The Effects of Various Customised Mouthguard Designs on Physiological Parameters and Comfort in Male Boxers

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Abstract: Athletes, who use mouthguards (MGs) as a protective device, often experience obstruction of airflow and interferences with performance. The aim of this study was to investigate the influence of three custom–made MGs (MG1, MG2, MG3), which differed in design and thickness, on respiratory flow and blood lactate during exercise. Fourteen elite male boxers (Age: 26 ± 8 yr; Mass: 80±11) performed newly developed sport specific protocol under laboratory conditions on four occasions – without a MG and with each of the three MGs. The exercise consisted of 4 boxing rounds of 3 mins, with a minute rest after each round. Breath-by-breath analysis (METALYZER® 3B, Cortex) showed that there were no differences in the uptake of oxygen ($p > 0.157$) between the four conditions. Likewise, the use of different MG did not affect blood lactate accumulation ($p = 1.00$). However, at the end of the first round the minute ventilation was higher when MG3 was used (86.2 ± 17.5 L/min) compared to MG2 (71.7 ± 13.2) and having no MG (73.7 ± 16.4) ($p = 0.002$). The fact that a negative effect was not determined on physiological responses could further encourage players to use MGs during both training and competition.

1 INTRODUCTION

A survey showed that 35.9% amateur boxers have sustained tooth injuries (N=338, males, 17.6 yrs); with crown fractures being the most common (40.7%) (Emerich and Gazda, 2013). Using a mouthguard (MG) in boxing is compulsory and has meant the athletes are 1.6-1.9 times more likely to prevent such injuries (Knapik et al., 2007). Customised MGs were found to be superior to the other 'over–the–counter' types in regards to functionality, fit and comfort (Duarte–Pereira et al., 2008; El–Ashker and El–Ashker, 2015). However, there are no set guidelines proposing the ideal characteristics of custom devices, therefore numerous variations of design exist.

There is an underlying belief amongst some sport participants that wearing a MG causes considerable discomfort, which could often reduce its use and player compliance (Gebauer et al., 2011). This could be due to the large popularity of commercial devices that usually have poor fit and low retention. Additionally, questionnaire–based studies have reported interferences with breathing as another reason for the low usage of MGs (Boffano et al., 2012; Kececi et al., 2005). However, previous research has shown no significant effects on gas exchange parameters and heart rate (HR) when a MG was worn compared to no MG condition (p > 0.05) (Bourdin et al., 2006; Duarte–Pereira et al., 2008; El–Ashker and El–Ashker, 2015; Kececi et al., 2005). El–Ashker and El–Ashker (2015) compared the effects of a stock MG and customised MG, whereas Duarte–Pereira et al. (2008) investigated the influence of a 'boil–and–bite' and customised MG. Both studies identified that the custom–made devices should be the preferred option due to minimal interference with performance.

To support the current findings, future work should use sport specific test protocols to investigate cardio–pulmonary changes in athletes wearing various MGs (El–Ashker and El–Ashker, 2015; Kececi et al., 2005). Additionally, further research could help determine whether the reported issues regarding obstruction of breathing are valid or based on psychological perception (Morales et al., 2015; Kececi et al., 2005).

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2 OBJECTIVES

The present study investigated the influence of three various custom–made MGs on respiratory flow and accumulation of blood lactate during newly developed sport specific protocol. It is hypothesised that there will be no difference in these physiological parameters when exercise is performed with and without a MG.

3 METHODS

Prior to any experimental work ethical approval was obtained from the School of Healthcare Science, Manchester Metropolitan University (Ethics Number: SE151683).

Fourteen elite male boxers, training at the same boxing academy, were recruited and completed all sessions. The physical characteristics of the sampled population are shown in Table 1. The average participation in sport was 7±9.38 years, whereas the time of competing was 5±7.85 years. All athletes were physically fit, currently taking no medications that may influence airflow, muscle fatigue and HR. Medical and dental assessment was completed to ensure all athletes met the inclusion criteria.

Table 1: Description of the sampled population (*N*=14).

Variable	Mean		SD
Age (yr)	26	±	8
Mass (kg)	80	±	11
Height (cm)	178	±	5
Body Mass Index	25	±	4
Hb (g/dL)	15.1	±	0.9
Lung Function (%)	80	±	7
VO_{2max} (ml/kg/min)	54	±	7

Blood samples were taken to determine the levels of haemoglobin (Hb). If any signs of anaemia (Hb < 13 g/dl) were present, the individuals were excluded (HemoCue® 201+ System, Crawley, England).

