Physiological Responses of a Jaw-Repositioning Custom-Made Mouthguard on Airway and Their Effects on Athletic Performance

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Abstract

Martins, RS, Girouard, P, Elliott, E, and Mekary, S. Physiological responses of a jaw repositioning custom-made mouthguard on airway and their effects on athletic performance. *J Strength Cond Res* XX(X): 000–000, 2018—Advanced dental techniques such as jaw-repositioning have shown to increase lower body muscular power such as vertical jump, but its effects on acceleration and speed have not been studied. Similarly, jaw repositioning is commonly used to increase airways volume and ventilation in a special population (i.e., obstructive sleep apnea); however, its ergogenic effects on aerobic performance have yet not been studied. The purpose of the cross-over study was to investigate the effects of a jaw-repositioning custom-made mouthguard (JCM) on volumetric changes in airway and jaw position and determine the effects this may have on aerobic and anaerobic performance. Results indicated that jaw-repositioning custom-made mouthguard may have an ergogenic effect on performance. The JCM condition showed an increase of 13% in upper airway volume ($p = 0.04$), 10% in upper airway width ($p = 0.004$), 7% in ventilation ($p = 0.006$), 5% in maximal aerobic power ($p = 0.003$), 4% in time to exhaustion ($p = 0.03$), 3% in vertical jump ($p = 0.03$), 2% in broad jump ($p = 0.009$), and a decrease of 4% in 20-m ($p = 0.04$) and 2% in 40-m ($p = 0.001$) sprint times. This is the first study to demonstrate a significant link between jaw repositioning, airway volumetric change, and performance enhancement in both aerobic and anaerobic performances. The results of this study may lead to a change in culture for the use of mouthguards in different sports applications, from high orofacial injury risk sports to other sports, specifically for ergogenic enhancement.

Key Words athlete, maximal aerobic power, anaerobic performance, upper airway, volumetric change, advanced dental techniques

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Introduction

The practice of sports increases the risk of athletes to suffer dental and craniofacial injuries—this risk is even higher for contact sports such as basketball, football, and rugby (34,42,43). The incidence is also high in sports where physical contact is not as common such as soccer in which it is estimated that 84% of professional soccer players in Brazil have suffered, at least, 1 craniofacial or dental injury (12). Despite the high incidence of dental and orofacial injuries and the American Dental Association recommendation of mouthguard use for 29 sports (2), most athletes do not wear mouthguards (12,42–44). For example, among fighting sports such as wrestling, karate, judo, and boxing, only 41% ($n = 68$) of the athletes wear mouthguards during practices and competitions (44). The number of athletes who use mouthguards is even lower, 7.8% ($n = 12$) for noncontact sports such as sailing, youth hockey, and horse riding (44). A study on mouthguard awareness among 53 basketball coaches and 351 players reported that 52.8% of the coaches and 93.7% of the players do not use/recommend the use of mouthguard (42). The main arguments for not wearing a mouthguard were impaired communication, discomfort, and fear of a decrease in performance (4,12). Although many athletes believe in a negative impact of mouthguard on performance, researchers failed to report any negative impacts (4,12,14,44) and suggested some ergogenic effects such as an increase in muscular power—especially from a jaw-repositioning custom-made mouthguard (JCM) (5,7,13,17,28).

One of the ergogenic claims about JCM is the effects of the mandibular protrusion caused by the device on upper airway volume (20). The increase in upper airway volume was successfully reported with the use of Mandibular Advancement Device (MAD) in the treatment of obstructive sleep apnea (10,26,40,41). The increase in upper airway volume is related to the advancement of the tongue complex, increasing the velopharynx volume (24,41). The protrusion of the tongue complex also pulls the hyoid bone forward (26) and increases the strength of the pharyngeal dilator muscles, which leads to a wider cross-sectional area (24). In addition to the increase in upper airway volume, an increase in ventilation and arterial oxygenation were reported because of the decreased airway resistance (39). Despite the fact that jaw protrusion is known to increase upper airway volume leading to an increase in airflow (10,24,26,39), there is still very little knowledge on how this anatomical change induced by a JCM in the upper airway, which causes an increase in airflow, could possibly alter aerobic performance. Studies on exercise physiology have stated that to achieve high maximal aerobic power (MAP) ($\dot{V}O_2max$), the human body requires a large increase in ventilation (1,6,19). Knowing that under certain circumstances pulmonary ventilation can be a limiting factor to aerobic performance (3), the increase in ventilation observed from jaw protrusion could possibly have an ergogenic effect on aerobic performance. Clarifying the effect of a JCM on ventilation and its relationship with aerobic performance might help further understand the basic mechanisms of the effect of a JCM on aerobic performance.

