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THE FUNCTIONAL EFFICIENCY OF MOUTHGUARDS IN MARTIAL SPORTS

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ABSTRACT
Purpose. The aim of this study was to evaluate the influence of three different mouthguards on the airflow dynamics of oral breathing under increased ventilatory conditions at peak workload. **Methods.** Twenty volunteer male martial art athletes were subjected to cardio-respiratory examination on a treadmill. Four trials were performed, without a mouthguard and with a maxillary boil-and-bite mouthguard, bi-maxillary boil-and-bite mouthguard, and PlaySafe custom-made maxillary mouthguard. For each of the four tests, subjects performed an identical incremental test to determine VO_2max and other respiratory values. **Results.** Collected data were analyzed using descriptive analyses and paired-samples t tests. The results indicated similarity in almost all measured variables when testing with the custom-made PlaySafe maxillary mouthguard to values recorded without a mouthguard, while tests performed with the maxillary and bi-maxillary boil-and-bite mouthguards showed greater differences. **Conclusions.** The custom-made PlaySafe maxillary and maxillary boil-and-bite mouthguards do not significantly reduce airflow dynamics of oral breathing when compared with the bi-maxillary boil-and-bite, instead, these two types of mouthguards were found to positively affect aerobic capacity.

Key words: mouth protector, VO_2max, incremental test, contact sport

Introduction

The best way to keep the teeth protected for athletes who compete or train in any contact sport (such as football, basketball, rugby, hockey, or boxing) is to use a mouth protector. A mouth protector is a resilient protective device that covers the teeth and gums preventing or reducing the risk of injuries [1, 2]. This device is designed to minimally interfere with breathing and speaking while offering protection against concussions and internal oral lacerations as well as protect the temporomandibular joints [2–5]. The first mouthguard was developed in 1890 by English dentist Woolf Krause as a protective device for boxers. By the 1930s mouthguards have become, and since then have remained, a required piece of safety equipment in boxing [4, 5]. It is worth mentioning that Jack Dempsey and Gene Tunney were probably the last heavyweight champions to fight without a mouthpiece (1927) [4]. The majority of scientific studies regarding the use of mouthguards have confirmed that athletes who use any type of mouthguard had significantly reduced incidence of oral-facial injuries [3, 6–9]. Knapik et al. [8] found that athletes who practice without any type of mouthguard have a 1.6–1.9 times higher risk of suffering injured than athletes who use a mouthguard. According to Badel et al. [10], in order to reduce the number of injuries in the oral regions, athletes who compete in contact sports should be recommended to use mouthguards, whereas Quarrie et al. [3] strongly advised the use of mouthguards by all athletes. Manufacturers of mouthguards claim that their products provide approximately 30% more protection for the teeth and jaws [11]. According to Vastardis [12], athletes who not use protective mouthguard are about 60 times more likely to sustain oral damage.

Mouthguards are available in a large range and variety of products, from models commonly available at sportswear stores to professionally manufactured custom-made models [13]. Although, mouthguards vary in terms of cost, comfort, and effectiveness, a prototypical mouthguard should fulfill a number of basic requirements, such as durability, resilience, comfort, ease of cleaning, and should not affect breathing, swallowing, or speaking [2]. As mouthguards can harbor a wide range of pathogenic microorganisms, proper hygiene is required. This is commonly performed by immersing the mouthguard in an antimicrobial solution between uses. Other recommended options include simply replacing the mouthguard at least once a week or using a single-use mouthguard [14, 15]. Finch et al. [16] did find that custom-made mouthguards offered significantly better protection than the commonly available and inexpensive mouthguards found in almost all sportswear stores. However, Wisniewski et al. [17] did not find any differences between these two types of mouthguards.

