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Review article

A Comparative Study and Review of Research Related to Oral Appliances and Athletic Performance: Understanding the Physiological Impacts

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Abstract

The oral appliance in the form of a mouthguard has been utilized in sports as a protective device. However, early research in the area of physiologic dentistry suggested that mouthguards could also boost performance, with current research suggesting improvements during anaerobic and aerobic exercise. However, no physiological mechanisms have been identified to support why these improvements may be occurring. Based on a review of the literature, the role of clenching as well as the placement of the genioglossus may provide viable explanations for noted improvements with mouthguard use during exercise. This review commences with an overview of early and more recent studies citing mouthguards use and how its use affects performance. A link is made between the sleep apneic research and mouthguard performance research, citing the importance of the genioglossus and type of mouthguard used in these lines of research. Clenching is also identified as it relates to changes in cerebral blood flow and influence on the genioglossus. Future research needs are identified related to mouthguard use during exercise, interaction with the genioglossus, and the role of clenching, in order to better understand the physiological changes as it relates to the hypothalamic-pituitary axis and respiratory factors.

Keywords: Mouthguards; Genioglossus; Respiratory Parameters; Clenching; Resistance; Exercise Aerobic Exercise

Abbreviations

ADA: American Dental Association;
COPD: Chronic Obstructive Pulmonary Disease;
CMJ: Counter-Movement Jumps;
CT Scans: Computed Tomography Scans;
DLPFC: Dorsolateral Prefrontal Cortex;
EMG:Electromyography;
EVA: Ethylene-Vinyl Acetate;
HPA: Hypothalamic-Pituitary Axis;
MORA: Mandibular Orthopedic Repositioning Appliance;
TMJ: Temporomandibular Joint

Introduction

Oral appliances, in the form of a mouthguard, as an application in sports have been used primarily to prevent oral-facial injury [1]. In a review of dental trauma literature, Glendor noted that participation in sports resulted in the greatest cause of dental injury [2]. A review by Newsome cited that early research estimated that players in contact sports such as American football and rugby had a one in ten chance of receiving a dental injury during a year of play, with a one and two chance in one's lifetime of playing such a sport [3,4]. Injuries without mouthguard protection range from crown fractures via high velocity objects, root fractions, mandibular fractures, tooth fractures to luxations from low velocity trauma [5]. Thus, due to the correlation between dental injuries and sport participation, the ADA recommends that athletes use a mouthguard during contact sports [6]. In addition, other governing bodies such as the National Federation of High Schools and the National Athletic Association mandates mouthguard use for athletes in a variety of contact sports such as football, field hockey, ice hockey, and lacrosse in order to minimize dental trauma during sport participation [7,8].

There is substantial evidence that mouthguard use reduces dental injury for individuals during contact sports/activities [9,10]. Early research in the field of mouthguard use and prevention of injury cited a significant reduction in injury as it related to mouth protection for high school football players [11]. In a more recent review of mouthguard use and injuries, Knapik and colleagues cited 69 quantitative studies on mouthguard use and prevention of injury [12]. Although there were difficulties in analyzing the data from the studies due to the methodology used, Knapik and colleagues concluded that there is a significant reduction in overall risk of orofacial injury with mouthguard use, specifically 1.6-1.9 times higher [12]. De la Cruz and colleagues supported this finding in their research with military individuals; specifically finding an overall risk of orofacial injury being 1.7 times greater during a period without mandated mouthguard use for all training events versus during periods when mouthguards were required for all training events [9]. While the use of mouthguards during contact sports is of utmost importance to the dental health of the athlete, adherence to the use of the mouthguard should continually be monitored based on studies citing a range between 16 to 46% of athletes who do not wear the appliance [13-15].

