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Research Article

Vented Mouthguard Effects on Cardiopulmonary Parameters in Basketball: A Pilot Study

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Abstract

Mouthguards improve the safety in sports. An airway obstruction and a decrease in the athletic performance are theoretical drawbacks. There is evidence that the performance is not reduced but even improved. The purpose was to evaluate the effects of a vented mouthguard on cardiopulmonary parameters in a basketball course. Eight male basketball players from the Second League of Leipzig completed a basketball specific course at medium and high intensity without and with a vented mouthguard on two consecutive days. The effects of a vented mouthguard on oxygen uptake, ventilation, blood lactate and heart rate were investigated. A comfort specific questionnaire was completed. Breathing rate, ventilation, heart rate, and lactate were all significantly lower with the mouthguard in medium and high intensity exercise testing. No significant differences were observed in VO_2 max and maximum heart rate. With mouthguard, ventilation and lactate were significantly reduced. It is hypothesized that the aerobic metabolism was improved due to changed biomechanics and a reduced peripheral cardiorespiratory drive. VO2 max was not reduced and the athletes must not expect a loss of performance.

Keywords: *Mouthguard; Aerobic Performance; Ventilation; Basketball*

Introduction

Although mouthguards reduce the incidence of injuries, many athletes do not use them because of possible effects on breathing, communication, and performance. Delaney and Montgomery [1] measured a negative impact on maximum ventilation and oxygen consumption with a boil-and-bite mouthguard. However, there is evidence that their use may not compromise but sometimes even improve the performance. Improvements in power output (peak exercise) or specific performance (e.g. counter-movement vertical jumps) have been described [2,3]. Other studies showed no impairment [4]. Positive effects on ventilation and sports ability were also related to the use of custom-made mouthguards [5].

Recently a "vented" mouthguard with breathing channels was developed. Bailey., *et al*. [6] investigated the effects in 15 recreationally trained males on cardiorespiratory responses in a maximum exercise and physical agility test. The vented mouthguard (VentMG) was related to higher workloads and vertical leaps. To the best of our knowledge, no basketball specific studies have been performed. Therefore the aerobic performance and related ventilatory and cardiorespiratory parameters were measured in a newly developed basketball specific course (BSC).

Material and Methods

Subjects

8 male basketball players between 19 and 37 years (height: 193 ± 9 cm, weight: 89 ± 10.49 kg) from the Second League participated in the study after informed consent. The exclusion criteria were any orthopedic, metabolic, or cardiorespiratory diseases. The investigation was approved by the Ethics Committee of the University of Leipzig. All subjects trained three hours daily five times per week. The players completed two randomly assigned trials without mouthguard or the "vented" mouthguard in a basketball specific course (BSC).

Mouthguard

The "vented" boil-and-bite "Nike adult max intake" mouthguard was used (Nike, Beaverton, OR, USA). It has patented breathing channels ("O-Flow ™"), designed to improve the ventilation and therefore the oxygen uptake. These additional air inlets should not restrict the breathing. This mouthguard was placed in boiling water for 30 seconds. Then it was carefully placed in the mouth to cover the upper teeth, and the subject was instructed to firmly bite down. A moderate pressure was placed on the lips and cheeks for 30 seconds. The mouthguard was then removed and washed with cold water.

Questionnaire

A questionnaire was completed after the tests [1,7]. In a scale from 0 (bad) to 10 (excellent) the comfort of the VentMG, and in a scale of 0 (not at all) to 5 (extremely) a dry mouth, thirst, burden, nausea, and retching were rated. The players also completed a questionnaire of mouthguard use and orofacial injuries.

Study Design

A controlled within-subject repeated-measure design was used. The randomized sessions occurred on two consecutive days. On each day the subjects completed a basketball specific course (BSC) at medium and high load.

Concept of the basketball specific course

The basketball specific course included all relevant competitive movements of a game. For reproducible loads, the running speed was established by an audio signal. Therefore, similar loads could be ensured due to the almost identical motion sequences.

NBA Data basis and use for the basketball specific test

The basketball specific course was based on elements which had been selected from the statistics of the National Basketball League (NBA, season 2013/2014). The components which represent basic offensive and defensive game situations were used. All game specific elements were taken together in a 10 minutes period (Table 1).