One common complaint of athletes is that mouthguards are uncomfortable to wear, causing nausea and impeding speech and breathing. The use of mouthguards

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while competing or exercising in contact sports may also potentially increase air-flow resistance during mouth respiration, causing a reduction in the lung oxygen capacity [18]. A study by Arent et al. [19] indicated that athletes perform better when they use a dentistry-designed mouthguard instead of a traditional mouthguard. However, Gebauer et al. [20] did not find evidence of custom-made mouthguards having any effect on ventilation, maximal oxygen uptake, and heart rate in athletes running at varying intensities (10 km/h and 12 km/h) or when performing at maximal effort. Francis and Brasher [21] tested different mouthguards and did not find significantly different VO_2max values when exercising at low intensity, although at a higher intensity VO_2max was significantly ($p < 0.05$) reduced. Furthermore, a study completed by Garner et al. [22] showed that use of a custom-fitted mandibular mouthguard resulted in improved gas exchange parameters such as increases in oxygen uptake, carbon dioxide production, and respiration. In addition, a number of studies reason that even if mouthguards may restrict forced expiratory air flow, they appear to be useful in prolonging exercise by improving ventilation [21, 23–25].

Consequently, the aim of this study was, without doubting the preventive efficiency of mouthguards in regards to injuries, to evaluate the influence of different mouthguards on the airflow dynamics of oral breathing under increased ventilatory demands at peak workload by use of a maximal spiroergometric test on a treadmill.

Material and methods

The present study was part of a larger project called "Evaluation of the impact different mouth-guards have on various physiological parameters" and conducted at the Institute of Sports Anthropology in Pristina, Kosovo throughout 2009–2010.

A group of 20 male elite martial arts (boxing and karate) athletes (mean age 21.4 years) from Kosovo voluntarily underwent four trials of an incremental spiroergometry test on a treadmill test to determine VO_2max at peak workload. All participants were healthy and free of any injury or any other conditions that could limit their ability to complete physiological testing. Participants' age, height, and mass are presented in Table 1. The exploratory procedures of this study were conducted in accordance to the Declaration of Helsinki, and received approval from the Ethics Committee of the University Clinical Center in Pristina, Kosovo. After explaining the risks and benefits of the study, each of the athletes provided their written approval prior to participation.

The participants were tested on four different occasions separated by a period of 48 h at approximately the same time of day (09.00–10.00). The athletes were instructed that on the test day they were to be normally hydrated, eat a light meal 2 h prior the test but not drink, eat, or consume any substances that could affect normal physiological functioning (i.e., tea, coffee, alcohol, or nicotine). They were also advised to refrain from strenuous activity for at least 24 h before each trial.

The first spiroergometric test (T1) was performed without a mouthguard. The second spiroergometric test (T2) was performed with a bi-maxillary boil-and-bite mouthguard, which was made of a soft rubberized material with two small breathing holes between the upper and lower plates. The third spiroergometric test (T3) involved a maxillary boil-and-bite mouthguard that consisted of single upper maxillary guard also made of a soft rubberized material. The fourth spiroergometric test (T4) had the athletes complete the trial with a custom-made maxillary mouthguard (PlaySafe, UK), which was individually fabricated for each athlete from thermoplastic materials using dental impressions.

Before testing, participants were familiarized with the experimental test procedures and equipment. Upon arrival in the laboratory, the participants rested for a period of 20 min. Afterwards, each athlete stretched their muscles for 2–3 min and performed a warm-up that consisted of running on the treadmill (model T-170, Cosmed, Italy) for 5 min at a speed of 5 km/h with 0% inclination.

The incremental treadmill test was then performed at an inclination of 1% at an initial velocity of 7 km/h increased by 1 km/h every minute of the test. The test was performed until the athlete reached exhaustion. They then completed a cool-down by walking at 5 km/h for another 3 min.