Literature review on oral appliances and performance

Early research on the effect of mouthguard use on performance

To potentially answer this question and to encourage athletes to wear a mouthguard, dental professionals in the late 1970s and early 1980s began to practice a new type of dentistry called "sports dentistry" [16]. Sports dentistry involved fitting athletes with mouthguards to correct malocclusions and temporomandibular joint (TMJ), while touting an improvement in performance along with protection of the teeth, specifically being named as physiologic dentistry by Fonder [16,17]. Subjective data associated with use of a mandibular orthopedic repositioning appliance (MORA) stated athletes improved performance in sports such as football, luge, and running. To aid to the understanding of these subjective claims, dentists and researchers sought to quantify any increases or improvements in strength and performance with the use of a MORA device [18-21]. Smith cited significant increases in strength in the isometric deltoid press in NFL football players (N=25) when wearing a wax bite versus during a teeth together condition while completing an isolated muscle movement [19]. In a later study Smith supported these findings citing a 66% significant improvement in strength using a custom vinyl mouthguard in professional football players [20]. In addition, Grunwaldt found in 41 members of the Green Bay Packers an 8-11% improvement in Cybex muscle testing in using corrective mouthguards [16]. However, comparing a MORA device, with no mouthguard, and a mouthguard condition, Yates et al. did not cite any significant differences in the isometric dead lift in college football players using whole body movement [22]. In addition, in testing isolated muscle groups, Welch and colleagues found no differences in strength when measuring strength measures, specifically the maximal grip strength and knee extension and flexion [23]. However, problems of small sample sizes (the Welch study sample was small, N=9), lack of control subjects, potential influence of the placebo effect, and the types of athletes (female volleyball players and NFL football players) studied makes it difficult to compare results. In addition, although Smith used an isolated relatively smaller muscle group (deltoids) and Yates a studied a whole body movement, critics could argue that differences may lie in the resistance training techniques and the impact of a mouthguard/mouthpiece on these movements [23,24].

In addition to the inability to make comparisons in methodologies between earlier studies, the type of mouth guard used in these studies would be difficult to replicate [20,23,24]. The MORA device was intended to cover the occlusal surfaces of the posterior teeth of the mandible, with an appropriate vertical thickness and resin splints covering the occlusal surfaces [25]. Yet, the techniques employed to determine proper vertical dimensions were subjectively applied by the individual researcher. For example, Welch and colleagues cited that they set the ideal vertical dimension based on the subject's manual resistance of the deltoid muscle. This technique is similar in other studies utilizing the MORA, in which the researcher(s) manually applied opposing force and measured the associated vertical dimension of occlusion during the greatest force production by the subject [19,23]. Thus, in many of the studies in the late 1980s, vertical displacement and its varying degrees of displacement was often used as a gauge to measure if differences in performance occurred with the MORA device.