3.1 Fabrication of Mouthguards

Figure 1. illustrates the selected MG designs, which were chosen based on common practice and previously published literature (Morales et al., 2015; Takeda et al., 2014). Once informed consent was obtained, a dental clinician took alginate dental impressions (Tropicalgin, Zhermack SpA, Italy). Then, three MG devices were fabricated for each participant in the dental laboratories at Manchester Metropolitan University. All MGs were thermoformed on a Biostar machine (BIOSTAR®, SCHEU-DENTAL GmbH, Iserlohn, Germany) and made of clear ethylene vinyl acetate (EVA) blanks, 120 mm Ø (diameter) (Bracon Ltd, Heathfield, UK). MG1 was fabricated from a 4 mm single EVA blank with a 4 mm extension in the palate, which was not present in the other two designs. In comparison, MG2 and MG3 were made of two layers, 2 mm and 4 mm EVA blanks. MG2 consisted of a double layer at the posterior region only, whereas MG3 had a double layer covering the anterior and the posterior teeth.

Figure 1: Customised mouthguards used by all participants.

3.2 Exercise Protocol

All participants were asked to attend six laboratory sessions in total, with at least a week in-between. The first and the last session involved running on a treadmill (Woodway Pro XL, Waukesha, US) until exhaustion (VO_{2max} test) to identify any change in the level of aerobic fitness pre and post testing with MGs. The participants ran at the same speed, which was pre-selected individually during the warm-up stage (10 ± 0.65 km/h), and a 1% increase in incline every minute, starting at 0%. The remaining four sessions included a 10-min warm-up and a sport specific protocol where all participants used the same punch bag (50cm Ø x 140cm, 60kg) (PRO–BOX Colossus Punch Bag, JPLennard Ltd., UK) and a pair of boxing gloves (10oz) (Lonsdale, Shirebrook, UK). The sport specific protocol consisted of 4 boxing rounds of 3 mins, with a minute rest after each round. During

Figure 2: Breath–by–breath data collected through a facemask during exercise.

each 3-min round, participants were given a verbal signal 'Go' every 6 secs and they all performed the same combination of 4 straight maximum punches. The participants were randomly assigned to perform with either one of the chosen MGs or without a MG.

3.3 Physiological Parameters

The following rest measurements were recorded at all visits: mass, stature, blood pressure, HR, Hb and blood lactate (BLa). During each testing session, the athletes wore a facemask, which was connected to a breath-by-breath analyser (METALYZER® 3B, CORTEX, Leipzig, Germany) (Figure 2.). The main parameters assessed in this study were absolute oxygen uptake (VO_2), minute ventilation (VE), HR and BLa. A baseline reading of the above measurements was taken by asking the participants to remain at rest for one minute prior to exercise. After each round a BLa sample was taken (Biosen C-line Analyser, Cardiff, UK) and participants were asked to rate their level of exertion on a standard Borg scale (6 – No Exertion to 20 – Maximal Exertion).

To control any possible variability in the data, the participants were asked to follow the same dietary intake and physical activity 24h prior to a session. Temperature and humidity were consistent during all visits, 20.0°±0.6 and 50% ±4 respectively.

3.4 Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics, Version 24.0. Armonk (IBM Corp., New York, US) and Microsoft Excel (2013).All cardio-pulmonary measurements were analysed using rolling averages of the last 30 secs and the maximum values of each interval (round). Paired samples t-test was used to compare the results of the VO_{2max} sessions. Depending on the parametricity of the data, repeated measures ANOVA (within subjects) with post-hoc (Bonferroni) or Wilcoxon test were performed to identify the effect of MGs on the aforementioned physiological parameters. Statistical significance was set at $p \leq 0.05$.

4 RESULTS

The first maximal effort exercise showed a lower VO_{2max} (50±7 < 54±7 ml/kg/min, p = 0.032) and HR_{max} (195±12 < 197±11 bpm, p = 0.527) than the second test at the end of the study.

