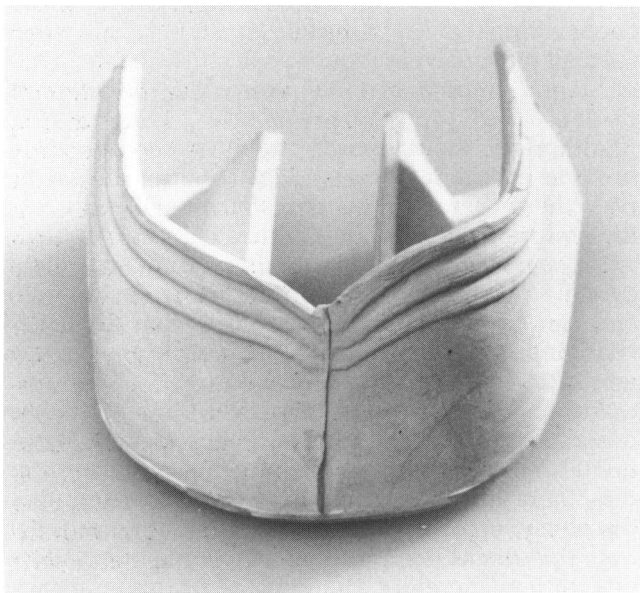

Figure 1. Frontal view of mouthguard 1

Figure 2. Frontal view of mouthguard 2 which is identical in structure to mouthguard 1 except it is bimaxillary with a hinge component

Figure 3. Frontal view of bimaxillary mouthguard 3

Measurements

An adult size Hans Rudolph two-way rubber face mask was used to collect expired gases. The face mask was made of light-weight, pliable plastic with a soft rubber gasket that fitted over the nose and around the mouth so that the subject could breath while wearing the mouthguard. Very low-resistance inhalation and exhalation valves in the mask permitted breathing without noticeable hindrance. FEV_1 was determined using a VS400 Volumetric Spirometer (Puritan-Bennett, Wilmington, MA, USA) and PEF was determined using a Wright Flow Meter (Armstrong Industries, Northbrook, IL, USA). Each subject's $\dot{V}O_2$ and minute ventilation (V_E) was determined from expired gases collected during the fifth minute of each of the four exercise periods. Values of oxygen consumption were determined using a standard open-circuit, semi-automated protocol; gas volumes were measured using expired gases collected in a Tissot spirometer; aliquots of expired gases were analysed for oxygen and carbon dioxide using PK Morgan oxygen and carbon dioxide analysers (PK Morgan, Andover, MA, USA). Both analysers were calibrated before and after each test using standardized gases.

Procedures

Each subject was tested on three different occasions separated by a period of 24–48 h. Each visit involved the testing of one of the mouthguards. The selection of the mouthguard was randomly determined. The order of testing at each visit is shown in *Figure 4*. Each visit consisted of the assessment of ventilatory function with and without the mouthguards followed by an exercise test. Ventilatory measurements with and without a mouthguard included a forced expiratory volume in 1 s (FEV_1) followed by the determination of the maximum flow rate in a single forced expiration (PEF). The average of the three trials was used for analysis. The trials were randomly
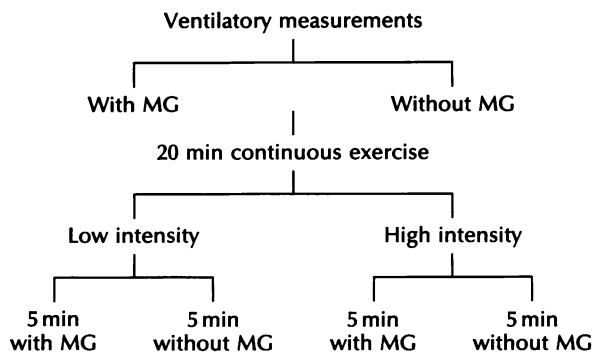
Ventilatory measurements

Figure 4. Sequencing of testing for each mouthguard (MG) which was randomized for each subject

performed with and without the mouthguards to eliminate learning bias.

The exercise test consisted of cycling an ergometer for a continuous 20-min period. The 20-min exercise period was randomly divided into four 5-min periods based on the intensity of exercise and the wearing of a mouthguard. The sequencing of the 20-min exercise period was: (a) 5 min exercise at the lower intensity workload with or without a mouthguard; (b) an additional 5 min exercise at the lower intensity workload with or without a mouthguard; (c) 5 min exercise at the higher workload with or without a mouthguard; (d) an additional 5 min exercise at the higher workload with or without a mouthguard.