Although the effects of a mouthguard on aerobic performance are not conclusive (2,4,12,14,20,34), the effects of a mouthguard on anaerobic performance was reported to have a significant impact on muscular power (7,13,17,28) and upper- and lower-body muscular strength (5,21,22). The suggested mechanism underlying the effects of mouthguard on anaerobic variables is related to the concurrent activation potentiation (CAP) (15), which was showed to increase muscle activation (18), enhanced rate of force development (RFD), and time to peak force (16). Despite the possible ergogenic effects of a custom-made mouthguard on power and strength, the effects of a JCM on volumetric change and athletic performance are inconclusive. In addition to the protective characteristic, the JCM is also known for realigning the temporomandibular joint, but its effects on anaerobic parameters such as vertical and horizontal power, speed, acceleration, agility, and strength are yet not well understood. Therefore, defining the possible ergogenic effects of a JCM on these anaerobic parameters might be beneficial for athletes who require these components to succeed in their respective sports. The aim of the present study was to address the gaps in the literature and investigate the physiological responses of a JCM on airway and their effects on aerobic and anaerobic performance. We hypothesized that (a) the protrusion of the jaw provoked by the JCM will increase the upper airway volume and that this increase in volume will lead to an increase in ventilation and therefore improve MAP and that (b) the use of a JCM will lead to an increase in anaerobic parameters such as power, speed, acceleration, agility, and strength.

Methods

Experimental Approach to the Problem

Subjects were randomly counterbalanced between the 2 experimental conditions, with JCM and without (CON) to assess the physiological effects on anaerobic and aerobic performance. Half of our subjects started the trials with a JCM and the other half of our participants started the trials in the CON group. The counterbalancing of our subjects allowed us to control for a learning effect. All the participants who were recruited in this study were already familiar with this kind of physical testing. Therefore, the athletes were not required to go through a familiarization phase. Participants came to the laboratory on 4 sessions: 1 session for acquisition of dental impressions, 1 session for mouthguard verification, and 2 randomized testing sessions of upper airway computed tomography and athletic testing with a minimum of 72 hours in between each session and a maximum of 96 hours in between each session. Athletic testing was performed at the Exercise Physiology Laboratory in the School of Kinesiology and at the Athletic Complex of Acadia University, Canada.

Subjects

In this study, 24 (women $n = 5$; men $n = 19$) active, college-aged participants (all values are reported in mean ± *SD*) (age = 21 ± 2 age range between 19 and 23 years; body mass = 88.2 ± 13.6 kg; height = 178.1 ± 7.1 cm; body mass index = 27.8 ± 3.8 $kg \cdot m^{-2}$) gave their written informed consent to volunteer in this study. All the participants in this study practiced a minimum of 150 minutes of moderate vigorous physical activity per week. The protocol was reviewed and approved by the Institutional Research Ethics Board of Acadia University and was conducted in accordance with recognized ethical standards and national/international laws.

Procedures

Mouthguards. Each participant was provided with a JCM (Dental Health Center, Dieppe, NB, Canada). First, the subject's dental impressions were obtained using disposable trays (Algimax–Chromatic 3 Phase Hydrocolloid Alginate 120 Hours; JBC and Company, Fredericksburg, TX, USA). Second, stone models were obtained by pouring these impression (Hydrocal 105 Gypsum Cement; USG, Chicago, IL, USA). Third, the participants' optimal jaw positioning was captured using a sibilant phoneme registration protocol (40) and was confirmed using the deltoid muscle's isometric strength test (8,21). All mouthguards were manufactured by the United Dental Laboratory (Halifax, NS, Canada) using Erkoflex material (Erkodent, Pfalzgrafenweiler, Germany).