All participants performed the sport specific protocol with each of the three MGs and without a MG. There were no statistical differences in the average VO_2 (L/min) in the final 30 seconds of each round between all MG conditions (p = 0.623) (Table 2.). However, the VE (L/min) at the minute prior to exercise (pre-test) and at the end of the first round was significantly higher when the participants wore MG3 compared to no MG and MG2 (p < 0.018). It was also found that at the end of the protocol HR was higher when MG3 was used compared to MG1 (p < 0.041). The highest levels of BLa was recorded for MG1 and the lowest BLa occurred when no MG was used, although these were not statistically different (p = 1.000) (Figure 3.). The rate of perceived exertion, which varied between 'Somewhat hard' and 'Hard' at the end of the exercise, did not differ significantly (p = 0.221).

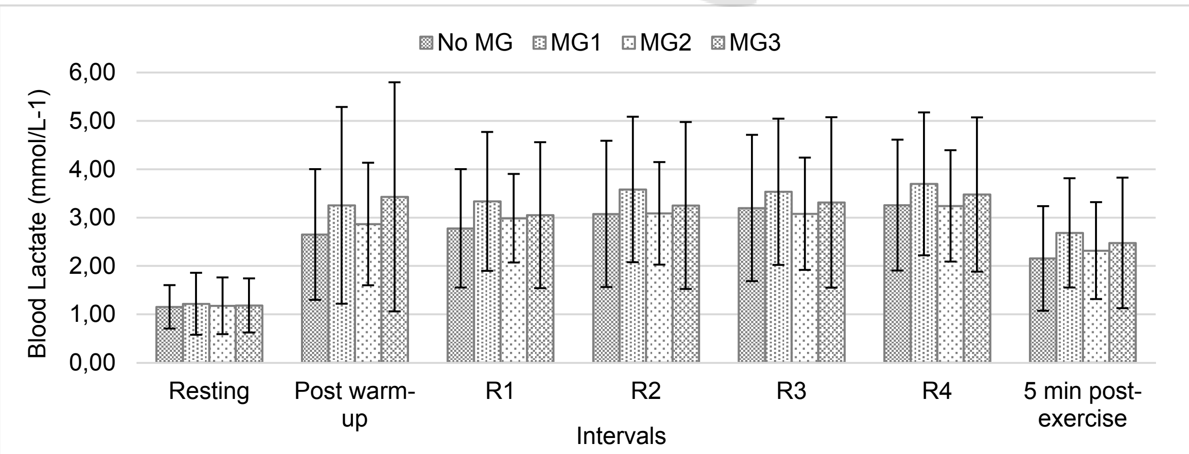

Figure 3: The differences in blood lactate levels at rest, post warm-up, rounds 1-4 (R1, R2, R3, R4) and 5 min post-exercise between conditions - with and without a MG (N=14). The error bars represent the standard deviation.

Table 2: The Mean ± SD of oxygen uptake (VO_2) and minute ventilation (VE), and the maximum values of heart rate (HR) for each round (R1-R4) while wearing no mouthguard (No MG) or any of the three selected designs (MG1, MG2 or MG3). The mean of VO_2 and VE represents the rolling average of the last 30 secs of the boxing rounds (*N*=14).

Variable	**No MG** [a]	**MG1** [b]	**MG2** [c]	**MG3** [d]	**Group Differences**	***p***
VO_2 (L/min)						
Pre-test/ Rest	0.63 ± 0.12	0.63 ± 0.13	0.60 ± 0.14	0.59 ± 0.17	ns	0.157
R1	2.60 ± 0.40	2.65 ± 0.42	2.61 ± 0.47	2.69 ± 0.42	ns	1.000
R2	2.60 ± 0.50	2.71 ± 0.40	2.75 ± 0.37	2.72 ± 0.51	ns	0.623
R3	2.57 ± 0.47	2.72 ± 0.37	2.64 ± 0.45	2.64 ± 0.51	ns	0.901
R4	2.62 ± 0.45	2.67 ± 0.41	2.69 ± 0.36	2.68 ± 0.56	ns	1.000
VE (L/min)						
Pre-test/ Rest	**23.2 ± 3.9**	22.7 ± 5.0	**19.7 ± 3.9**	**20.5 ± 6.2**	**(a-c), (a-d)**	**0.018**
R1	**73.7 ± 16.4**	73.4 ± 15.7	**71.7 ± 13.2**	**86.2 ± 17.5**	**(a-d),(c-d)**	**0.002**
R2	79.3 ± 20.8	78.9 ± 15.9	78.9 ± 14.1	81.3 ± 23.5	ns	1.000
R3	79.5 ± 20.2	81.3 ± 18.2	79.2 ± 15.3	79.7 ± 22.3	ns	1.000
R4	83.3 ± 21.5	83.3 ± 18.1	82.1 ± 14.7	82.9 ± 24.1	ns	1.000
HR (bpm)						
Pre-test/ Rest	105 ± 20	103 ± 16	108 ± 33	102 ± 17	ns	0.701
R1	156 ± 24	162 ± 25	165 ± 24	165 ± 22	ns	0.096
R2	159 ± 18	165 ± 17	171 ± 18	171 ± 16	ns	1.000
R3	157 ± 22	165 ± 22	168 ± 23	171 ± 20	ns	0.074
R4	160 ± 16	**165 ± 16**	167 ± 17	**169 ± 16**	**(b-d)**	**0.041**