	NBA Stats			Specific Course (Round)			Difference %
Elements	**N**	**Mean**	**SD**	**1-3**	**4-6**	**1-6**	
Duration of ball-possession (min)	216	1.01	0.56	2.26	2.46	2.36	234
Distance (m)	216	760	40	950	950	950	125
Distance in offence (m)	216	410	30	560	560	560	137
Distance in defence (m)	216	350	20	390	390	390	111
Average speed (km/h)	216	4.55	0.23	7.15	8.04	7.60	167
Average speed (km/h) offense	216	4.86	0.31	8.01	8.93	8.47	174
Average speed (km/h) defense	216	4.23	0.21	6.29	7.14	6.72	159
Touches	216	10.59	2.65	9.00	9.00	18.00	170
Passes	216	7.85	2.37	3.00	3.00	6.00	131
Rebounds	216	1.22	0.55	6.00	6.00	12.00	984
Drives	216	0.45	0.47	3.00	3.00	6.00	1333
Catch and shoot field goal attempts	216	0.64	0.41	3.00	3.00	6.00	938

Table 1: *Relevant elements of Sports VU database, their real values (NBA Stats), fixed course values (rounds) and the differences (%) in comparison (NBA stats vs. BSC).*

Test configuration

A regular basketball court was used. The distances between the elements were set according to the average mileage of a player during a game. The average speed of each section was calculated and used for the setting of an audio signal. These signals were used for the pacing of lap durations and rest periods. The pace was set by marks on the ground, which had to be reached in the moment of the audio signal. In a number of pre-tests it was obvious, that reproducible and reliable lap times were maintained. The measuring error was less than 1 second per round. This is consistent with former running tests [8].

The test duration was fixed to 10 minutes. The medium intensity load (Test 1) reflected the average load of NBA games. For the high intensity level (Test 2), the speed was increased and the breaks were decreased by 12 % of Test 1. Both tests were performed with and without the mouthguard. Each test consisted of three runs (run 1,2,3), and each run consisted of two rounds (Table 2 and 3).

	Round A	Break after round A	Round B	Break after round B	Exercise duration	Total duration
Test 1 (s)	39.20	11.36	22.16	22.70	184.08	286.26
Test 2 (s)	34.50	10.00	19.50	20.00	162.00	252.00

Table 2: *Timetable for the intensities, rounds and breaks by the audio signal for the BSC. Each run consisted of two rounds. The intensity of Test 1 was based on the average NBA values. In Test 2 the intensities were increased by 12%, and the breaks reduced by 12%.*

Element	Movement	Duration (s)
1 (Round A)	4 m speed steps forward, backward left side, right side	6.00
2 (Round A)	Receiving a throw in and dribble 26 m forward, 5 m backwards, cover dribbling 3 m, drive and lay up	11.70
3 (Round A)	Two vertical jumps on each corner of the basket board, slide 4 m	10.00
4 (Round A)	Defense slide 6 m, ends with back pivot zigzag sprint: 3 x 6 m sprint, each ends with back pivot, followed by 15 m sprint	11.50
5 (Round B)	20 m zigzag dribbling	7.00
6 (Round B)	Pass, followed by 7 m sprint, ends with back pivot, catch and shot	7.00
7 (Round B)	6 m run to free throw line, receiving pass and shot, followed by 22.5 m sprint	8.16

Table 3: *Basketball specific movements and durations for Test 1 (medium intensity). Run A (elements 1-4) is focused on coordinative, agility and ball handling movements. Run B (elements 5-7) reflected the typical phases of running dominated game situations. In Test 2 the intensities were increased by 12 %, and the breaks reduced by 12%.*

Exercise testing

All parameters were measured using either no mouthguard (NoMG) or the "vented" boil-and-bite mouthguard (VentMG).

Exercise conditions: Continuous measurements: heart rate (HR), oxygen uptake (VO_2), ventilation (VE), tidal volume (VT), respiration rate (RR), carbon dioxide output (VCO_2). Spiroergometric data (K4b^2, Cosmed, Italy) were measured. VO_2 and VCO_2 values were calculated from the end-expiratory gas concentrations and ventilation. The ventilation was calculated as the product of breathing rate and tidal volume. All maximum values were calculated for the last 10 seconds of Test 2 (run 4,5,6).

The blood sampling for the lactate measurement (20 μl) was done prior to the warm-up, during each break, and immediately after the completion of each test (Super GL, ISO 7550, Germany).