Upper Airway Assessment. The upper airway volume was assessed using a cone beam computed tomography (CBCT) scan (Galileos Comfort Plus; Sirona 3D, Österreich, Austria). In a standing upright position, the participants rested their mandible on the CBCT support while maintaining the Frankfort horizontal plane parallel to the ground. The CBCT was positioned at approximately the level of the fifth cervical vertebrae to maximize upper airway coverage. The CBCT volumetric datasets were imported in the format of Digital Imaging and Communication in Medicine (DICOM) files into the Sicat Suit Version 1.3 (Sirona Dental Systems, Bonn, Germany) for upper airways volume assessment. The anatomical references for measuring were a plane from the posterior end of the hard palate to the posterior wall of the oropharynx to the top of the epiglottis. Once the anatomical reference points were marked, software compared both CON and JCM conditions.

Table 1. Effects of a JCM on the upper airway.*		
	JCM	Control
Volume (mm^3)	21,329 ± 6,709	18,792 ± 4,140
Area (mm^2)	267 ± 120	232 ± 73
Depth (cm)	13 ± 4	14 ± 3
Width (mm)	31.7 ± 7†	28 ± 6

*JCM = jaw-repositioning custom-made mouthguard.
†Statistically different from the control ($p \leq 0.01$).

Performance Measures, Anaerobic Tests, Vertical Power. Vertical power was assessed with the countermovement vertical jump (CVJ) test using the Vertec measuring device (Sports Import, Columbus, OH, USA). The subject's reaching height was measured with the subject reaching upward as high as possible and touching the highest vane. The subject stood under the Vertec device with feet shoulder width apart and performed a rapid countermovement, followed by a vertical jump. The CVJ height was measured by subtracting the CVJ height by the reaching height. A 30-second rest was given between each of the 3 trials, and the highest jump was recorded. Power output was calculated with CVJ height and body mass using the Sayers formula (38).

Horizontal Power. Horizontal power was assessed with the countermovement broad jump (CBJ) test. The subject stood behind the starting line with feet shoulder width apart and performed a rapid countermovement, followed by a CBJ. The CBJ distance was measured from the bottom of the starting line to the nearest heel. A 30-second rest was given between the 3 trials, and the longest jump was recorded. Power output was calculated using the equation: Power (W) = −2,722 + 47.03 × BM (kg) + 1,423 × distance (m) (36).

Acceleration/Peak Velocity. Both acceleration and speed were assessed through a 40-m sprint with a 20-m split. The times were assessed electronically through timing gates (Brower Timing System Speedtrap 2, Draper, UT, USA) placed at the start, 20- and 40-m marks. The subject began with a conventional 3-point start using a thumb timing mat. Each subject completed 2 trials with 4 minutes of rest in between. The fastest time was used in our analysis.

Aerobic Tests: Maximal Aerobic Power. Maximal aerobic power was assessed using the modified Astrand running protocol on a treadmill (Trackmaster TMX425C; Full Vision, Inc., Newton, KS, USA). Each subject performed a 3-minute warm-up at 5.6 $km \cdot h^{-1}$ at 0% inclination. After the warm-up, the speed increased to 8.0 $km \cdot h^{-1}$, which was constant throughout the protocol, with an increase of 2.5% in inclination every minute until volitional fatigue. Oxygen uptake ($\dot{V}O_2$, in $ml \cdot min^{-1} \cdot kg^{-1}$) was determined continuously on a 15-second basis using an automated cardiopulmonary exercise system (Parvo Medics, East Sandy, Utah). Gas analyzers were calibrated before each test using a gas mixture of known concentrations (16.0% O_2 and 4.05% CO_2). The turbine was calibrated before each test using a 3-L syringe at several flow rates. The highest $\dot{V}O_2$ over a 30-second period during the test was considered as the peak oxygen uptake ($\dot{V}O_2$peak, $ml \cdot min^{-1} \cdot kg^{-1}$).

