Effects of mouthguards on vertical dimension, muscle activation, and athlete preference: a prospective cross-sectional study

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Mandibular repositioning and subsequent neuromuscular signaling are proposed mechanisms of action for commercial mouthguards marketed for performance enhancement. A prospective cross-sectional study of 24 healthy adult weightlifters with normal occlusal relationships was designed to determine whether 2 self-fit performance mouthguards; a custom-fabricated, bilaterally balanced, dual-laminated mouthguard; and no mouthguard (control) differed in their effects on vertical dimension, muscle activation, and user preference during a 75% maximum power clean lift. Each subject was tested for each of the mouthguard categories: Power Balance POWERUP, Under Armour ArmourBite, custom, and no mouthguard.

Interocclusal distance was measured at baseline and with each mouthguard. Mean and peak activity of the anterior temporalis, masseter, sternocleidomastoid, and cervical paraspinal muscles was measured during sitting and during a 75% maximum power clean lift. A mouthguard preference questionnaire was completed. Analyses were conducted to determine whether interocclusal distance differed among mouthguard type and to examine the effect of mouthguard type on mean and peak muscle activation during the clean lift. Interocclusal distance was affected by mouthguard type ($P = 0.01$). Mean and peak activity of the anterior temporalis and masseter muscles and mean activity of the sternocleidomastoid muscle differed among mouthguards ($P < 0.05$). Mouthguard type did not influence muscle activation of the cervical paraspinal muscle group. Overall, the Power Balance mouthguard produced more muscle activity. Participants preferred custom mouthguards nearly 2:1 over self-fit performance mouthguards ($P = 0.05$). Participants perceived that they were stronger and were less encumbered when using a custom mouthguard during submaximum power clean lifts.

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The relationship between optimal mandibular position and muscular strength among trained athletes has been reported.[1] Stenger theorized that optimal positioning of the temporomandibular joint (TMJ) with a mandibular orthopedic repositioning appliance improved the position of the cervical vertebrae and promoted proper cranial nerve signaling, affecting muscular performance in the extremities.[1] Various designs of mandibular orthopedic repositioning appliances have been reported to reposition the mandible so as to increase the vertical dimension, which theoretically prevents overloading of the joint and decreases aberrant vascular and neurological signaling from the stomatognathic system.[2-6] This optimal positioning of the mandible enhances posture and ultimately muscular activation and performance in the rest of the body.[2-6] These proposed muscular and neurological benefits of mandibular repositioning have been researched in subjects with symptomatic and asymptomatic muscles and TMJ dysfunction.[6-8] However, the physiological effects of mandibular repositioning in a healthy population are still unclear.[9]

Studies using surface electromyography (EMG) have been conducted to better understand how mandibular repositioning can elicit a neuromuscular response. Neuromuscular splinting seeks to restore the optimal length-tension relationship of the muscles of mastication, as evidenced by increases in occlusal force, muscle activation, and normalization of TMJ functioning. EMG of the muscles of mastication as well as the sternocleidomastoid (SCM), trapezius, and cervical flexor muscles during maximum-effort jaw clenching in different mandibular positions demonstrates a possible link between mandibular position and muscular enhancement in the rest of the body.[7,10-12] An increase in the vertical dimension of occlusion in individuals with derangements of the TMJ complex has been shown to increase EMG activation, in that jaw clenching increases activity in the anterior temporalis and superficial masseter muscles.[13] The activity of the trapezius and sternocleidomastoid muscles has also been shown to increase 7 to 33 times during clenching compared to during rest, which could account for improved performance during dynamic movements.[14]

The relationship between increased activity of the muscles of mastication in healthy individuals and athletic performance is still largely unknown and has only recently resurfaced in the literature.[15,16] Few studies have attempted to correlate their findings on athletic performance with data gathered from the changes in dental occlusion or muscle activity.[17] Given that many contact sports require the use of a maxillary mouthguard, the use of an oral appliance that favorably repositions the mandible and provides orofacial protection would serve 2 purposes. Similarly, healthy individuals participating in noncontact sports, such as weightlifting, might benefit from increases in muscle activation resulting from use of a mouthguard.