Statistical Analysis

All data were presented as the means ± SD. All statistical tests were paired t-tests (control vs. vented mouthguard). Gauss distribution was confirmed using the Kolmogorov-Smirnov normality test. A p-value < 0.05 was considered significant. All analyzes were performed using the GraphPad InStat software (GraphPad Software, La Jolla, CA 92037 USA).

Results and Discussion

The calculation with included breaks reflects all physiological conditions due to the exercise and recovery periods, such as O_2 debt and the increased post exercise ventilation and heart rate. In summary the breathing parameters, heart rate and lactate were markedly lower with VentMG, whereas the VO_2 values were almost equal (Table 4).

Parameter	Intensity	Mean (SD)		p-value
		VentMG	NoMG	
Oxygen consumption (l x min^{-1})	Medium	3832 (382)	3970 (391)	n.s.
	High	3995 (416)	3997 (506)	n.s.
Carbon dioxide output (l x min^{-1})	Medium	3720 (425)	4025 (487)	< 0.049
	High	4004 (608)	3988 (412)	n.s.
Heart rate (bpm)	Medium	169 (12)	175 (12)	< 0.022
	High	177 (12)	180 (10)	< 0.028
Ventilation (l x min^{-1})	Medium	120.5 (17.90)	133.9 (18.29)	< 0.008
	High	137.8 (19.70)	151.9 (20.00)	< 0.023
Breathing rate (breath x min^{-1})	Medium	46.28 (7.40)	50.5 (5.90)	< 0.008
	High	52.38 (7.10)	57.24 (5.50)	< 0.001
Tidal volume (l)	Medium	2.68 (0.32)	2.73 (0.27)	n.s.
	High	2.69 (0.42)	2.72 (0.35)	n.s.
Respiratory quotient	Medium	0.99 (0.10)	1.01 (0.10)	n.s.
	High	0.98 (0.07)	1.00 (0.06)	n.s.
Blood lactate (mmol x l^{-1})	Pretest	1.44 (0.69)	1.22 (0.30)	n.s.
	Medium	6.93 (1.17)	9.93 (2.20)	< 0.008
	High	9.25 (2.07)	12.39 (3.37)	< 0.008

Table 4: *Exercise results with breaks included.*

The heart rate, ventilation, breathing rate and lactate values were all lower with VentMG in Test 1. In Test 2, the ventilation, breathing rate, and lactate were markedly lower with VentMG. The FeO_2 values were lower and the FeCO2 values were higher, indicating an increased oxygen extraction with VentMG. The ventilation and breathing rate were markedly higher in Test 2, whereas VO_2 max was almost equal (Table 5).

Parameter	Intensity	Mean (SD)		p-value
		VentMG	NoMG	
Oxygen consumption (ml x min^{-1})	Medium	3969 (347)	4080 (366)	n.s.
	High	4190 (459)	4170 (382)	n.s.
	Maximum	4406 (433)	4450 (441)	n.s.
Heart rate (bpm)	Medium	167.8 (12.30)	175.0 (11.00)	< 0.001
	High	176.9 (12.40)	179.1 (9.22)	n.s.
	Maximum	179.6 (9.70)	181.1 (9.00)	n.s.
Ventilation (l x min^{-1})	Medium	124.9 (16.90)	137.7 (17.40)	< 0.001
	High	145.4 (21.40)	156.9 (18.20)	< 0.012
	Maximum	151.4 (23.70)	162.6 (20.00)	< 0.022
Breathing rate (breath x min^{-1})	Medium	47.9 (7.30)	51.1(5.30)	< 0.011
	High	54.62 (6.69)	57.7 (5.33)	< 0.001
	Maximum	56.8 (7.20)	60.5 (5.80)	< 0.007
Tidal volume (1 x min^{-1})	Medium	2.66 (0.30)	2.73 (0.22)	n.s.
	High	2.71 (0.41)	2.77 (0.27)	n.s.
	Maximum	2.70 (0.43)	2.72 (0.36)	n.s.
FeO_2 (vol %)	Medium	16.93 (0.44)	17.19 (0.36)	< 0.021
	High	17.30 (0.44)	17.60 (0.25)	< 0.024
	Maximum	17.25 (0.55)	17.52 (0.30)	n.s.
$FeCO_2$ (vol %)	Medium	3.93 (0.53)	3.80 (0.33)	n.s.
	High	3.63 (0.41)	3.36 (0.18)	< 0.048
	Maximum	3.67 (0.19)	3.36 (0.19)	< 0.041
Expiration time (s)	Medium	0.69 (0.14)	0.64 (0.08)	n.s.
	High	0.60 (0.12)	0.57 (0.08)	n.s.
	Maximum	0.56 (0.12)	0.53 (0.08)	n.s.
Inspiration time (s)	Medium	0.60 (0.069)	0.65 (0.09)	< 0.0035
	High	0.52 (0.04)	0.55 (0.05)	< 0.0008
	Maximum	0.49 (0.04)	0.52 (0.05)	< 0.006
Inspiration time/tidal volume time (s)	Medium	0.49 (0.04)	0.49 (0.02)	n.s.
	High	0.48 (0.03)	0.48 (0.02)	n.s.
	Maximum	0.48 (0.03)	0.49 (0.04)	n.s.
Respiratory quotient	Medium	0.98 (0.05)	1.02 (0.08)	n.s.
	High	1.00 (0.06)	1.01 (0.06)	n.s.
	Maximum	0.99 (0.07)	0.97 (0.07)	n.s.