Statistical Analyses

All data were reported as mean ± *SD*. Paired *t*-tests were used to evaluate differences in performance between JCM and CON conditions. Follow-up analysis were conducted using a Bonferroni correction for each of our 3 families (aerobic, anaerobic, and upper airway volume). The level of significance was set at $p \leq 0.01$ for all our data. To assess the direct relationship between $\dot{V}O_2$peak and upper airway volume, we performed a median split of our sample. We divided our population sample based on $\dot{V}O_2$peak (individuals with lower $\dot{V}O_2$peak [$n = 12$] and individuals with higher $\dot{V}O_2$peak [$n = 12$]). We then attested the relationship between the $\dot{V}O_2$peak and the upper airway volume in both JCM and CON conditions using a paired *t*-test between both conditions.

The magnitude of the difference was assessed by the effect size (ES), calculated according to the following equation:

$$ES = \frac{M_2 - M_1}{SD_{pooled}}$$

where ES is the effect size, M_1 and M_2 are the mean of the first and second trial,

Table 2. Aerobic and anaerobic variables for JCM and control condition.*		
	JCM	Control
Aerobic parameters		
Minute ventilation ($L \cdot min^{-1}$)	149.4 ± 33.3†	136.4 ± 36.9
$\dot{V}O_2$max ($ml \cdot kg^{-1} \cdot min^{-1}$)	49.9 ± 8.1†	47.6 ± 8.5
Time to exhaustion (s)	735 ± 132	689 ± 149
Anaerobic parameters		
Vertical power (W)	5,459 ± 1,459	5,313 ± 1,521
Horizontal power (s)	4,768 ± 999†	4,666 ± 1,088
20-m time (s)	3.26 ± 0.3	3.35 ± 0.4
40-m time (s)	5.92 ± 0.6†	6.03 ± 0.6

*JCM = jaw-repositioning custom-made mouthguard.
†Statistically different from the control ($p \leq 0.01$).

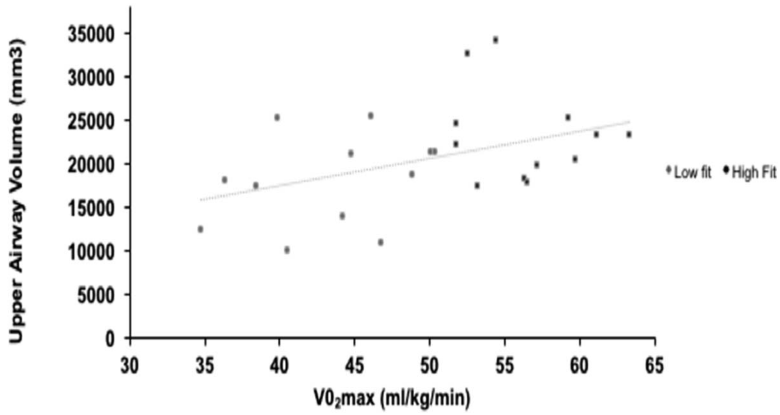

Figure 1. Relationship between upper airway volume and maximal aerobic power with JCM. JCM = jaw-repositioning custom-made mouthguard.

respectively, and SD_{pooled} is the pooled SD, calculated as follows:

$$SD_{\text{pooled}} = \sqrt{\frac{S_1^2 \times (n_1 - 1) + S_2^2 (n_2 - 1)}{(n_1 + n_2 - 2)}}$$

where S_1^2 and S_2^2 are the variances of the first and second trial, respectively, and n is the number of participants.

Results

Structural Changes

The JCM was observed to have a significant impact on upper airways structure as seen in Table 1. There was