In order to equate the work between the sexes, the intensity of work at the lower workload required the men to cycle at 100 W and women at 75 W. The heavier workload required the men to cycle at 150 W and women at 125 W. These two workloads were chosen in order to produce V_E values that would be above and below a V_E of 30–40 l/min. At a threshold of 30–40 l/min, an individual switches from nose to mouth breathing to lower the work of breathing[7]. The small standard deviation in oxygen consumption recorded at both the light and heavier workload (*Tables* 3 and 4) indicates that these workloads were approximately the same for both men and women. An ANOVA was used to determine if there were any statistically significant differences between gender and any of the measured variables. A P value < 0.05 was used as the minimal criterion for significance. Because there were no statistical differences, values for men and women were combined before performing an ANOVA of repeated measures on values obtained from wearing the different mouthguards and no mouthguard at all.

Results

Table 2 shows that each of the three mouthguards used in this study significantly reduced air flow (P < 0.05). Mouthguard 1 reduced FEV_1 by 8%, mouthguard 2 by 14% and mouthguard 3 by 12% in comparison with not wearing a mouthguard. Similarly, peak expiratory flow rates were significantly reduced by the different mouthguards (P < 0.05). Mouthguard 1 reduced PEF by 7% and mouthguards 2 and 3 each reduced PEF by approximately 15%.

Table 3 presents the effects of wearing the different mouthguards on ventilation and gas exchange during light intensity exercise. None of the values was significantly changed as a result of wearing a mouthguard. V_E averaged approximately 28 l/min, 20-s expiratory volume averaged 11 litres and the ratio of $V_E{:}\dot{V}O_2$ was constant at 21.4 for all three mouthguards.

Table 4 presents the effects of wearing the different mouthguards on ventilation and gas exchange during heavy intensity exercise. Each of the mouthguards significantly reduced $\dot{V}O_2$ and V_E in comparison with not wearing a mouthguard (P < 0.05). Decreases in $\dot{V}O_2$ ranged from 8% with mouthguard 2 to 10% with mouthguards 1 and 3. V_E decreased 14.5% while wearing mouthguard 1, 12.5% and 19% while wearing mouthguards 2 and 3 respectively. In contrast, the 20-s expiratory volume was significantly increased (P < 0.05) by the wearing of each mouthguard. Expiratory volume increased from 41% with mouthguard 2 to 59.5% with mouthguard 1. The ratio of $V_E{:}\dot{V}O_2$ was not significantly changed by the wearing of any of the mouthguards. There were no statistically significant differences between mouthguards of any of the physiological parameters while exercising.

Table 2. Effect of wearing one of three different mouthguards on ventilatory parameters in 17 subjects*

	FEV_1 (litres)	PEF (l/min)
No mouthguard	3.46(0.70)	508.65(70.25)
Mouthguard 1	3.17(0.16)†	472.88(68.44)†
Mouthguard 2	2.97(0.19)†	432.31(78.99)†
Mouthguard 3	3.04(0.86)†	428.38(65.02)†

* Values represent mean(s.d.); † values are significantly different (P < 0.05; ANOVA) from the values recorded with no mouthguard

Table 3. Effect of wearing one of three different mouthguards on gas exchange and ventilation during light exercise in 17 subjects*

	$\dot{V}O_2$ (ml/kg min^{-1})	V_E (l/min)	Expired volume (l/20 s)	$V_E{:}\dot{V}O_2$ (l/l)
No mouthguard	18.64(2.49)	30.15(10.53)	11.18(3.92)	23.20(3.54)
Mouthguard 1	19.03(3.74)	28.92(6.28)	11.68(3.67)	21.76(2.77)
Mouthguard 2	17.89(2.28)	27.99(8.50)	10.33(3.11)	21.47(2.58)
Mouthguard 3	18.74(4.35)	28.81(9.93)	11.21(3.26)	21.01(2.71)

* Values represent mean(s.d.)

