Published online: 2019-06-05

Influence of Mouthguards on Physiological Responses in Rugby

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Key words
rugby, mouthguard, performance, ergogenic aid

received 03.01.2019
revised 18.03.2019
accepted 08.04.2019

Bibliography
DOI https://doi.org/10.1055/a-0891-7021
Sports Medicine International Open 2019; 3: E25–E31

ISSN 2367-1890

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ABSTRACT

Mouthguards (MGs) are highly recommended in rugby. Airway obstruction and a resulting decrease in power output are potential disadvantages of their usage. The aim of the study was to assess possible limitations of "vented" (MG_V) and custom-made mouthguards (MG_C) on rugby players' performance. The MG effects were investigated in 13 male first-league rugby players ranging from 18–34 years old. First a lung function test was completed. Then a double incremental treadmill test was performed to measure maximum aerobic performance, ventilation, VO_2, VCO_2, heart rate, and lactate. Effects on sprint times (10 and 40 m) and countermovement jumps were also investigated. Peak flow values were significantly decreased with MG_V by about 0.9 l/s. Neither ventilatory parameters nor oxygen uptake were affected by either of the mouthguards. Maximum lactate was significantly decreased in both MG types vs. no MG use. The maximum running velocity was similar in all tests. The aerobic energy turnover was moderately increased with the MG_C and MG_V. No effects were seen on sprint times or jump tests. Although neither type of mouthguard had a significant impact on maximum performance in treadmill running, the anaerobic energy turnover was decreased.

Introduction

Considering the risk of dental trauma in contact sports, mouthguards are an essential piece of safety gear for athletes to soften impacts and prevent injuries [1, 26, 27]. The American Dental Association recommends the use of MGs in 29 sports [5]. The Fédération Dentaire International [14] subdivides organized sports into two categories based on the risk of traumatic dental injuries: high-risk sports (such as American football, hockey, ice hockey, lacrosse, martial arts, rugby, inline skating, skateboarding and mountain biking) and medium-risk sports (such as basketball, soccer, handball, squash, gymnastics, parachuting and water polo). Use of an MG is mandatory for rugby players. Nevertheless, 12–37 % of rugby players do not use an MG during training or competition [8, 23, 24, 28, 31]. The major concern is a possible decrease in performance and increase in breathing resistance.

A custom-made MG (MG_C) is characterized by a better fit and comfort when compared to a boil-and-bite MG [6, 35]. However due to lower costs, often boil-and-bite MGs are used [25, 29]. Many players do not use an MG because they expect negative respiratory effects. Recently, an MG with breathing channels was developed (Nike Adult Max Intake, Beaverton, OR, USA). Studies on this type of MG (MG_V) have been performed by Bailey et al. [5] (recreationally trained males using a cycle ergometer) and Schulze et al. [32] (basketball specific tests). In these settings ventilation and blood lactate were significantly decreased with MG_V.

The results for oxygen uptake and ventilation at maximum and sub-maximum load for MG_C are inconsistent: five studies reported no differences in either respiratory or cardiac parameters with the MG_C [6, 9, 25, 30, 35]. Garner et al. [17] found significantly higher oxygen uptake and ventilation in constant-load exercise. Two studies showed a significantly improved cycle ergometer performance with an MG_C [30, 35]. However, no significant differences were found in running performance with an MG_C [6, 9, 25].

Important elements in rugby are sprint performance and explosive strength. The use of a mouthguard may have positive effects on neuromuscular chains. A mouthguard may facilitate powerful jaw clenching and a subsequent concurrent activation potentiation through a remote voluntary contraction of the mandible muscles [2, 7, 12]. Remote voluntary contractions are a muscle action of the prime mover while performing a simultaneous muscle action with another part of the body [12].

A common disadvantage of all the above-mentioned studies was that the athletes were not accustomed to MG use. The current study is new in three aspects: 1. The subjects were highly trained first-league rugby players who used mouthguards regularly. 2. Typical sports-specific elements were used in a laboratory setting (double incremental treadmill tests, sprints and countermovement jumps) to investigate the mouthguard effects on oxygen uptake, ventilation and blood lactate. 3. Two mouthguard types were compared to no mouthguard use: custom-made mouthguards with an advantage of proper fit, and vented mouthguards with an advantage of specific breathing channels. For coaches and athletes, the study aimed to determine whether a mouthguard with a specific design for improved ventilation would have better physiological responses in comparison to a custom-made mouthguard with a known high level in comfort and protection.