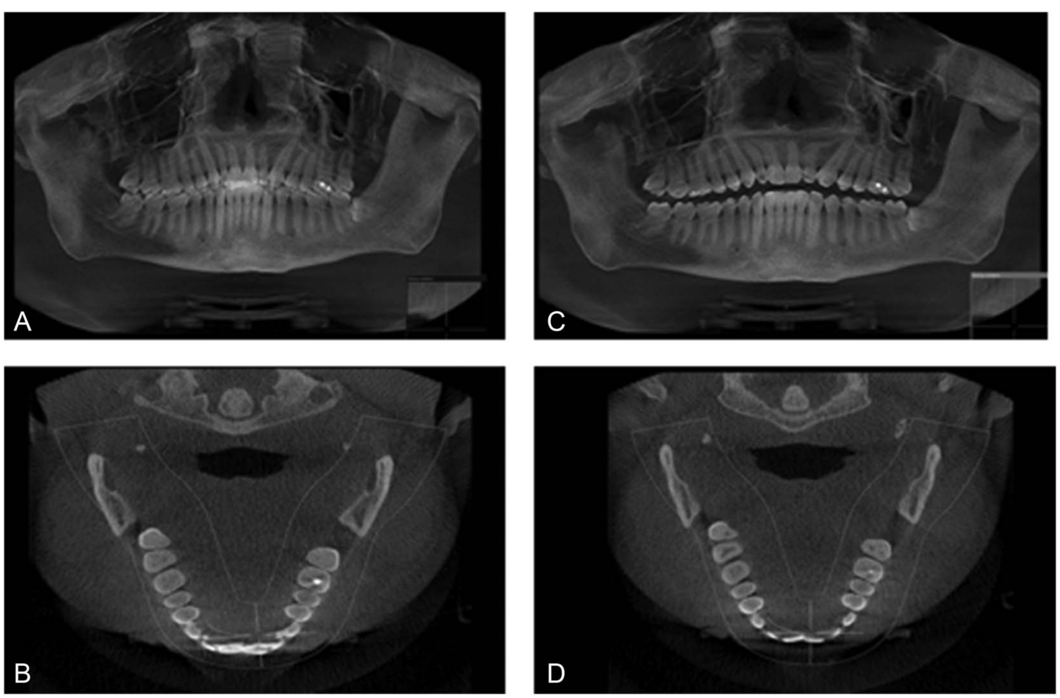

Figure 2. Position of the jaw in one participant with (1 and 2) and without (3 and 4) a jaw-repositioning custom-made mouthguard.

a nonsignificant increase of 13% in upper airway volume in the JCM condition compared with the CON condition (21,329 ± 6,706 vs. 18,792 ± 4,140 mm^3, $p = 0.04$, ES = 0.45). In addition, there was a significant increase of 10% in upper airway width in the JCM condition compared with the CON condition (31 ± 7 vs. 28 ± 6 mm, $p = 0.004$, ES = 0.46).

Maximal Aerobic Power

The effects of wearing a JCM on aerobic performance are presented in Table 2. There was a significant increase of 7% in minute ventilation (VE) at maximal effort in the JCM condition when compared with the CON condition (146.6 ± 29 vs. 136.8 ± 28 L·min^{-1}, $p = 0.006$, ES = 0.35). In addition, there was a significant increase of 5% in $\dot{V}O_2$peak in the JCM condition compared with the CON condition (49.9 ± 8 vs. 47.6 ± 8 ml·kg^{-1}·min^{-1}, $p = 0.003$, ES = 0.4). A nonsignificant increase of 4% was also observed in time to exhaustion in the JCM group compared with the CON condition (747 ± 117 vs. 715 ± 110 seconds, $p = 0.03$, ES = 0.28).

Results examining the relationship between the upper airway volume and $\dot{V}O_2$peak are illustrated in Figure 1. The analysis revealed that a higher $\dot{V}O_2$peak was selectively associated with higher upper airway volume only in the JCM condition ($p = 0.03$).

Anaerobic Performance

The effects of wearing a JCM on anaerobic performance are presented in Table 2. Power production was significantly higher in the JCM condition compared with the CON condition. There was a nonsignificant 3% increase in vertical power in the JCM condition compared with the CON condition (5,459 ± 1,459 W vs. 5,313 ± 1,521 W, $p = 0.03$, ES = 0.1) and a significant 2% increase in horizontal power in the JCM condition compared with the CON condition (4,768 ± 999 W vs. 4,666 ± 1,088 W, $p = 0.009$, ES = 0.1).