The quest for a custom or self-fit mouthguard that would provide both benefits has been a driving factor in consumer marketing in recent years.[6,18] Two commercially available self-fit mouthguards, Under Armour ArmourBite Mouthguard (UA; Under Armour, Inc.) and Power Balance POWERUP Mouthgear (PB; Power Balance Technologies, Inc.), use proprietary inserts that claim to impart

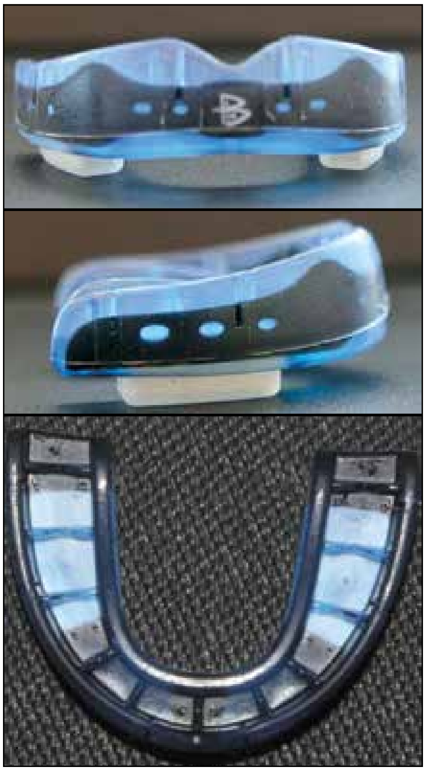


Fig. 1. Power Balance POWERUP Mouthgear.

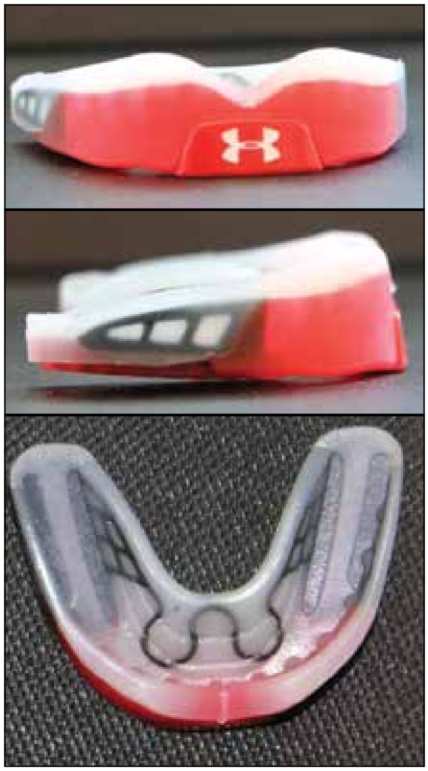


Fig. 2. Under Armour ArmourBite Mouthguard.

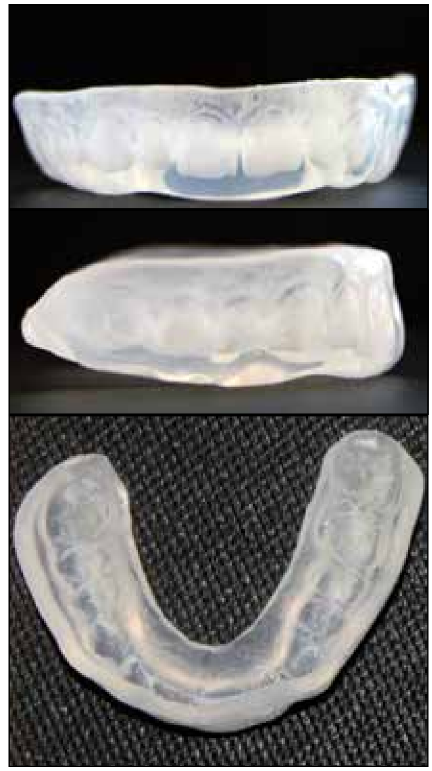


Fig. 3. Custom dual-laminated, bilaterally balanced mouthguard.

performance-enhancing properties.[19,20] The primary purpose of the present study was to determine the effect of self-fit UA and PB and a custom (CUS), dual-laminated, bilaterally balanced mouthguard on vertical dimension and head and neck muscle activation during a dynamic athletic movement in healthy, physically active individuals. The power clean lift was specifically chosen because of its widespread use among the projected participant population.