Table 5: *Exercise results without breaks. For the maximum values, means of the last 10 s from Round B of the runs 4, 5 and 6 were taken.*

Mouthguard wear

One from eight basketball players reported to use a custom fitted mouthguard. All other players had never used a mouthguard. The reasons were "never thought about it" (30.8 %), followed by "uncomfortable to wear" (23.1 %), "speaking interference" (15.4 %), and 7.6 % each "breathing interference", "not at high risk for dental injury", and "a lot of effort". All basketball players believed in the protective role of mouthguards.

Orofacial injury

Five from eight basketball players had orofacial injuries: lip or cheek lacerations (n = 5), and each n = 1: mandible luxation, tooth fracture, tooth loss, and tongue injury (multiple responses were possible). After tooth fracture one basketball player regularly used a custom-fitted mouthguard.

Mouthguard comfort and complaints

The VentMG assessments of fitting, stability on running, comfort, and breathing as well as the complaints are presented in table 6.

VentMG Impairment	Value in a scale from 0 (bad) to 10 (excellent)	VentMG Complaints	Value in a scale from 0 (not at all) to 5 (extremely)
Fit	8.25 ± 0.46	Dryness	2.50 ± 1.07
Stability	8.13 ± 0.83	Thirst	2.25 ± 0.89
Comfort	7.50 ± 0.76	Nausea	0.50 ± 1.07
Breathing	7.25 ± 0.89	Retching	0.63 ± 1.41
Communication	4.88 ± 1.73		

Table 6: *Mean scores of impairment and complaints by VentMG.*

The exercise performance and cardiopulmonary parameters were measured in a newly established basketball specific course (BSC). The course design included all relevant competitive specific movements of a game in a reproducible field test. The control of the intensity (medium or high) was established by the shorter course duration and breaks, whereas the specific movement components in Test 1 and Test 2 were constant. Therefore the relatively complex sports specific components of a basketball game could be adjusted only by the modification of the round speed. This method for quantifying the physiological response in a sports specific test can be adapted to other team sports.

Ergospirometry and heart rate

The VO_2 measurement has a double effect in exercise: the aerobic energy expenditure can be quantified, and other parameters can be related to the aerobic metabolism and not only to the work intensity. During the medium and high intensity, the exercise VO2 values were almost equal with or without mouthguard. This means that there were no mouthguard effects on the work efficacy and performance.

Unexpectedly the ventilation and breathing rate were both significantly lower with VentMG although the work efficiency was similar. The ventilation is a marker of muscle action and the resulting respiratory drive via C3/4 afferent nerves [9]. Therefore the ventilation is an indicator of muscle strain. Because the VO_2-values were similar, a similar ventilation was expected. Nevertheless the peripheral ventilatory drive was markedly lower with VentMG, indicating decreased muscular reflexes on the respiratory center.These reflexes are mainly due to a breakdown of glycogen and creatine phosphate, and an increase in the intracellular inorganic phosphate and osmolality [9]. The markedly lower lactate values point in the same direction.

The heart rate is an effect of the central sympathetic drive and regulated via nerval and hormonal actions. The HR is almost linearly related to the exercise intensity. The HR was also significantly lower with VentMG in both tests, and this again indicated a lower peripheral strain.