In addition, there was a nonsignificant decrease of 4% in 20-m time in the JCM compared with the CON (3.26 ± 0.3 vs. 3.35 ± 0.4 seconds, $p = 0.04$, ES = 0.6) and a decrease of 2% in the 40-m time in the CON group (5.92 ± 0.6 vs. 6.03 ± 0.6 seconds, $p = 0.001$, ES = 0.21) (Figure 2).

Discussion

To the best of our knowledge, this is the first study to close the gap between upper airways volumetric measurements, advanced dentistry theories and exercise physiology theories, and analyze how they interact to affect physical performance. Maximal aerobic power, upper airway volume, top speed, acceleration, and vertical and horizontal power were assessed in 24 college-aged participants. The findings of this study report that the JCM used in this study promoted statistical changes in MAP, upper airway width, top speed, and horizontal power production. We also observed strong nonstatistical trends that a JCM could possibly improve vertical power, acceleration, upper airway volume, and time to exhaustion.

One of the main findings from this study was a 10% increase in upper airway width ($p = 0.004$) with the JCM condition when compared with the CON condition. Although our upper airway volume was not statistically significant, there was a strong trend toward the JCM condition improving upper airway when compared with the CON condition (3% increase in upper airway volume, $p = 0.04$). Our findings are in line with previous studies in the dentistry field that have reported an increase in upper airway volume and width with mandibular protrusion (10,38). A study by Sutherland et al. (41) reported an increase of 4% in upper airway volume when participants used a MAD compared with the control group. Similar results were also reported by Shete and Brah (39) and Chan et al. (10) who reported an increase of 19 and 10%, respectively, in upper airway volume with MAD. In addition, Shete and Brah (39) and Chan et al. (10) reported an increase of 15 and 22%, respectively, in airway width with jaw protrusion. By repositioning the mandible forward, there is a forward pull of the muscles connected to the hyoid bone, which increases the oropharynx lumen. It also causes a change in the compliance of the muscles in the oropharynx and an increased tone of the oropharynx dilator muscles. This oropharynx expansion could possibly lead to a decrease in upper airway resistance and therefore increase airflow (24,26).

In addition to the increase in upper airway volume and width with JCM, our findings also reported an increase of 5% in $\dot{V}O_2$peak ($p = 0.003$) and 9% in minute ventilation at maximal effort ($p = 0.006$) in JCM condition compared with the CON condition. Maximal effort exercise requires a high level of gas exchange because the metabolic demand surpasses the respiratory system's capacity to oxygenate the blood (1). Therefore, the ability to exchange high amounts of air is necessary to achieve high $\dot{V}O_2$max because of the increased requirement for alveolar ventilation to maintain hemoglobin saturation (6). In addition, a decrease in resistance to airflow during exercise is believed to decrease the work from the respiratory muscles, which may increase the blood flow to working muscles (25,32). This economy in the cost of breathing is particularly important at near-maximal effort because the work of breathing has a direct impact on exercise performance and exercise tolerance (25). Our results are in accordance with the available literature (6,25,32) that the increase in $\dot{V}O_2$max was associated with increased upper airway volume and minute ventilation at maximal effort. Another finding from our study is that our median split supports the connection between high $\dot{V}O_2$peak being associated to high upper airway volume ($p = 0.03$) in the JCM condition. This finding provides additional support to our hypothesis that the jaw protrusion increases upper airway volume, leading to an increase in ventilation and MAP.

In contrast to our findings, when wearing a mouthguard, studies have found no significant effects of mouthguard on $\dot{V}O_2$max (2,4,12,14,23,44), VE (4,14,23,44), and time to fatigue (12,44). These differences may be related to some limitations from previous studies such as the absence of airway volume assessment and different types of mouthguards used such as stock (14,23), boil-and-bite (2,4,12,23), and custom-made (4,14) instead of a JCM. The type of mouthguard used is especially important because stock, boil-and-bite, custom-made, and JCM have different manufacturing guidelines and different fitting (9) and grades in a 10-grade scale of protection (33). For example, stock is grade 1 of protection, boil-and-bite is grade 2, custom-made can be grade 5 through 8, and the JCM used in this study is grade 8 (33). In addition, the type of mouthguard used is also expected to alter aerobic exercise because of its different fitting. Stock mouthguard (type I) requires continuous jaw-clenching to remain in place because it has a loose fitting. The boil-and-bite mouthguard (type II) is self-molded by biting; however, it provides a poor fit and requires jaw-clenching to remain in place. Last, the custom-made mouthguard (type III) has the best fit of all types and does not require jaw-clenching to be kept in place (9,32).