Although coaches and athletes are aware of the need for mouthguard protection during contact sports, many athletes have chosen not to wear mouthguards because of discomfort, breathing difficulty, speech difficulties, or lack of availability.[21-25] Protective mouthguards do not appear to negatively affect heart rate, gas exchange, and power production; a psychological barrier may be the greatest impediment.[18,21,23,26,27] The secondary purpose of this study was to assess participants' perceptions of each mouthguard type in relation to its perceived effect on strength, explosive power, and exertion; its comfort; their overall preference; and their willingness to use it during practice and competition.

Materials and methods

Design

This study used a prospective cross-sectional study design. The independent variable was mouthguard type: PB (Fig. 1), UA (Fig. 2), CUS (Fig. 3), and, as control, no mouthguard (NMG). The dependent variables were interocclusal distance; normalized mean and peak muscle activation of the anterior temporalis, masseter, SCM, and cervical paraspinal muscles during a 75% maximum power clean lift; and participant preferences for the various types of mouthguards while performing a 75% maximum power clean lift. Specifically, participants ranked the 4 conditions (3 mouthguards and control) with respect to perceived strength, perceived explosive power, ease of use, and comfort. Participants also used a 5-point Likert scale to indicate how likely they would be to use any mouthguard during regular practice or during competition. Last, participants indicated which of the 3 mouthguards they preferred to use for regular practice and competition.

Participants

Twenty-four (14 male and 10 female) healthy, physically active individuals participated. The mean age of participants was 32.2 (SD, 7.3) years; mean height was 173.4 (SD, 8.8) cm; mean weight was 77.5 (SD, 12.1) kg. To be included in the study, participants had to be at least 18 years of age, an experienced weightlifter (defined as having a minimum of 2 years of experience), and currently involved in regular weightlifting, including the power clean lift, more than 3 days per week. The participants were currently in good health, had no current acute or chronic illnesses, and were free of musculoskeletal injuries for at least 1 month prior to testing. Exclusion criteria included absence of the

Table 1. Baseline intraoral measurements of participants (N = 24).

Measurement	Mean (SD)	95% Confidence interval
Overbite (mm)	2.58 (0.65)	3.23-1.94
Overbite (%)	33.13 (10.63)	43.76-22.49
Overjet (mm)	2.79 (0.93)	3.26-2.32
Interocclusal distance (mm)	3.54 (0.93)	4.46-2.62

Table 2. Surface electrode placement and maximum voluntary isometric contraction (MVIC) test position.

Muscle	Electrode placement[28]	MVIC test position[29]
Anterior temporalis	Electrodes were placed vertically over the midbelly, just above the zygomatic arch.	While seated, the participant clenched the teeth and performed a maximum-effort bite.
Masseter	Electrodes were placed vertically along the muscle fiber, at the midpoint between the zygomatic arch and angle of mandible.	While seated, the participant clenched the teeth and performed a maximum-effort bite.
Sternocleidomastoid	Electrodes were placed obliquely, mid-distance between the mastoid process and sternal notch and slightly posterior to the muscle belly.	While the participant was seated, the head was rotated to the opposite side and resistance was applied to the lateral aspect of the face.
Cervical paraspinals	Electrodes were placed vertically and approximately 2 cm lateral to the spine in the midcervical region (approximately at C4) over the muscle belly.	While the participant was seated, the head was extended from a neutral position and resistance was applied to the posterior head (in the area of the external occipital protuberance).

first molars; presence of a removable oral prosthesis; open or impinging deep bite; TMJ or muscle pain on palpation; previous diagnosis of internal derangements of the TMJ; medical disorders that might affect muscle function, such as arthralgias or myalgias; and presence of a significant (greater than 2-mm) centric slide. The local institutional review board approved the study, and all participants provided informed consent.