Recent research on the effect of mouthguard use on performance

Mouthguard effect on anaerobic performance

In the early 2000s research interest in the use of custom fit mouthpieces regained momentum and this partly due to the subjective feedback provided by athletes wearing mouthpieces designed by Shock Doctor, Bite Tech, and Makkar Athletics mouthguard companies that marketed the effectiveness of mouthguard use during exercise performance. Yet the question remained to the effectiveness of mouthguard use during exercise performance. Current studies have sought to elucidate effectiveness of these various mouthpieces on exercise performance with varied outcomes [26-30]. Ebben and colleagues found significant improvements during knee extensions, with an 11% increased average torque and 10% increase in peak torque with subjects clenching on a mouthpiece versus no mouthpiece condition [29]. Dunn-Lewis and colleagues also cited a significant increase in bench throw power and force, increased rate of power production in the vertical jump for the Pure Balance mouthguard versus no mouthguard and an over the counter mouthguard [27]. Utilizing a TMJ repositioning mouthguard, Arnet and colleagues gauged the effect on physical performance parameters in collegiate and professional athletes using neuromuscular dentistry (a method in which TENS surface electromyography is applied to the jaw to facilitate muscular relaxation and in turn cite the optimal bite position, with a mouthguard fabricated based on this position). They found that that when subjects wore a TMJ repositioning device that there was a 3% improvement in vertical jump and average mean power for the Wingate anaerobic test versus a standard custom fit mouthpiece designed to protect the teeth [26]. These findings as it relates to the Wingate protocol were later substantiated using a maxilla mouthguard (Cleverbite®, Cleverbite SL, Terrassa, Spain). Research also cited a 4% improvement in peak power and a 1% improvement with mean power during the Wingate anaerobic test in the mouthguard condition, these being the same findings (4% and 1%, respectively) by Arnet and colleagues using the same protocol [26,30]. Durante Pereira and colleagues also found significant improvements in testing counter-movement jumps (CMJ) in 10 rugby players. Yet they found no differences for a 15 second rebound jump nor in the spirometer data with each of these tests. Yet, the improvement in the CMJ test should be viewed with caution due to the small sample size (N=10) [28]. However, using the same CMJ test, Busca and colleagues utilized a larger sample size (N=28) and measured vertical CMJ, and found significant improvements in mean power and height in the mouthguard condition versus a clenching no mouthguard condition and a no clenching no mouthguard condition. The mouthguard used in this study was the Cleverbite (as described earlier in this review) which relies on digital scans of the maxilla and mandible with a resultant maxilla mouthguard of 1.4 mm EVA overlaid with 4 mm Polyethylenterephthalat-1. In addition, they cited significant improvements during the hand grip test, and the back-row isometric force test (force development and peak force) in the mouthguard condition versus the other 2 conditions (clenching no mouthguard, and no clenching no mouthguard) [31].

Respiratory parameters and mouthguard use during exercise

While much of the research has focused on anaerobic performance outcomes with mouthguard use, other research has focused on objective measures assessing differences in oxygen uptake, heart rate, and ventilation with and without mouthguard use [32-40]. While Bourdin and colleagues cited no significant differences in visual reaction time and explosive power at rest and during exercise, yet interestingly, as it relates to respiratory parameters, the commercially available mouthguard showed differences in respiratory rate during stages of incremental exercise on the cycle ergometer [33]. The use of this mouthguard resulted in a 9% difference in breaths per minute during stage 1 of the incremental protocol and 5% difference when comparing the commercially available mouthguard to the no mouthguard condition [33]. These appear important in light of later research cited by Garner and colleagues finding significantly lowered respiratory rates with various mouthpieces utilized in their studies [33,36,37]. Bailey and colleagues also cited significant differences in ventilation in the vented moldable maxilla mouthguard versus the no mouthguard and standard boil and bite maxilla mouthguard during a graded exercise protocol. Specifically the vented mouthguard lowered ventilation as compared to the no mouthpiece condition with a 9% difference at maximum workload and a 6% difference at 200 Watts. In addition, they cited a significant reduction in blood lactate levels with the vented mouthguard as compared to the no mouthguard and standard boil and bite mouthguard at both the 200 W and maximum workloads [32]. While these studies have utilized various sample sizes and protocols, it is apparent that a trend or a significant difference occurs with respiratory parameters with mouthguard use during higher intensity exercise. Yet why would such changes in respiratory parameters during exercise be important to individuals during exercise?

An earlier study by Francis and Brasher helps shed light on a possible mechanisms and impact on exercise performance with mouthguard use [41]. In this study, they had 17 subjects perform 20 minutes of continuous exercise with varying intensities with the following conditions: no mouthguard (No), unfitted upper mouthguard (MG1), unfitted bimaxillary mouthguard (MG2), and a bimaxillary guard with a breathing hole (MG3). In comparing all conditions for the subjects with conditions randomly assigned, they found that during heavy intensity exercise that subjects had significantly lower ventilation with the mouthguard conditions as compared to the no mouthguard condition, with expired volume of gas being higher in the mouthguard condition. They then concluded that the use of the mouthguard may actually result in an improved breathing pattern that would improve alveolar ventilation. They cited that this could be due to a type of pursed-lip breathing that would enable subjects to take in less air with a given amount of oxygen thereby affecting ventilation and expired gas [41]. In their protocol they examined effects during both light and maximum exercise on a cycle ergometer, with only the maximum exercise demonstrating differences.