Materials and Methods

Subjects

The study was approved by the Institutional Review Board and Human Medical Research Committee at the University of Leipzig, Germany (No. 445–15–21122015). Written informed consent was obtained from all participants after they confirmed complete understanding of the study protocol. The study conformed to the Standards for Ethics in Sport and Exercise Science Research [22] and required players to provide informed consent before participation. Participants included 13 male subjects between 18 and 34 years old (mean 24.7 ± 4.9 years, height = 184.6 ± 5.7 cm, weight = 89.25 ± 12.8 kg, BMI = 26.25 ± 3 kg/m^2) who played in the first German rugby league and had a middle position in the league ranking. Exclusion criteria were: acute/chronic infections, antibiotic therapy, chronic/systemic diseases, joint problems, and injuries. In total, 16 players were measured. After 3 dropouts due to sickness or incomplete data acquisition, 13 players were included.

Mouthguards

The subjects were told that two different kinds of mouthguards would be tested. No information was given about possible advantages or disadvantages in comparison to their personal mouthguards. Two types of mouthguards were used: the vented boil-and-bite mouthguard (MG_V, Nike, Beaverton, OR, USA) and the custom-made mouthguard. The MG_V has patented breathing channels (O-Flow™) designed to improve the ventilation and oxygen uptake during athletic activity (▶ **Fig. 1**). Compared to traditional mouthguards, these additional air inlets are designed to allow less restricted breathing. The MG_V was placed in boiling water for 30 s and was then carefully placed in the subject's mouth to cover their upper teeth. The subject was instructed to bite down firmly. Moderate pressure was placed on the lips and cheeks for 30 s. The MG_V was then removed and rinsed in cold water.

The custom-made mouthguard (MG_C) was vacuum-formed over a stone model that had been prepared from the dental impression (alginate) and a bite registration to adjust an occlusal equilibration (▶ **Fig. 2**). The thermoforming plate had a thickness of 5 mm (Bioplast Xtreme, Scheu Dental, Iserlohn, Germany).

Lung function measurements

Prior to the exercise tests, a lung function measurement at rest was performed using a tube (Easy on-PC, NDD, Zürich, Schweiz). Vital capacity (VC), forced vital capacity (FVC), peak flow (PEF), and forced 1-second expiratory volume (FEV1) were displayed.

Treadmill protocol

The subjects performed two subsequent treadmill tests with a 5-minute rest in between (double incremental treadmill exercise, Test A and Test B). In Test A, all spiroergometric data were meas-

▶ **Fig. 1** Vented mouthguard used in this study (MG_V).

ured. Test B was used to measure the individual lactate equilibrium (lactate minimum test [34]). In Test A, no lactate samples were taken because the stops for blood sampling would have disturbed the spiroergometric measurements. The treadmill was adjusted to an incline of 1 %. Test A began with a 4-minute warm-up (2 min at 6 km/h and 2 min at 8 km/h). Then the load was increased by 1 km/h each minute until exhaustion to produce near-to-ramp increments. During the 5 min recovery, a speed of 6 km/h was maintained. Lactate samples (20 µl) were taken at rest from the hyperaemized ear lobe immediately after Test A and after the first, third, and fifth minute of the break. This break allowed for lactate distribution in the intra- und extracellular space.

In Test B, the running speed was increased by the usual increments of 2 km/h every 2 min until exhaustion. A 5-min. recovery at 6 km/h followed. Lactate was taken after each speed step (at which point the subjects stood on the side bars for 15 s) and after the first, third, and fifth minute of the break. The treadmill tests (n = 39) were performed in a randomized order using either no MG, the MG_V or MG_C in the Sports Medicine laboratory at the University of Leipzig.

Exercise testing

Heart rate (HR), oxygen uptake (VO_2), ventilation (VE), tidal volume (VT), breathing rate (BR), and carbon dioxide output (VCO_2) were measured. The spiroergometric data was measured breath-by-breath with a mask (K4b^2, Cosmed, Italy). The VO_2 and VCO_2 values were calculated from the end-expiratory gas concentrations and VE. VE was calculated as the product of BR and VT. HR was taken from the continuous ECG recording. Super GL (ISO 7550, Germany) was used for the blood lactate measurement.