Electromyography

The MyoSystem 1200 EMG acquisition system (Noraxon U.S.A., Inc.) was used to record surface EMG activity simultaneously from the anterior temporalis, masseter, SCM, and cervical paraspinal muscles during maximum-effort occlusion and power clean lift tests. A single-ended amplifier was used (impedance > 10 MΩ; gain, 1000) with a fourth-order Butterworth filter (10-500 Hz) and a common mode rejection ratio of 130 dB. A receiver with a sixth-order filter (gain, 2; total gain, 2000) was used to further amplify the signal. The signal was passed to a computer through a 16-channel NorBNC connector system and a 12-bit analog-to-digital card (Noraxon U.S.A., Inc.). The sampling rate was 1000 Hz. EMG files were stored on the computer and MyoResearch software (version MR-XP 1.07, Noraxon U.S.A., Inc.) was used for processing and analysis. Data were full-wave rectified (ie, linear envelope detection), integrated with a sixth-order Butterworth filter, and smoothed over a 15-ms moving window (version MR-XP 1.07, Noraxon U.S.A., Inc.).

The peak of 3 maximum voluntary isometric contractions (MVICs) was averaged for each muscle and used for normalizing EMG in the seated occlusion and power clean lift tests. The mean and peak EMG data for each muscle during the maximum-effort jaw clenching and 75% maximum power clean lift tests were normalized as a percent of MVIC.

Procedures

Participants attended 2 sessions. During the first session, participants completed paperwork, including informed consent, biographical information, and self-reported 1-repetition maximum effort in the power clean lift. Next, each participant received an extraoral examination, which consisted of a review of the medical and dental health history, head and neck muscle palpation, and observation of mandibular mobility.

A single investigator (CCG) recorded intraoral measurements of each participant. Interocclusal distance was used to measure changes in vertical dimension of the jaws induced by each mouthguard. Initial interocclusal distance of jaws at rest was measured at the central incisors with an intraoral ruler. This measurement was taken while the patient was sitting, maintaining a natural head position, and repeating the word *emma* 3 times to attain a predictable rest position of the mandible. Other intraoral measures, taken for descriptive purposes, included the maximum overjet of the maxillary teeth and maximum overbite. All measurements were recorded to the nearest 0.50 mm (Table 1).

Following the extraoral and intraoral examinations, maxillary and mandibular alginate impressions were taken for fabrication of the custom mouthguards. Sufficient vestibular detail was obtained to allow optimal fit of the final mouthguards. Regisil polyvinylsiloxane occlusal registration material (DENTSPLY International) was used intraorally to capture occlusal registration. The casts were poured immediately in high-detail die stone and used to fabricate the custom mouthguards.

The custom mouthguards were constructed from a 3-mm-thick clear ethylene vinyl acetate that was laminated over the dental cast at 90 psi on a Drufomat Scan Pressure Machine (Dreve Dentamid GmbH). A second, 1-mm-thick layer of clear ethylene vinyl acetate was placed on

Table 3. Mouthguard type and interocclusal distance (N = 24).

Mouthguard	Mean (SE) interocclusal distance (mm)	95% Confidence interval
NMG	3.54 (0.46)	2.62-4.46
PB	5.33 (0.46)[a]	4.41-6.25
UA	3.52 (0.46)	2.60-4.44
CUS	3.69 (0.46)	2.77-4.61

Abbreviations: CUS, custom mouthguard; NMG, no mouthguard (control); PB, Power Balance POWERUP Mouthgear; UA, Under Armour ArmourBite Mouthguard.

[a]Significantly different from no mouthguard ($P = 0.001$), Under Armour mouthguard ($P = 0.001$), and custom mouthguard ($P = 0.006$).

the posterior (first premolar to second molar) occlusal surfaces of the mouthguards. The occlusal registration was then used to mount the maxillary and mandibular casts of each mouthguard on an articulator. Each mouthguard was trimmed and polished, and the opposing occlusion was indexed into the mouthguard at approximately 3 mm of posterior opening.