Blood lactate

The lactate is an indirect measure of anaerobic metabolism and was lower in the tests with VentMG. The lactate is also affected by the pre-existing muscle glycogen levels [10]. Due to the randomized testing and instructions for nutrition goals, relevant effects of different glycogen stores were not expected which is also confirmed by the similar pre-exercise lactate values. Therefore higher values without MG can only be explained by an increased anaerobic metabolism, i.e. a reduced oxygen delivery to the muscles.

Which are the possible mechanisms of the observed results? The exercise ventilation and heart rate are effects of the central sympathetic drive (CSD). The CSD is regulated by the central co-innervation and peripheral reflex mechanisms [11] such as increases in the interstitial potassium and osmolality. The potassium increases are linearly related to the muscle exercise [9]. The osmolality increase occurs due to a water shift into the cells, which is linearly related to the exercise induced increases in intracellular molecules such as ADP, creatine, inorganic phosphate (Pi), lactate, and CO_2 [12]. The increases in potassium and osmolality boost the impulse rate of C3/C4 afferent nerves [12]. This generates an increase in the central and peripheral sympathetic tone. Another factor of cardiorespiratory modulation is a potassium increase in the arterial blood [13]. In summary the use of VentMG resulted in a lower cardiac and respiratory drive, and a markedly decreased anaerobic metabolism.

The FeO_2 difference and $FeCO_2$ values were higher with VentMG, indicating a higher aerobic metabolism. This is consistent with lower lactate values. Therefore the VentMG may improve the oxygen delivery to the pulmonary capillaries.

Four mechanisms may be relevant: 1. Opening of additional alveolar capillaries; 2. Increased O_2-pressure in the alveoli [14]; 3. Reduced respiratory work; 4. Improvement of movement efficiency.

- **Ad1:** It is unclear how the VentMG would induce an opening of the alveolar capillaries.
- **Ad 2:** No resting spirometry with VentMG vs. NoMG was performed, but the in- and expiration times during the exercise tests were measured. In the case of a marked airway obstruction at least the expiration time would have been markedly increased with VentMG. The in- and expiration times were not significantly increased, also indicating no relevant airflow restriction.
- **Ad 3:** It may be speculated that the VentMG had a direct effect on the breathing efficacy. The air channels may have, e.g., accelerated the inspiratory airstream [6] and therefore the ventilatory energy expenditure may have been decreased, causing a major decrease in VO_2 and lactate values. The total amount of energy used for breathing during exercise is approximately 8% of the total metabolism [15]. This would correspond to 312 ml VO_2 measured in this study. The ventilation was decreased by 7% in the maximum load with VentMG, the reduced work of breathing would correspond to a reduced VO_2 of approximately 22 ml. This can explain none of the observed results in ventilation, heart rate, and lactate. Obviously only an irrelevant part of the reduced metabolism can be attributed to a decrease in the work of breathing.
- **Ad 4:** There might be a change of the total body biomechanics due to VentMG. It is known that the core muscles play an important role in the body stabilization during exercise. The players often bite on their teeth in the moment of throwing the ball which would not happen e.g. during a cycle-ergometry test. It may be speculated that the jaw is a second total body stabilization area together with the core muscles. Much more compression forces are tolerated with a mouthguard due to its elasticity. Therefore, it is hypothesized that mouthguards improve the total body biomechanics and therefore the energy efficacy, but the experimental proof is missing.

The number of subjects was too small to allow a general statement about the energy expenditure and possible conclusions. But the statistical significance and the fact, that similar results have been seen in other studies with a less sports specific methodology confirm the relevance of the observed data.

Mouthguard comfort

The interference of speaking with VentMG was rated poor. This may be due to the specific breathing channels which may impair the lips and tongue. A study by Collares., *et al.* [16] showed a communicative, possibly also psychological, and not physiological impairment by the mouthguard.

Conclusion

The use of a VentMG in a basketball specific course did not impair the exercise related physiological data. The indicators of physiological strain such as the VO_2, lactate, ventilation, and heart rate values were even improved with the VentMG. The mouthguard as a mandatory protective equipment is strongly recommended. The results confirm that no physiological and minor subjective drawbacks were associated with VentMG.

Conflicts of Interest

There are no conflicts of interest, no sources of funding, and no financial interest.

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