Significant main effects are highlighted in bold. Group differences (p <0.05) are highlighted by: ns = no significance, [a] = No MG and MG1; [b] = No MG and MG2; [c] = No MG and MG3; [d] = MG1 and MG3.

1. Data are Mean ± Standard Deviation. Significant main effects are highlighted in bold.
2. Group differences between No MG and MG1 are highlighted by a = P<0.05, aa = P<0.01, aaa = P<0.001.
4. Group differences between No MG and MG2 are highlighted by b = P<0.05, bb = P<0.01, bbb = P<0.001.
5. Group differences between No MG and MG3 are highlighted by c = P<0.05, cc = P<0.01, ccc = P<0.001.

5 DISCUSSION

To the best of our knowledge, the current study is the first one to investigate the influence of three various customised MGs on respiratory flow and BLa of elite boxers, performing a sport specific protocol.

The sampled population showed good level of aerobic fitness (VO_{2max} = 52±7 ml/kg/min, HR = 193±7 bpm). In order to minimise the training effect between the testing sessions, it was important to recruit participants with high fitness level and same standard of competition.

No statistical differences were observed in VO_2 (L/min) and BLa with and without a MG, or between MG type. Participants also reported similar levels of perceived exhaustion during all tests. Although, at the first round VE was highest when MG3 was worn (86.2±17.5) and lowest at MG2 condition (71.7±13.2), these differences could possibly be explained by the differences in VE prior to exercise (p < 0.018). Hence, it could be considered that the changes in VE did not occur due to change of MG condition but due to variation of warm-up intensity. At the last boxing round, HR values were significantly lower during MG1 condition compared to having MG3 (p < 0.041). From these findings, it could be concluded that there were no interferences with respiratory flow when customised devices were used during exercise. Additionally, this was supported by the similar BLa values between conditions.

There are controversial views about the effects of MGs on performance and physiological biomarkers (Bourdin et al., 2006; Duarte–Pereira et al., 2008; El-Ashker and El-Ashker, 2015; Gebauer et al., 2011; Kececi et al., 2005; Morales et al., 2015; Schulze et al., 2018). Previously, only one study has examined the effects of stock and custom-made devices on the airflow of male boxers (El-Ashker and El-Ashker, 2015). However, their exercise protocol consisted of running on a treadmill at two different intensities (12 and 14 km/h). Statistical differences were only recorded at the higher intensity exercise, where the VO_2 whilst wearing a stock MG was 40.54±5.68 (ml/kg/min) compared to 46.48±3.65 (ml/kg/min) with custom-made MG and 47.37±5.34 (ml/kg/min) without a MG (p = 0.02) (El–Ashker and El–Ashker, 2015). Although, this test may have high physiological value, the exercise protocol did not specifically address the characteristics of boxing. It could be argued that the newly developed protocol of the current study could provide more objective results to determine the effect of customised MGs on airflow and blood lactate accumulation. Future work should examine changes in physiological parameters in professional boxing, where the number of rounds and exercise effort are higher.

The outcomes of the present study may have important implications in relation to increasing the use of custom-made MGs. Coaches should be aware of the benefits of custom devices and educate not only the athletes but also the parents of young children. The fact that a negative effect was not determined on physiological responses could further encourage players to use MGs during both training and competition.

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