During each test respired gases were collected on a breath by breath basis and analyzed using a Quark b2 automated open-circuit gas analysis system (Cosmed, Italy). In order to provide reliable VO_2max measures, the gas analyzer was regularly maintained and calibrated using ambient air (20.93% oxygen, 16% carbon dioxide) and certified standard gases (16% oxygen, 5% carbon dioxide). Additionally, the turbine flow meter (through which the respired air flowed) was calibrated with a 3 liter calibration syringe. The gas analysis system was used to analyze the following respiratory variables:

– t – test duration expressed in minutes;
– RF – breathing frequency (respiratory rate) indicated by THE number of breaths per minute;
– VT – tidal volume calculated by the amount of air inhaled or exhaled with each breath;
– VE – minute ventilation as the product of respiratory rate and tidal volume, or the amount of air that an athlete breathes per minute;
– VO_2 – oxygen consumption as the measure of the volume of oxygen used by the athlete;
– VCO_2 – rate of elimination of carbon dioxide during the expiration phase;
– VO_2maxrel – maximal oxygen consumption (uptake) indicated by the maximum amount of oxygen that can be utilized relative to kg of body mass (ml/kg/min).

The mean values of the tests performed with the different types of mouthguards were compared with those attained without a mouthguard. Systematic differences between the four tests were expressed as descriptive statistical parameters, where the statistical significance of differences was verified using paired-samples *t* tests. All statistical testing was two-tailed with the level of statistical significance set at $p < 0.05$. Statistical procedures were conducted with SPSS ver. 17 for Windows (IBM, USA).

Results

Descriptive statistics of the measured variables for each of four tests are summarized in Tables 1–4. Comparisons between the mean values measured during the tests with the three different types of mouthguards to those recorded without a mouthguard found systematic differences, suggesting that the three types of mouthguards have a different impact on the airflow dynamics of oral breathing under increased ventilatory conditions at peak workload. An example of changes in the ratio between O_2 uptake and CO_2 elimination recorded from one of the participants is presented in Figures 1–4 for each of the tests.

The significance of the registered differences was analyzed using paired-samples *t* tests, using the values recorded without the mouthguard as a baseline. Evaluation of mean differences and the significance for each separate variable is shown in Table 5.

The results indicated that while testing with the bi-maxillary bite-and-bite mouthguard, athletes featured significantly lower breathing frequency ($p < 0.00$), greater tidal volume ($p < 0.02$), and lower minute ventilation ($p < 0.00$) when compared with testing without a mouthguard. Significant differences were also found for the maxillary bite-and-bite mouthguard, with the athletes featuring significantly longer test duration ($p < 0.01$), lower respiratory rate ($p < 0.00$), greater tidal volume ($p < 0.00$), and greater elimination of CO_2 ($p < 0.04$) when compared with values recorded without a mouthguard. Testing with the custom-made PlaySafe maxillary mouthguard showed the athletes featured significantly ($p < 0.00$) greater tidal volume, with no significant differences for the other variables when testing without a mouthguard.

Discussion

The purpose of this study was to evaluate the functional efficiency of three types of mouthguards by comparing respiratory variables during a spiroergometric test. These variables included breathing frequency (RF), tidal volume (VT), minute ventilation (VE), oxygen consumption (VO_2), carbon dioxide elimination (VCO_2), and maximal oxygen uptake relative to body mass (VO_2maxrel). The tests found systematic differences in almost all measured variables between the different types of mouthguards and without a mouthguard. Analyses of the descriptive data (Tab. 1–4) and the mean differences between paired variables (Tab. 5) allowed for the conclusion that the custom-made mouthguards by PlaySafe permitted athletes to perform with the highest values of maximal relative oxygen uptake (VO_2maxrel), minute ventilation (VE), oxygen consumption (VO_2),

Table 1. Characteristics of participants and descriptive statistics of Test 1 – without mouthguard

	Min	Max	$\bar{x}$	*SD*
Age	17.00	34.00	21.4	4.86
Height	158.50	189.00	175.80	6.41
Mass	53.50	94.90	71.79	8.91
t	11.00	16.00	13.00	1.41
RF	35.93	72.12	51.46	9.55
VT	1.81	3.25	2.59	0.31
VE	90.91	191.11	132.42	23.63
VO_2	2648.02	4452.67	3683.59	573.10
VCO_2	3072.49	4912.93	4075.87	599.64
VO_2maxrel	38.38	64.53	51.47	6.49