Sprint and jump protocol

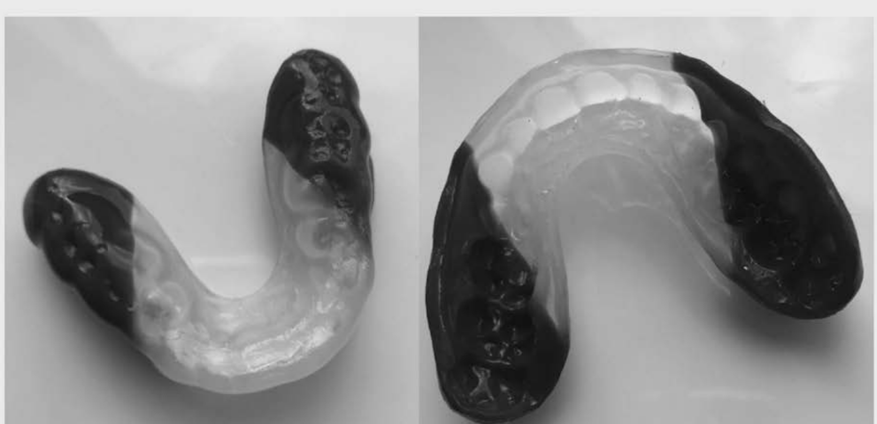
Sprint and jump tests are performance markers for team sport athletes. Ten- and forty-meter sprint tests were used to determine acceleration, maximum speed, and anaerobic performance. Countermovement jumps (CMJ) were performed to measure explosive lower-body power performance and explosive strength. Sprint and countermovement tests are generally used by strength and conditioning coaches as differential measurements of speed and strength. For the measurement of sprints and jumps, SmarTrack Diagnostics from Humotion (Münster, Germany) was used. This mobile measuring system consists of a hip belt with an integrated electronic unit. The performance was measured by two modules. The jump module independently detects and records three different jump modes: squat jump (SJ), countermovement jump (CMJ) and drop jump (DJ). The sprint module records the exact running times in the linear sprint. The length of the sprints can be varied by mobile magnetic barriers. A complex sensor system was used to collect the data. The acceleration in all three directions is registered by an acceleration sensor, which also detects the static acceleration due to gravity. The measurement of the movement is performed by a 3-D magnetic field sensor. The speed of the body movement is registered in all three directions via rotational speed sensors. The interaction of all sensors makes it possible to follow the movements of the body or individual body segments.

Prior to the tests, the subjects took part in a standardized warm-up. For the sprint tests the subjects started 1 m before the starting line. After the last sprint, the jump force was measured after a 2 min break. Three consecutive countermovement jumps were then performed with a 1 min break between the jumps. The athletes performed the tests in a randomized order with the MG_V, MG_C, and NoMG. Before testing, the subjects had practice sessions to train for the countermovement jumps.

In all anaerobic tests, the subjects were advised to bite on the MG to ensure an occlusal position [21], but no breathing instructions were given.

Statistical analysis

Results are expressed as the means ± SD. Data for all variables were tested for and found to be normally distributed using the Shapiro-Wilk test. A repeated-measures ANOVA design was used to assess the statistical significance of differences between the mean values of the different conditions. To confirm differences between groups, Tukey's post hoc test was used. A p-value < 0.05 was considered significant and a p-value < 0.005 was considered highly significant. Also, the 95 % confidence interval (CI) was calculated. All analyses were performed using the GraphPadInStat Software (GraphPad-Software, La Jolla, CA, USA) and the IBM Statistics package software, version 22.0 (IBM SPSS Statistics, Armonk, NY, USA).



▶ **Fig. 2** Custom-made mouthguard used in this study (MG_C).

▶ Table 1 Lung function results (SD in brackets).

	NoMG	MG_V	MG_C	p-value
VC (l)	5.52 (0.62)	5.50 (0.82)	5.40 (0.80)	n.s.
FVC (l)	5.43 (0.63)	5.37 (0.69)	5.32 (0.61)	n.s.
FEV1 (l)	4.91 (0.64)	4.80 (0.63)	4.80 (0.63)	n.s.
Peak flow ($l \times s^{-1}$)	10.90 (1.84)	9.99 (1.63) *	10.60 (1.66)	0.002 (NoMG vs. MG_V) 0.04 (MG_V vs. MG_C)
FEF 25–75 % of FVC ($l \times s^{-1}$)	5.82 (1.43)	5.64 (1.27)	5.86 (1.66)	n.s.