Participants were instructed and supervised in fitting of PB and UA mouthguards. The manufacturers' instructions for boil time and oral adaptation techniques were followed.

The second session was conducted in a neuromuscular research laboratory for performance tests (maximum-effort occlusion and 75% maximum power clean lift) 2 weeks after the initial session. At this time, all mouthguards were verified for adequate retention during mouth opening. An intraoral ruler was used to measure the distance between the maxillary mouthguard and the mandibular incisors to determine the interocclusal distance for each mouthguard.

Participants were prepared for EMG measurements; preparation included shaving the skin surface to remove any overlying hair and cleaning the skin with a 70% isopropyl alcohol swab to minimize skin impedance. Self-adhesive silver/silver chloride surface electrodes with a 10-mm diameter and 10-mm interelectrode distance were used (Noraxon U.S.A., Inc.). Bipolar surface electrodes were placed on the skin overlying the anterior temporalis, masseter, SCM, and cervical paraspinal muscles, and a reference electrode was placed on the clavicle (Table 2).[28] Correct placement of all electrodes was confirmed by monitoring activity during a maximum-effort occlusion (anterior temporalis and masseter) or isolated muscle testing (SCM and cervical paraspinal) by EMG signal identification on an oscilloscope.

After proper electrode placement was confirmed, standardized manual muscle testing procedures were used to record an MVIC for each muscle (Table 2).[29] Prior to each test, the myoelectric signal was calibrated with the participant in a relaxed, seated position to establish baseline EMG activity. During MVIC tests, participants were instructed to provide maximum clenching or to resist with maximum effort against the investigator's manual resistance for 5 seconds. The average of 3 MVICs for each muscle was used for EMG normalization during data processing.

Following MVIC tests, participants performed maximum-effort occlusion tests with each mouthguard while EMG data were collected for each muscle. Sitting in a comfortable position, participants were instructed to bite (clench) using maximum effort for 5 seconds. Three repetitions of occlusion EMG were collected for each type of mouthguard and the control condition. The order of mouthguards used during testing was randomized to reduce order effect across participants. The normalized mean EMG during clenching was used in data analyses.

Next, participants performed 75% maximum power clean lifts under each condition while EMG data were collected for each muscle. The power clean lift was performed as the participant lifted the bar from the ground to the level of the clavicles in a fluid, explosive manner. A triaxial accelerometer (NeuwGhent Technology) was attached to the bar to track its movements during the power clean lift. The accelerometer measured ±10 g in each axis (x, y, and z) with a 500-Hz bandwidth and sensitivity of 200 mV/g. Leads, 1 per axis, were connected into NorBNC analog input channels and into a personal computer, where the results were displayed using MyoResearch software (version MR-XP 1.07, Noraxon U.S.A., Inc.). The accelerometer signals were synchronized with EMG data and later used to mark the start and end of the power clean lift.

Participants completed a perception form at the end of the lifts. The form was developed by the study investigators and consisted of several single-item questions. Participants ranked, in order from 1 to 4, the 4 conditions (3 mouthguards and no mouthguard control) with regard to each of the following parameters: perceived strength, perceived explosive power, ease of use, and comfort. Participants also used a 5-point Likert scale (1, very likely; 5, very unlikely) to indicate how likely they would be to use any mouthguard during regular practice and during competition. The participants were also asked an open-ended question at the end to specify the characteristics of their least favorite mouthguard, if one existed.

Statistical analysis

Descriptive and inferential analyses were performed on collected data. A 1-way analysis of variance with repeated measures was used to determine whether interocclusal distance differed among the 4 conditions (PB, UA, CUS, and NMG).