Table 2. Descriptive statistics of Test 2 – bi-maxillary boil-and-bite mouthguard

	Min	Max	$\bar{x}$	*SD*
t	8.00	15.00	12.80	1.61
RF	25.20	56.29	39.92	9.08
VT	2.29	4.19	2.88	0.52
VE	89.90	139.45	111.41	13.86
VO_2	3069.65	4169.13	3590.08	339.59
VCO_2	3467.92	4574.26	4004.06	331.77
VO_2maxrel	32.84	61.76	49.21	7.03

Table 3. Descriptive statistics of Test 3 – maxillary boil-and-bite mouthguard

	Min	Max	$\bar{x}$	*SD*
t	12.00	16.00	13.61	1.18
RF	32.15	66.96	45.40	9.57
VT	2.09	4.04	2.93	0.48
VE	107.10	184.82	130.01	19.72
VO_2	2913.39	4574.16	3760.74	494.33
VCO_2	3544.68	5373.19	4355.65	496.47
VO_2maxrel	39.58	67.77	52.65	6.48

Table 4. Descriptive statistics of Test 4 – custom-made PlaySafe maxillary mouthguard

	Min	Max	$\bar{x}$	*SD*
t	12.00	16.30	14.09	1.12
RF	38.71	63.63	46.88	8.33
VT	2.67	3.63	3.09	0.34
VE	113.47	180.49	143.18	19.19
VO_2	3276.56	4843.86	4071.61	520.47
VCO_2	3822.18	5480.12	4721.94	519.98
VO_2maxrel	47.83	64.80	55.53	5.57

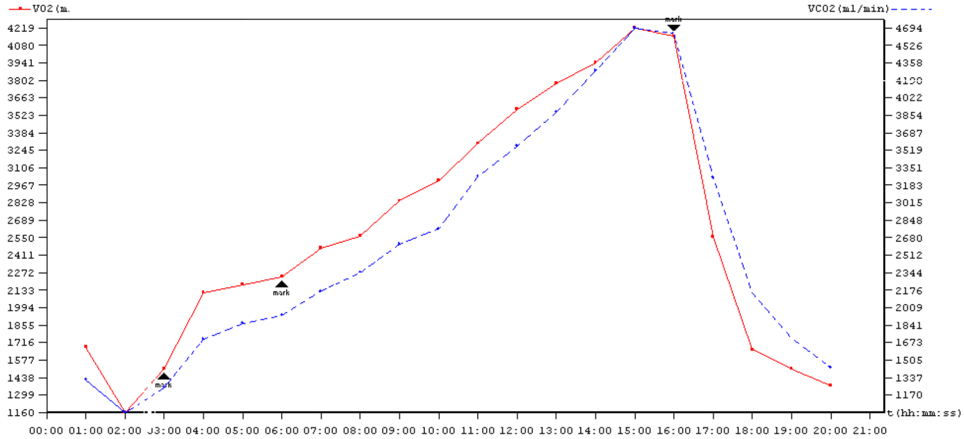

Figure 1. Graphic presentation of O_2 uptake and CO_2 elimination without a mouthguard