Results

Lung function results

Peak flow was significantly decreased with MG_V vs. NoMG or MG_C. No mouthguard effects on other lung function parameters were seen (▶ **Table 1**).

Treadmill testing results

Compared to NoMG use, the oxygen uptake was moderately, however insignificantly, higher with the MG_C at submaximal and maximum load (▶ **Table 2**). Maximum lactate values were lower when using a mouthguard (MG_V: $p < 0.002$; MG_C: $p < 0.04$).

The relation between VO_2 and lactate values in all test conditions was significantly higher with the MGs (▶ **Table 3**).

Sprint and jump results

The results for the sprints and vertical jumps were almost identical. However, there was a tendency for better sprint times with an MG (▶ **Table 4**).

Discussion

Lung function

In the current study, only the peak flow was significantly lower with MG_V vs. NoMG or MG_C. No further significant differences in lung function were seen, which is in line with other studies [6, 10]. However, these conditions do not reflect the game situation because the jaw was fixed in the tests by biting on the mouth tube. When a mask is used instead of a mouth tube, the airflow may be affected even less [3]. The increased inspiratory resistance at rest may be reduced in hyperpnea conditions [3]. The expiratory airflow can also be affected by the MG thickness and the position of the head, neck and jaw [3]. According to Amis et al. [3], the natural flow pattern of the oral cavity may even be positively influenced by the MG_C so that the airflow becomes less turbulent. All these aspects must be considered as a possible cause for the differences between the two MGs regarding expiratory flow and maximum exercise ventilation.

Aerobic and metabolic responses

In the current study, the maximum blood lactate was significantly lower with MG use (approximately 10 % for MG_V and 4 % for MG_C, respectively). The blood lactate values are dependent on the anaerobic metabolism and muscle glycogen stores [34]. The tests were performed in a randomized order and instructions for nutrition goals were given to refill the glycogen stores. Therefore, different glycogen stores were not expected.

The maximum running speed was almost equal in all tests and there was a tendency toward even higher VO_2 values with MG. Theoretically this might indicate slightly reduced energy conversion efficiency. However, lower blood lactate together with a slightly increased VO_2 more likely indicates an improved aerobic metabolism due to the MG.

Lower lactate concentrations with MG were also found in other studies [5, 16, 18, 32]. Garner and McDivitt [16] hypothesized that an increase in the respiration diameter and a resulting increase in CO_2 elimination might explain the lower lactate values with MG use. This cannot be confirmed by the current or former results [32], where no differences in CO_2 output were measured at maximum load. Bailey et al. [5] found significantly lower lactate concentrations at submaximal and maximum load with the MG_V. They assumed that the aerobic energy production might have been improved in the MG_V condition. A possible explanation has been given by Francis and Brasher [15]. They hypothesized that the MG might cause a "pursed-lip" type of breathing, which has been shown to decrease CO_2 tension, and increase oxygenation and exercise tolerance [15]. If this applies, a higher O_2 gradient between the alveoli and the lung capillaries might result. This could also explain slightly increased VO_2 and decreased blood lactate values as observed in the current study.

Cardiorespiratory responses

Although the peak flow was lower with the MG_V in the current study, maximum VE was similar to NoMG and MG_C. This may indicate that the major effect of the MG_V cannot be attributed to the air channels but to the use of a mouthguard in principle.

HR and VE were similar in all conditions. With respect to recent studies, the type of exercise (ergometer, treadmill, or sports-specific course) may affect the cardiorespiratory response. In the majority of treadmill tests, ventilation was not affected by MG use [6, 13, 19, 21, 25]. In contrast, VE was lower with MG in cycle ergometer testing [5, 15]. In a sports-specific environment, VE was lower with MG [32, 33]. No explanations are provided for the differences in cycle ergometer and treadmill testing. In contrast, in a field setting, the body biomechanics may be different because the jaw may act as a second whole body stabilization area together with the core muscles [32]. It is unlikely that this effect plays a role in a laboratory treadmill or cycle ergometer test.

Sprint and jump results

The sprint time over a short distance is an indicator of anaerobic performance. The sprint time was also used to assess the influence

▶ **Table 2** Exercise results.