Lactate and cortisol

While understanding the effect of mouthguard use during exercise on respiratory physiology provides more objective measures of identifying the mouthguard effect, Garner and colleagues and Dudgeon and colleagues have sought to add to the body of objective measures by assessing the effect of mouthpiece use during exercise on lactate and cortisol [35,42-45]. Thus, based on the differences cited in respiratory physiology and the potential mechanisms to explain the mouthguard effect, Garner and McDivitt measured the width and diameter of the oropharynx with and without a mouthpiece using CT scans. They cited a 9% increase in both diameter and width for subjects using a mouthpiece but found no difference in lactate levels during an exercise protocol, yet the sample was small (N=10) [35]. Thus, based on the changes in the airway parameters, they conducted a study with a larger population (N=24) and found that lactate levels were significantly improved after 30 minutes of running at moderate intensity exercise, specifically noting a 23 percent change of lowered lactate levels with mouthpiece use versus a no mouthpiece condition [45]. As it relates to anaerobic exercise, Morales and colleagues also cited improvements in lactate measures, citing an 8% improvement in lactate with the mouthguard use and significant improvements in all variables associated with anaerobic testing with mouthguard use compared to no mouthguard condition [30].

In addition to differences in lactate during exercise with mouthpiece use, researchers have also studied effects of mouthpiece use during exercise on cortisol levels, citing a trend towards lowered cortisol levels with mouthpiece after 30 minutes of running [43]. Yet, the exercise intensity may not have been substantial enough to elicit significant changes in cortisol. Thus, to test this theory, in a later study researchers utilized a more intense protocol of 1 hour with resistance exercise. In this protocol Division I football team completed a routine resistance training session while cortisol was measured before, during and after the session. With mandibular mouthpieces being randomly assigned, they found a 51% reduction in cortisol levels 10 minutes post exercise (N=28) [44].

Reductions in cortisol in the human with mouthpiece use during exercise is significant for a few reasons. Firstly, cortisol with mouthpiece use had not been measured in humans, though a similar measure had been assessed in rats under stress while biting on a stick [46,47]. Secondly, research shows that cortisol levels increase significantly from baseline to post intensive resistance exercise and this was the case in the no mouthpiece condition, thus corresponding with the literature [44,48,49]. Thirdly, it is well understood that elevated cortisol affects protein synthesis and immunity [50,51], thus these findings link mouthpiece use with a potential recovery aspect of exercise. Supporting these findings by Garner and colleagues [26] was a follow up study by Dudgeon and colleagues in which they had subjects complete a highly intensive protocol of 10 sets of 6 repetitions of back squats at 80% of the individual's one-repetition maximum with and without a mandibular mouthpiece. They cited significant reductions in cortisol and lactate, specifically finding a 39% reduction in cortisol and 22% reduction in lactate 30 minutes post exercise with mouthpiece use [42]. In conclusion, the studies by Garner and colleagues and Dudgeon and colleagues cite objective measures which can be linked to potential mechanisms that would support the mouthguard effect. Thus based on the most recent objective data, the next sections of this review will delve into these theories of the mouthguard effect which have been substantiated in other fields of research, thus providing a greater understanding and knowledge of how to better study this area of sport dentistry.

Literature review of theories to support performance enhancement

Genioglossus and tongue position

The complexity of the tongue organ can be found in studying its involvement in respiration, swallowing, speech, and mastication [52-58]. The tongue muscle, specifically the genioglossus, is the main protruding muscle (See Figure 1). The genioglossus is innervated by the hypoglossal (cranial nerve XII) which along with the hypoglossus, causes a pressing down of the tongue base [52,58]. The importance of the genioglossus is its role in increasing muscular tone during the inspiratory phase of breathing [59,60] which in turn is important for dilating of the pharyngeal area.