A mixed linear model with random effects for participants was used to examine the mean and peak muscle activation during the 75% maximum power clean lift across mouthguard type (fixed factor) while controlling for maximum-effort occlusal force muscle activation (covariate). Effectively, muscle activation during the lift was "normalized" for each participant by controlling for his or her muscle activation while biting the mouthguard in a nonlift mode. Hence, a significant result for these analyses may be interpreted as a significant difference between mouthguards when results have been controlled for normalized activation within the individual. Bonferroni-corrected pairwise comparisons were used for post hoc analyses. Data were logged due to nonnormality of the distributions and back transferred to geometric means.

Freidman nonparametric tests were used to determine whether participant perceptions differed among the 4 conditions. The α level was established a priori at 0.05, 2-tailed. Data were analyzed with SPSS software (version 22.0, IBM Corporation).

Table 4. Mean and peak muscle activation (% MVIC) during power clean lift, by mouthguard type.

	Anterior temporalis		Masseter		Sternocleidomastoid		Cervical paraspinals	
Mouthguard	Mean (SE)	Peak (SE)	Mean (SE)	Peak (SE)	Mean (SE)	Peak (SE)	Mean (SE)	Peak (SE)
PB	10.4 (1.2)	66.9 (1.1)	18.3 (1.2)	31.0 (1.2)	27.1 (1.2)	63.2 (1.2)	45.6 (1.2)	93.0 (1.2)
95% CI	7.3-14.9	58.4-76.8	11.7-28.7	21.4-44.9	19.7-37.2	45.7-87.4	32.6-63.5	63.5-136.2
UA	6.7 (1.2)	71.2 (1.1)	11.0 (1.2)	21.4 (1.2)	21.5 (1.2)	48.5 (1.2)	44.7 (1.2)	85.4 (1.2)
95% CI	4.7-9.6	62.0-81.7	7.0-18.2	14.8-31.1	15.6-29.5	35.0-67.0	32.0-62.3	58.4-124.7
CUS	9.0 (1.2)	68.6 (1.1)	15.2 (1.2)	27.4 (1.2)	27.4 (1.2)	59.4 (1.2)	53.4 (1.2)	97.9 (1.2)
95% CI	6.3-12.9	59.9-78.7	9.6-23.9	18.8-39.8	19.9-37.6	42.9-82.2	38.4-74.2	67.3-142.5
NMG	8.0 (1.2)	62.5 (1.1)	11.7 (1.3)	23.0 (1.2)	18.5 (1.2)	41.9 (1.2)	40.5 (1.2)	86.7 (1.2)
95% CI	5.6-11.4	54.7-71.6	7.4-18.7	15.7-33.7	13.6-25.4	30.5-57.7	29.0-56.5	59.2-126.8

Abbreviations: CI, confidence interval; CUS, custom mouthguard; MVIC, maximum voluntary isometric contraction; NMG, no mouthguard (control); PB, Power Balance POWERUP Mouthgear; UA, Under Armour ArmourBite Mouthguard.

Results

Interocclusal distance

The type of mouthguard evaluated had a statistically significant effect on interocclusal distance ($P < 0.001$). PB produced the largest interocclusal distance, 5.33 mm (SE, 0.46 mm), which was significantly greater than that of the CUS ($P = 0.006$), NMG ($P = 0.001$), and UA ($P = 0.001$) values (Table 3).

Muscle activation

Mean and peak muscle activation values for anterior temporalis, masseter, SCM, and cervical paraspinal muscles are presented in Table 4 and Charts 1 and 2. The mouthguard had a statistically significant effect on mean activation of the anterior temporalis muscle ($P = 0.002$) and no significant effect on its peak activation ($P = 0.46$). Mean activation of the anterior temporalis muscle was significantly greater with PB than with either CUS ($P = 0.002$) or NMG ($P = 0.05$). CUS elicited significantly greater mean activation of the anterior temporalis than did UA ($P = 0.03$).

The mouthguard had a significant effect on mean ($P = 0.001$) and peak ($P = 0.03$) activation of the masseter muscle. PB elicited significantly greater mean ($P = 0.002$) and peak ($P = 0.019$) activation of the masseter than did UA and greater mean activation than did NMG ($P = 0.015$). CUS elicited significantly greater mean activation of the masseter than did UA ($P = 0.05$).