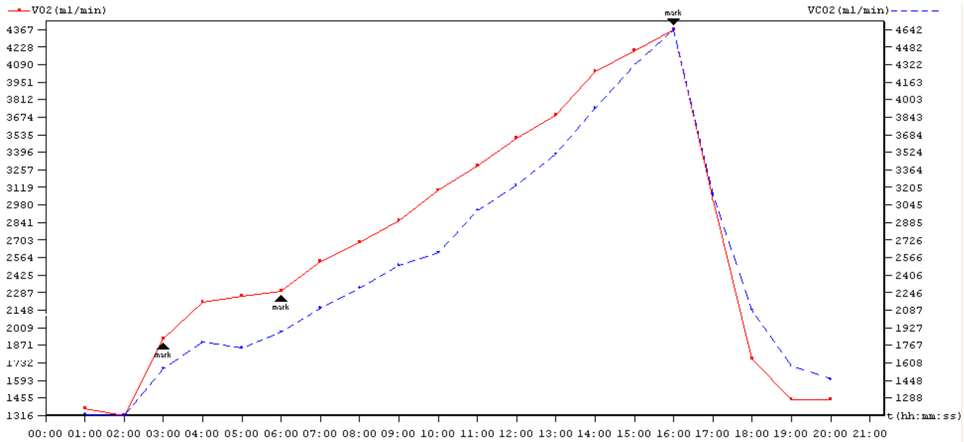

Figure 2. Graphic presentation of O_2 uptake and CO_2 elimination with the bi-maxillary boil-and-bite mouthguard

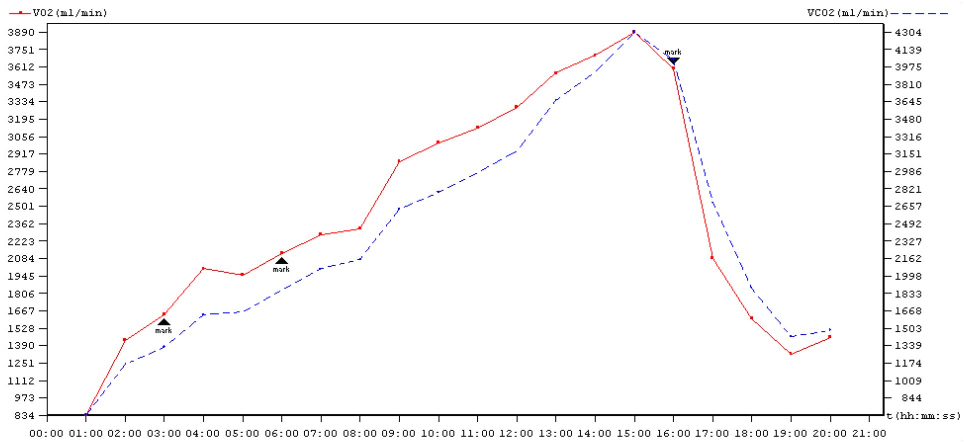

Figure 3. Graphic presentation of O_2 uptake and CO_2 elimination with the maxillary boil-and-bite mouthguard

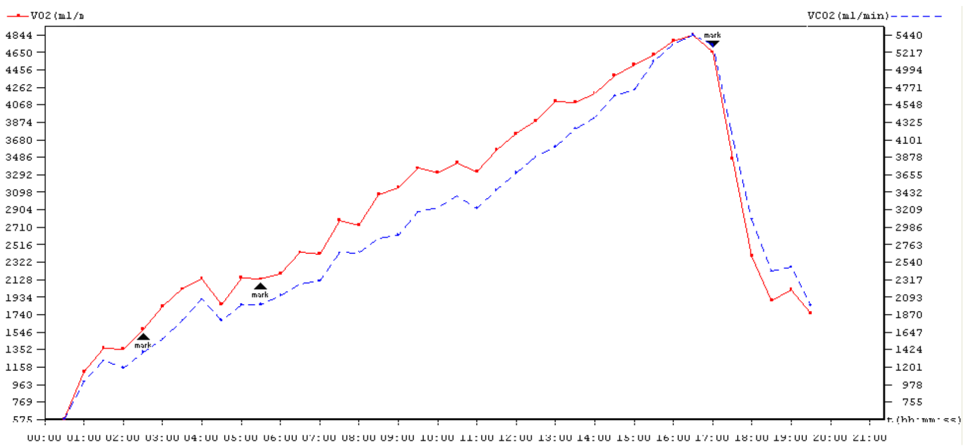

Figure 4. Graphic presentation of O_2 uptake and CO_2 elimination with the custom-made PlaySafe maxillary mouthguard

Table 5. Mean differences between paired variables and results of paired-samples *t* tests