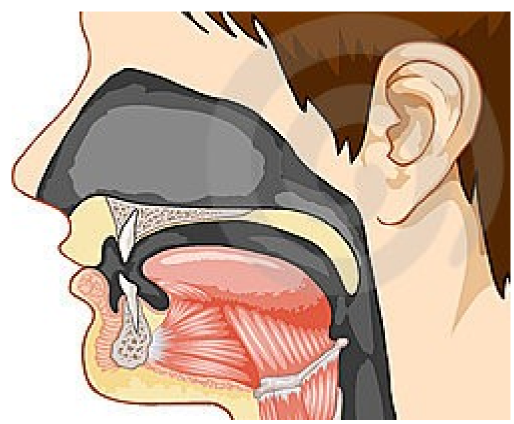

Figure 1. Genioglossus muscle

The importance of tongue muscle placement has been cited as playing a key role in the opening of the pharyngeal area, with sleep apneic studies citing a forward shift of the mandible and subsequent forward protrusion of the tongue using sleep apneic mouthpieces designed to promote enhanced breathing mechanics [61-64]. Specifically, these devices have been shown to increase the pharyngeal area, with Kyung and colleagues citing a 19% improvement in cross sectional area of the retroglossal (defined as the back of the tongue to the wall of the pharynx) area of the pharynx using a 75% mandibular advancement mouthpiece [64]. While Mann and colleagues cited increases in the diameter of the hypopharyngeal area with genioglossal stimulation, resulting in a mean 133% increase from baseline [53]. Earlier research cited that contracting the genioglossus results in pulling the base of the tongue down and forward, with later researcher citing that this occurs with the help of the protruder muscles, which will subsequently open the pharyngeal area [65,66]. To clarify how this occurs, Saboisky and colleagues [55] cited a complexity of networks linking the hypoglossal motonuerons which innervate the genioglossus. Specifically they cite increased genioglossus discharge rates during both inspiration and expiration thereby leading to tongue protrusion [55]. In addition, research has shown that the number of hypoglossal motoneurons will also be affected by exercise, citing an increased number of these motoneurons activated with increased exercise intensity, resulting in increased EMG activity of the genioglossus [67].

Miller [58] states that the tongue, in order to operate optimally, receives complex somatosensory input via the central nervous system, resulting in both complex to simple reflex actions [58]. Initial animal and human research to more recent research supports this hypothesis [58,68-73]. With the animal model, Lowe and Sessle cites the interaction between the jaw and tongue when they opened the cat jaw as little as 4 mm, resulting in genioglossus activity. This outcome thereby led to their conclusion that the temporomandibular joint significantly affects the activity of the tongue due to reflexes originating in orofacial regions [74]. In earlier human research, Weber and Smith [73] stated a reflex exists between the jaw, tongue and lip by demonstrating increased EMG activity of the masseter, orbicularis oris inferior, and the genioglossus with mechanical stimulation [73]. In the human model, Takata and colleagues found genioglossus and orbicularis orbis EMG activity increase with jaw opening and ceased with jaw closing during gum chewing, suggesting the link between tongue, lip and the jaw [75]. Hiyama's lab also found similar outcomes with EMG activity of the genioglossus, with EMG increasing during jaw opening, hypothesizing that this collaboration of activity between the jaw and tongue would not be explained by a sequential reflex response but possibly preset into the central nervous system within the lower brain stem [57].