Discussion

As might be expected, the restriction in air flow patterns shown in *Table 2* supports the frequent subjective comments that mouthguards create difficulty with breathing. Even though the double maxillary mouthguards reduced air flow more than twice that of the single mouthguard, subjects subjectively reported that the single mouthpiece restricted air flow to the same extent as the double mouthguard. At first glance, therefore, it would appear that the complaints of air flow restriction are substantiated and that the benefit of reduced trauma afforded by the mouthguard might be offset by the ventilatory and symptomatic disadvantages resulting from airway restriction. The physiological data recorded in *Table 4*, however, indicate the opposite.

Surprisingly, the data shown in *Table 4* appear to offer a physiological advantage to wearing mouthguards when exercising at the higher workload. Regardless of the type of mouthguard (single or bimaxillary), the physiological benefit during exercise is about the same. The decreases in $\dot{V}O_2$ and V_E that occur during heavy exercise while wearing a mouthguard may be similar to the changes produced by the technique of pursed-lip breathing (PLB) used with patients with chronic obstructive pulmonary disease (COPD)[8]. PLB has been shown to be an effective form of breathing that improves ventilation in COPD patients who might have a limited ventilatory reserve[8,9]. During PLB, less air has to be breathed to absorb a given amount of oxygen. Peak and mean expiratory flow rates are reduced, respiratory rate is decreased and tidal volume is increased. All these factors result in an improved alveolar ventilation and the enhancement of ventilation of previously under ventilated areas[9,10]. While the direct measurement of tidal volume was not recorded in the present study, indirect means of estimating air movement as indicated by 20 s expired volume and the direct measures of V_E and $\dot{V}O_2$ indicate that breathing with a mouthguard is analogous to PLB.

Mueller *et al.*[11] suggest that the symptom relief provided by PLB may be linked to the degree with which PLB increases tidal volume and decreases the respiratory rate. Since neither tidal volume nor respiratory rate were measured in this study it is uncertain whether the wearing of a mouthguard is the same phenomenon as PLB. However, the significant increase in expired volumes accompanied by a decrease in V_E that occurred as a result of wearing one of the three mouthguards (*Table 4*) indicates that events may be similar.

Another resemblance between PLB and exercising while wearing a mouthguard is the advantage to total body work economy. The consistency of the ratio of $V_E{:}\dot{V}O_2$ during heavy work despite the wearing of a mouthguard may reflect a reduction in the metabolic work of breathing. Decreases in absolute values of both $\dot{V}O_2$ and V_E shown in *Table 4* while wearing mouthguards suggest an improved alveolar ventilation and oxygenation which allows the individual to sustain a given rate of exercise with less metabolic cost. Similarly, Casciari *et al.*[12], in a study of the effect of PLB on exercise tolerance in patients with COPD, reported that PLB improved metabolic cost and improved performance without increasing the respiratory rate or decreasing arterial oxygen concentration.

Evidence of physiological impairments resulting from the wearing of mouthguards during light exercise is equivocal (*Table 3*). This might be expected to be due to the intensity of exercise which resulted in an average V_E of between 28 and 30 l/min which is below the 30–40 l/min level that requires an individual to shift to mouth breathing to meet increased air flow[7]. Without the requirement of mouth breathing, the PLB effect would not be induced.

From a physiological standpoint, therefore, it can be concluded that the wearing of mouthguards may actually produce an effective pattern of respiration during brief periods of heavy exercise which may improve tissue oxygenation and lower metabolic cost. Additional studies such as the measurement of changes in blood gases while exercising with a mouthguard are needed to delineate the mechanism by which mouthguards improve total body work economy.

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Table 4. Effect of wearing one of three different mouthguards on gas exchange and ventilation during heavy exercise in 17 subjects*

	$\dot{V}O_2$ (ml/kg min^{-1})	V_E (l/min)	Expired volume (l/20 s)	$V_E/\dot{V}O_2$ (l/l)
No mouthguard	30.46(4.37)	50.98(19.72)	11.18(3.92)	21.86(3.68)
Mouthguard 1	27.38(5.34)†	43.57(9.47)†	17.84(6.01)†	22.12(2.90)
Mouthguard 2	28.10(3.47)†	44.63(12.98)†	15.79(4.52)†	20.95(2.87)
Mouthguard 3	27.39(5.68)†	41.34(14.24)†	16.07(4.84)†	20.90(2.88)

* Values represent mean(s.d.); † values are significantly different ($P < 0.05$; ANOVA) from the control values recorded without the use of a mouthpiece

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