Parameter	Intensity	NoMG	MG_V	MG_C	p-value
VO_2 (ml × min^{-1})	sub	4461 (533)	4589 (570)	4697 (530)	n.s.
		(4139–4783)	(4245–4934)	(4376–5017)	
	max	4541 (575)	4608 (612)	4747 (598)	n.s.
		(4193–4888)	(4238–4978)	(4386–5108)	
VCO_2 (l × min^{-1})	sub	4895 (626)	5042 (611)	5045 (491)	n.s.
		(4517–5272)	(4673–5411)	(4748–5342)	
	max	5131 (640)	5131 (690)	5159 (646)	n.s.
		(4745–5518)	(4714–5548)	(4769–5549)	
HR (bpm)	sub	183.8 (7.8)	183.4 (6.6)	182.0 (5.9)	n.s.
		(178.8–188.8)	(179.2–187.6)	(178.2–185.7)	
	max	184.4 (5.9)	183.7 (5.7)	182.6 (6.1)	n.s.
		(180.6–188.1)	(180.1–187.3)	(178.7–186.4)	
VE (l × min^{-1})	sub	135.2 (17.2)	135.6 (16.4)	137.3 (21.1)	n.s.
		(124.8–145.6)	(125.7–145.5)	128.0–146.6)	
	max	143.8 (16.7)	139.5 (18.4)	142.6 (23.7)	n.s.
		(133.7–153.9)	(128.4–150.6)	(128.0–146.6)	
BR (breath × min^{-1})	sub	47.6 (8.2)	46.9 (6.3)	47.6 (5.0)	n.s.
		(42.6–52.5)	(43.1–50.7)	(44.5–50.7)	
	max	50.7 (6.1)	47.9 (4.7)	49.1 (5.9)	n.s.
		(47.0–54.3)	(45.1–50.8)	(44.5–50.7)	
VT (l)	sub	2.92 (0.57)	2.95 (0.53)	2.92 (0.48)	n.s.
		(2.58–3.26)	(2.63–3.27)	(2.63–3.21)	
	max	2.90 (0.54)	2.95 (0.49)	2.94 (0.51)	n.s
		(2.57–3.22)	(2.65–3.24)	(2.63–3.25)	
RQ	sub	1.10 (0.10)	1.10 (0.10)	1.08 (0.07)	n.s.
		(1.04–1.16)	(1.05–1.16)	(1.04–1.12)	
	max	1.13 (0.08)	1.12 (0.10)	1.09 (0.09)	n.s.
		(1.08–1.18)	(1.06–1.18)	(1.05–1.13)	
FeO_2 (vol %)	sub	15.64 (0.61)	15.57 (0.39)	15.63 (0.48)	n.s.
		(15.27–16.01)	(15.34–15.81)	(15.34–15.92)	
	max	15.84 (0.49)	15.57 (0.32)	15.65 (0.50)	n.s.
		(15.54–16.13)	(15.37–15.76)	(15.36–15.94)	
$FeCO_2$ (vol %)	sub	5.91 (0.73)	6.00 (0.69)	5.89 (0.60)	n.s.
		(5.48–6.35)	(5.57–6.40)	(5.53–6.25)	
	max	5.85 (0.62)	5.85 (0.81)	5.89 (0.588)	n.s.
		(5.47–6.22)	(5.36–6.35)	(5.53–6.24)	
Inspiratory time (s)	sub	0.63 (0.10)	0.64 (0.08)	0.61 (0.08)	n.s.
		(0.57–0.69)	(0.59–0.69)	(0.56–0.66)	
	max	0.58 (0.07)	0.62 (0.06)	0.60 (0.08)	n.s.
		(0.54–0.62)	(0.58–0.66)	(0.56–0.65)	
Expiratory time (s)	sub	0.67 (013)	0.67 (0.11)	0.65 (0.11)	n.s.
		(0.59–0.76)	(0.60–0.73)	(0.58–0.71)	
	max	0.62 (0.10)	0.65 (0.08)	0.64 (0.10)	n.s.
		(0.56–0.68)	(0.60–0.70)	(0.58–0.70)	
Velocity (km × h^{-1})	sub	15.08 (1.32)			
	max	15.54 (1.05)	15.38 (1.39)	15.23 (1.36)	n.s.
		(14.90–16.17)	(14.55–16.22)	(14.41–16.05)	
Blood lactate (mmol × l^{-1})	pre	0.85 (0.19)	0.75 (0.14)	0.74 (0.11)	n.s.
		(0.73–0.97)	(0.66–0.83)	(0.67–0.81)	
	max	10.42 (2.27)	8.94 (1.89) *	9.42 (2.39) *	0.002 (NoMG vs. MG_V)
		(9.06–11.79)	(7.82–10.06)	(7.98–10.86)	0.04 (NoMG vs. MG_C)
AT_{lac} (km × h^{-1})		10.6 (1.5)	10.6 (1.5)	10.9 (1.0)	n.s.
		(9.71–11.52)	(9.71–11.52)	(10.3–11.55)	