Role of clenching

In addition to the important role the genioglossus plays in dilating the airway as innervated by the hypoglossal motoneurons, research has also examined the impact that clenching and placement has on the EMG activity of this muscle. Firstly, researchers have cited an increase in EMG activity in the genioglossus with mild to maximal clenching during non-exercise protocols [72,76]. Valdés and colleagues support a link between the masseter while clenching and its effect on the tongue, noting the interaction using 30 healthy subjects with no current or past pain in the TMJ, mouth, or tongue. In measuring the EMG activity of the masseter and temporalis during clenching and swallowing, they cited significantly lower EMG activity in the masseter during clenching with the tongue on the floor of the mouth versus on the hard palate, this being explained by the effect the tongue creates when placed on the floor of the mouth, against the mandibular, lingual side of the incisors, which consequently linked to the masticatory muscles [72]. Indeed Sabiosky and colleagues cite an optimal placement of the tongue to generate the greatest to lowest force production. They cite optimal tongue position, resulting in the greatest force production, as being when it is retracted between 12 and 32 mm, with the mean maximal force being 28.3 N at 24 mm, and the lowest forces (14.9 N) produced with tongue protrusion at 12 mm [77]. Not only did the researchers find increased force production but also cited in a significant decrease in breathing rate with tongue on the floor of the mouth (15.47 BPM) versus tongue on the roof of the mouth (16.15 BPM, $p=0.023$). [77]

Not only has clenching been cited to effect genioglossus activity and masticatory muscles, clenching has also been shown to affect cerebral activity in activation of the cortical areas in the brain, thereby affecting the hormone response [46,47,78-80]. As cited earlier, studies have cited decreases in cortisol levels with both clenching and chewing, with and without physical activity [44,79]. Yet what mechanism can explain the purported improvements in hormone levels with clenching? A rat model may explain the potential mechanisms that occur with a reduced stress response during clenching. Specifically, researchers have cited that restrained and stressed rats, when biting on a stick, had reductions in corticotrophin releasing factor and c-Fos in the hypothalamus which may be modulated by suppression of extracellular signal-regulated protein kinase 1/2 (pERK 1/2) in the paraventricular nucleus [46,47,81]. This link between the hypothalamus and the involvement in the jaw muscle via clenching may be explained by neuronal projections from the lateral hypothalamic connecting to the trigeminal motor nucleus in the rat model [82]. In addition, it was observed that the trigeminal motor nucleus is innervated by corticotrophin releasing factor immunoreactive fibers within the amygdala, providing another explanation of effects on hormonal response during clenching [82].

Yet rat models cannot completely explain the stress response mechanisms involved in humans during chewing and clenching, thus researchers use functional magnetic resonance imaging or positron-emission tomography to assess cortical activity and blood flow dynamics during clenching and chewing which has been cited to be a valid measure of assessing these tasks [78,80,83-86]. Momose and colleagues [83] demonstrated mastication increased cerebral blood flow in the sensorimotor cortex by approximately 26.5% during clenching. Later studies cited significantly increased middle cerebral blood flow and significant activation of the sensorimotor cortex with clenching versus other tasks such as gum chewing and a hand motor task [78,84]. Research also cites that activation within the dorsolateral prefrontal cortex (DLPFC, an area in the cerebral cortex) is most likely dependent on continuous teeth contact as occurs during clenching, and that intensity of the clenching most likely influences that magnitude of the cerebral activity within the sensorimotor cortex (area in cerebral cortex responsible for motor function) [80,87]. Qin and colleagues [88] cited that the function of the DLPFC is likely affected by the HPA axis by decreasing levels of the catecholamines [88]. These findings are significant as it relates to mouthpiece use during exercise as they provide potential explanations for the cited decreases in cortisol and lactate with mouthpiece use during exercise [35,43-45]. Thus, enhanced cerebral blood flow may be a key piece in understanding these effects, with researchers citing improved cerebral blood flow rate when subjects are in a mandibular physiologic rest position [89]. Research by Otsuka and colleagues demonstrated how an experimentally induced retrusive mandibular position using a splint (defined as placing the mandible in a more backward position) resulted in a activation of the hypothalamus during clenching in 2 of 8 subjects [90]. Though this evidence is not sufficient to make any definitive links between malocclusion and activation of the hypothalamus and subsequent stress response, it is another step in understanding a mechanism that could explain the cortisol response during exercise with a mouthpiece, a mouthpiece which has been cited as placing the mandible in a more forward mandibular position [37,43,44]. In closing, more recent research aims to elucidate how increased cerebral blood flow could affect the hypothalamic response from stress with subsequent hormonal production such as cortisol. Miyake and colleagues [85] demonstrate that biting during stress and its effect on the hypothalamic response appears to be mediated by nitric oxide levels, specifically with biting resulting in decreased levels of nitric oxide versus not biting which leads to elevated nitric oxide levels [85]. They surmise that masticatory activity (biting down) during physiological stress results in an anti-stress response that may be facilitated by nitric oxide in the brain in which nitric oxide acts as an amplifier or feedback mechanism for neuronal activity during stress [85].