Our findings partially supported the hypothesis that the use of a JCM would alter anaerobic parameters. Horizontal power production improved significantly by 2% in the JCM condition. Vertical power did not improve significantly but there was a strong trend toward the JCM condition ($p = 0.03$). Our results corroborate with those of Cetin et al. (7), who assessed the effects of a JCM in lower-body power production and reported a significant ($p < 0.05$) increase in peak and average power, 5 and 3%, respectively. A study by Ebben et al. (17) showed significant changes in l power production while participants were clenching on a custom-made mouthguard. In addition, an increase of 26% in jump height, 8.3% in RFD to peak force, and 2.9% in ground reaction force while clenching on the custom-made mouthguard was reported (17). The mechanism behind the increase in anaerobic power is yet not well understood. According to Morales et al. (28), the CAP seems to be the most appropriate mechanism to explain an increase in power production. This theory explains that the simultaneous activation of 2 areas of the motor cortex led to increased frequency of output signals to the active muscles (11). A study by Ebben et al. (18) on CAP reported an increase of 12.6–25.6% in muscle activation in the prime mover while participants clenched the custom-made mouthguard.

The results of this study also reported that the JCM condition showed a nonsignificant decrease in acceleration time over 20 m (4% decrease, $p = 0.05$) and a significant decrease in top velocity time over 40 m (2% decrease, $p = 0.001$). To our knowledge, this is the first study to report significant difference in top velocity while wearing a JCM. A study by Cetin et al. (7) reported no significant difference in speed while wearing a custom-made mouthguard. This conflicting result between our study and Cetin et al. (7) may be because the author failed to report an increase in horizontal leg power in the custom-made mouthguard condition. In addition, the mouthguard design used by Cetin et al. (7) was different (custom-made mouthguard) from the 1 used in this study (JCM). Previous studies have reported that both vertical and horizontal power production have a significant impact on acceleration and maximal speed (27,29,31,32,35). A study by Kawamori et al. (27) reported that higher accelerations are achieved when the runner is able to produce high amounts of horizontal force without an increase in ground contact time. Similarly, Morin et al. (29) reported that one's acceleration capability is related to the capacity of one's neuromuscular system to produce high amounts of horizontal force at high velocities. On the other hand, one's ability to reach a high top speed is related to one's capacity to produce high amounts of vertical and horizontal power in a short period of ground contact time (30). Our findings are in agreement with the relationship explained above: the JCM conditions produced higher amounts of power as reflected by an increase in acceleration and top speed.

In the present study, no mouthguard comparisons were performed, and this is a limitation of this study. In addition, the reported body mass index in this study classifies the participants as overweight, and therefore, the absence of a body composition assessment is another limitation of this study. In future research, different types of mouthguards (JCM, boil-and-bite, and stock mouthguards) should be compared as they differ in design and fitting.

In conclusion, this was the first study to evaluate the effects of a JCM on upper airway volume, aerobic, and anaerobic performance. Our results demonstrate that a JCM can significantly improve both aerobic and anaerobic performance. The improvements in MAP, top velocity, and horizontal power production could be relevant for athletic training and competition. Our findings lead us to suggest future studies regarding the effects of JCM on precision tasks, which require a modified respiratory pattern such as breath-holding for a few seconds during the draw-and-aim phase (37) and on the application of the JCM in the medical field for respiratory conditions that are associated with an increase in upper airway resistance and therefore a decrease in airflow.

Practical Applications

The use of mouthguard as orofacial protective device should be promoted in all sporting activities. Athletes should be encouraged to wear these not only for their protection but also as a means to optimize their potential performance; the jaw-repositioning custom-made mouthguard, in this study, has shown the ability to increase the volumetric airway and produce positive ergogenic effects on ventilation, MAP, power production, speed, and acceleration.

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