Mean value (SD) and confidence interval in brackets. Maximum values (max): mean values corresponding to the highest speed in each test series (NoMG, MG_V, MG_C). Submaximum values (sub): mean values corresponding to the series (NoMG, MG_V, MG_C) with the lowest maximum speed. Pre: pre-exercise values. AT_{lac} (anaerobic lactate threshold): running speed corresponding to the lactate minimum (18) in Test B. * = significant.

▶ **Table 3** Metabolic rate in the tests due to the use of mouthguards (SD in brackets).

	Aerobic kcal × min⁻¹	Anaerobic kcal × min⁻¹	Total kcal × min⁻¹	Aerobic/anaerobic Quotient
NoMG	184.9 (28.07)	12.99 (3.32)	17.25 (1.81)	15.00 (3.60)
MG_V	178.2 (27.29)	11.11 (2.57)	17.27 (1.75)	16.68 (3.11)
		$p<0.001$		$p<0.02$
MG_C	185.6 (34.54)	11.78 (3.74)	17.83 (2.45)	16.63 (3.70)
		$p<0.04$		$p<0.03$

P-values refer to the differences between NoMG and MG_V or MG_C.

▶ **Table 4** Sprint and vertical jump results.

Test		NoMG	MG_V	MG_C	p-value
40 m sprint (s)	mean	5.44 (0.3)	5.42 (0.3)	5.42 (0.3)	n.s.
		(5.26–5.62)	(5.22–5.62)	(5.24–5.60)	
	best	5.39 (0.3)	5.37 (0.4)	5.36 (0.4)	n.s.
		(5.21–5.57)	(5.16–5.58)	(5.15–5.56)	
10 m sprint (s)	mean	1.58 (0.1)	1.57 (0.1)	1.58 (0.1)	n.s.
		(1.53–1.63)	(1.53–1.61)	(1.54–1.62)	
	best	1.57 (0.1)	1.56 (0.1)	1.56 (0.1)	n.s.
		(1.52–1.61)	(1.51–1.60)	(1.52–1.60)	
Jump height (cm)	mean	41.3 (7.5)	41.9 (6.4)	41.5 (7.4)	n.s.
		(36.8–45.9)	(38.0–45.75)	(37.0–46.0)	
	best	43.9 (7.7)	44.6 (6.7)	44.0 (7.6)	n.s.
		(39.4–48.4)	(40.7–48.4)	(39.6–48.3)	

Means (SD) and confidence interval in brackets.

of the $MG_{C/V}$ on anaerobic performance. In the current study, no significant effects were found with both MGs. This is in line with other studies [4, 5, 11, 18, 20].

Although the current study did not show any significant differences in the countermovement jumps, the most frequent peak values were seen under the influence of the MG_V. Recent studies reported significant improvements for the CMJ with the MG_C [4, 11]. Bailey et al. [5] found higher vertical jump values with the MG_V. However, as in the current study, most studies did not reveal any significant differences [10, 11, 20].

The current study is based on treadmill testing, sprints, and countermovement jumps to isolate the specific mouthguard effects. Ventilation was not reduced as seen in handball- and basketball-specific studies [32, 33]. However, there were also no negative effects on breathing or performance during exercise. The laboratory tests did show an ergogenic effect on the aerobic metabolism. Therefore, for future studies a rugby course will be created and evaluated for sports-specific field testing and then compared to the current laboratory test results in a larger cohort for general implications. Furthermore, studies on the longitudinal effects of the different mouthguard types will be of interest.

Conclusions

Custom-made and vented mouthguards have no negative effects on rugby-specific performance or breathing parameters when tested in a laboratory setting. Maximum exercise capacity, sprints, and jumps are not affected by the use of these two mouthguard types. It is a new observation that aerobic energy turnover may even be improved in rugby-specific motion elements, regardless of whether custom-made or vented mouthguards were used. Presumably, these results can be transferred to authentic game and training situations.

Acknowledgements

We thank Tim Albrecht and Christian Senf for their support in data acquisition.

Conflict of Interest

Authors declare that they have no conflict of interest.

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