Genioglossus and clenching and involvement of the mouthguard

Although there is substantial evidence of the importance of the genioglossus, as well as the effect of clenching, how does this relate to mouthguard use during exercise? Firstly, an appliance provides some type of stimulus to the tongue muscle as well as an increased opportunity for the individual to clench during exercise. Hidaka and colleagues found that with increased clenching, there was a resulting shift on the bite force such that there was a more balanced bite force (with balance bite force being defined as force placed on all occlusal contacts). They hypothesized that this outcome may be a mechanism which prevents damage to teeth and to the temporomandibular joint [91]. Murakami and colleagues stated that the surface of the mouthguards were finished such that there was an even bite surface between the mouthguard and the opposing occlusal surface [92]. This is supported by Pae and colleagues who noted that in creating their mouthguard, that "all teeth contacted equally at maximal intercuspal positions" a study in which they cited significant improvements in club head speed and driving distance in professional golfers [93]. Similar to these findings was a study by Lee and colleagues in which they utilized a MORA device but noted that the fit of the appliance required that all teeth have even contact [94]. Their findings revealed significant EMG measurements in isometric improvements with the following muscle groups: sternocleidomastoid muscles, cervical and lumbar erector spinae, upper trapezius, biceps, triceps, rectus abdominis, and internal and external oblique [94]. Thus, using a mouthguard may improve clenching capacity thereby resulting in changes of cerebral blood flow and hypothalamic response as noted earlier. Secondly, the design of the mouthguard is important to understand in light of its potential effect on the tongue muscle, i.e., a mandibular mouthguard versus a maxilla mouthguard differs in its impact on the tongue and may thereby affect outcomes associated with the genioglossus.

Physiologic Effects	Outcomes with Mouthpiece Use	Impact on individual (requires research to confirm)
Respiratory system	Decreases in respiratory rate during submaximal aerobic exercise	Lowered respiratory rates may be linked to decreases in fatigue
Lactate	Decreases in lactate levels after submaximal aerobic exercise	Lowered lactate levels would suggest decreases in fatigue
Cortisol	Decreases in cortisol levels post 1 hour resistance exercise	Lowered cortisol levels post exercise would suggest improvements in muscle synthesis post exercise

Table 1. Summary research findings of potential impact on physiologic parameters with mouthpiece/mouthguard use during exercise

As stated earlier in this review, it is well researched within sleep apneic research that forward mandibular placement devices are utilized to open the airway and improve breathing for this population [61,62,95]. Consequently, due to findings in the sleep apneic literature, Garner and McDivitt studied a mandibular forward placement mouthpiece (as advertised by the company, Bite Tech, Inc.) utilizing CT scans and studying the effects of mouthguard use on exercise performance demonstrated a significant 9% increase in width and an increase in diameter of the oropharynx with mouthpiece use versus a no mouthpiece condition [35]. They surmised that the enhanced airway openings as seen in the CT scans with mouthpiece use signify forward mandibular placement and thereby explain improvements in lactate [35]. In addition they suggested a link between the mandibular placement of this mouthpiece and effect on the genioglossus, citing increased activation of the genioglossus in a case study referred to in a published study [37]. Thus, understanding the degree of mandibular advancement and vertical displacement and subsequent effect on the genioglossus in future mouthguard/mouthpiece studies should be addressed to further clarify understanding of the mouthpiece effect.