	Test 1:2			Test 1:3			Test 1:4		
	Mean differ.	*t*	*p*	Mean differ.	*t*	*p*	Mean differ.	*t*	*p*
t – *t*	0.20	0.89	0.39	–0.61	–3.06	0.01**	–0.79	–1.34	0.21
RF – RF	11.55	5.67	0.00**	6.06	4.25	0.00**	4.60	1.44	0.19
VT – VT	–0.29	–2.48	0.02*	–0.34	–3.67	0.00**	–0.46	–5.63	0.00**
VE – VE	21.01	4.94	0.00**	2.41	0.70	0.50	–8.11	–0.95	0.37
VO_2 – VO_2	93.51	1.02	0.32	–77.15	–0.76	0.45	–324.52	–1.15	0.28
VCO_2 – VCO_2	71.81	0.68	0.50	–279.78	–2.17	0.04*	–540.27	–2.05	0.07
VO_2maxrel – VO_2maxrel	2.26	1.52	0.15	–1.17	–0.84	0.41	–4.48	–1.57	0.15

* significance at < 0.05, ** significance at < 0.01

and elimination of carbon dioxide (VCO_2) when compared with the other tests. Similar results were reported by other authors [21, 23, 24], finding the custom-made PlaySafe and maxillary bite-and-bite mouthguards to offer a physiological advantage when exercising at higher workloads when compared with testing without a mouthguard. In this study, the lowest values of the measured variables were found with the bi-maxillary bite-and-bite mouthguard. Overall, the results found that the mouthguard most in line with the variables recorded during testing without a mouthguard was the custom-made PlaySafe maxillary mouthguard, while other two mouthguards (bi-maxillary and maxillary boil-and-bite) showed greater differences.

One common variable that significantly differentiated the tests without a mouthguard and the three with a mouthguard was VT (Tab. 5). In the three tests completed with a mouthguard, significant higher values of VT were recorded than without a mouthguard, with respectively lower values of respiratory rate. This is probably due to the fact that athletes wearing mouthguards achieved gas exchange mainly by increasing the depth of respiration under increased ventilatory conditions at peak workload, whereas during testing without a mouthguard this was achieved by increasing breathing frequency (respiratory rate). Some studies suggest that the use of oral appliances that advance the condyles of the mandible down and forward by 8 mm may improve air flow [25] and that these devices have are helpful for individuals with sleep apnea [23, 25–27]. In a sports context, an improvement of breathing mechanics leads to reduced work of the respiratory muscles. This can consequently result in a decreased need for oxygen and blood flow by these muscles and may therefore allow for prolonged exercise [28]. Harms et al. [29] also observed that decreased work of the respiratory muscles led to increased duration of exercise performed until exhaustion.

Subjective reporting by the tested athletes included complaints that they had difficulty breathing and swallowing with the bi-maxillary boil-and-bite mouthguard, whereas most complained that the maxillary boil-and-bite mouthguard fell out from the upper jaw and caused breathing difficulties. It is worth mentioning that no complaints were made after testing with the custom-made PlaySafe maxillary mouthguard.

Conclusions

Testing found that neither type of mouthguard had any significant impact on maximal oxygen uptake (VO_2max). These results are congruent to findings by other authors [20, 21, 23, 24, 30–32]. It can be concluded that a custom-made PlaySafe maxillary and maxillary boil-and-bite mouthguard do not significantly reduce the airflow dynamics of oral breathing compared with a bi-maxillary boil-and-bite mouthguard. Instead, it was found that the custom-made PlaySafe maxillary mouthguard and the maxillary boil-and-bite mouthguard increased values of tidal volume (VT), minute ventilation (VE), the duration of effort until exhaustion (*t*), oxygen uptake (VO_2), carbon dioxide elimination (VCO_2), and relative maximal oxygen uptake (VO_2maxrel).

When considering the subjective feedback of the athletes, the results of the present study, and findings made by other authors, contact sports athletes are advised to use a custom-made PlaySafe maxillary mouthguard for training and competition, or, if unavailable, to choose a maxillary boil-and-bite mouthguard as it least impairs aerobic capacity than the bi-maxillary boil-and-bite mouthguard.

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