Finally the design of the mouthpiece and how it affects tongue placement may be of importance to understand differences in outcomes within these studies. Francis and Basher cited that in comparing their three mouthguards, that the one which resulted in the most significant improved ventilation was a bimaxillary mouthguard with a small breathing hole. Bailey and colleagues also noted significantly lowered lactate levels and ventilation at 200 W and maximum workloads with a vented mouthguard versus no mouthguard condition and a traditional boil and bite maxilla mouthguard [32]. While Francis and Basher [41] cited that the improvements in ventilation in their study may be due to a type of pursed lip breathing, Bailey and colleagues stated that plausible differences in ventilation could be due to the construction of the mouthguard [32,41]. Garner and colleagues also hypothesized that a type of pursed lip breathing could be occurring with their lower mouthpieces as a potential explanation in the decreased respiratory rate noted in the lower custom and boil and bite mouthpieces [36,37]. As mentioned earlier, this type of breathing leads to improved ventilation in COPD patients both at rest and during exercise [96,97] and this being may be linked to displacement of the tongue. Garrod and colleagues stated that they were unable to explain the mechanisms for the improvements in respiratory parameters with pursed lip breathing [96]. Garner hypothesized that the decreased vertical displacement created by the mouthpiece used in the study may have resulted in less space to allow air in and out of the mouth, causing subjects to contract the tongue, thereby opening the airway and in turn explaining the respiratory improvements in this study [37]. Nevertheless, studies to confirm a potential link between pursed lip breathing and tongue placement as well as other mechanisms to explain respiratory improvements with pursed lip breathing should be explored.

Conclusion

Findings during this review reveal that there are a variety of acute outcomes with mouthguard/mouthpiece use during exercise which include the impact on the genioglossus as well as the clenching effect with mouthguard use and its subsequent effect on the HPA-axis. Thus the use of a mouthguard/mouthpiece appears to impact physiological mechanisms during exercise which include respiratory, metabolic, and hormonal changes (see Table 1). However, rather than making conclusive remarks about the use of mouthguard use, it is the goal of this review to raise appropriate questions to enable researchers to illuminate appropriate avenues to explore as it relates to mouthguard use during exercise. Finally, in noting the acute improvements cited in many of these studies, results denote seemingly minimal improvements, i.e. on average ranging from 3-10%. Thus dental professionals should examine if these improvements are meaningful for the client in fitting the individual with an appliance. However, it is the belief of the author that research in this area may be more promising in understanding the consistent use of mouthpiece/mouthguards during and post exercise in view of the research related to lactate and cortisol. Specifically, research should focus on impact on recovery and subsequent training sessions. If, as the research suggests, there are reductions in lactate and cortisol post training sessions, then the impact on physiological recovery is meaningful. We know that elevated cortisol impairs muscle recovery and immune function, while elevated lactate impedes training by prolonging post oxygen exercise consumptions so that the body can rid the body of elevated hydrogen ions associated with lactate [98]. Thus research should explore use of mouthguards/mouthpieces during and after exercise to determine training impact on the individual over a longer period of time. Yet whether the impact of mouthguard use benefits occur during or post exercise, such a finding should encourage the athlete to wear a mouthguard for both protection and performance reasons.

Competing Interests

The author has no professional relationship with the manufacturer of any mouthpieces/mouthguards mentioned in this article and will not gain any monetary benefit from promotion of any of these oral appliances. In addition, the author does not endorse any one product based on the results of these studies.

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