The mouthguard had a significant effect on mean activation of the SCM muscle ($P = 0.014$) and no significant effect on its peak activation ($P = 0.073$). PB produced significantly greater mean activation of the SCM than did NMG ($P = 0.01$).

The mouthguard had no statistically significant effect on mean ($P = 0.47$) or peak ($P = 0.78$) activation of the cervical paraspinal muscles.

Perceptions of mouthguards

There was a statistically significant difference ($P = 0.03$) in how participants ranked the lifting condition (PB, UA, CUS, NMG), based on perceived strength, from strongest (1) to weakest (4). Participants perceived themselves as strongest while using CUS (mean rank, 1.9), followed by UA (mean, 2.4) and NMG (mean, 2.8), and weakest using the PB mouthguard (mean, 2.9). There was no statistically significant difference in participants' ranking based on their perception of explosive power; that is, most powerful to least powerful did not differ ($P = 0.07$). There was a significant difference ($P = 0.049$) in participants' ranking of their perception of ease of completion from easiest (1) to hardest (4). Participants perceived use of the CUS mouthguard to result in the easiest lifting condition (mean, 2.1), followed by NMG (mean, 2.4) and UA (mean, 2.4). Lifting was ranked as hardest to complete when PB was used (mean, 3.1).

Participants' ranking of mouthguards for perceived comfort, from most comfortable (1) to least comfortable (4), did not differ significantly ($P = 0.17$). The 3 mouthguards and control achieved the following mean ranks: CUS, 2.2; UA, 2.8; PB, 2.7; and NMG, 2.2. However, common responses to the open-ended question about characteristics of the individual participant's least favorite mouthguard indicated that the pad of PB and the shape of UA were uncomfortable. These participants reported that the mouthguard felt too big, they could not close their mouth, or it was difficult to bite or clench when wearing PB or UA.

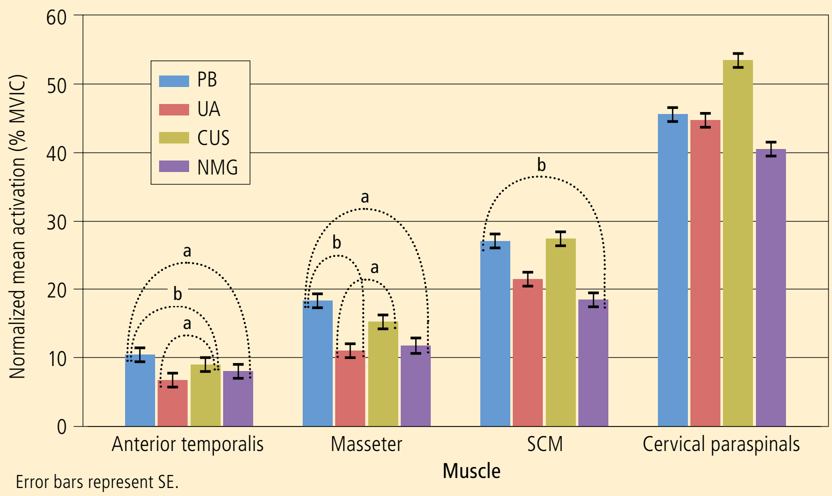
When asked if they would use a mouthguard for practice, athletes provided the following responses: very unlikely, 4.2%; not likely, 16.7%; neutral, 33.3%; likely, 37.5%; very likely, 8.3%. For competition, participants predicted the following levels of usage: not likely, 16.7%; neutral, 41.7%; likely, 25.0%; very likely, 16.7%. No respondents indicated that they would be very unlikely to use a mouthguard during competition.

Participants indicated a significantly greater preference ($P = 0.049$) for a custom mouthguard (54.2%) over UA (16.7%), PB (25.0%), or NMG (4.2%).

Discussion

The purpose of the current study was to investigate differences in interocclusal distance, head and neck muscle activation during 75% maximum power clean lifts,

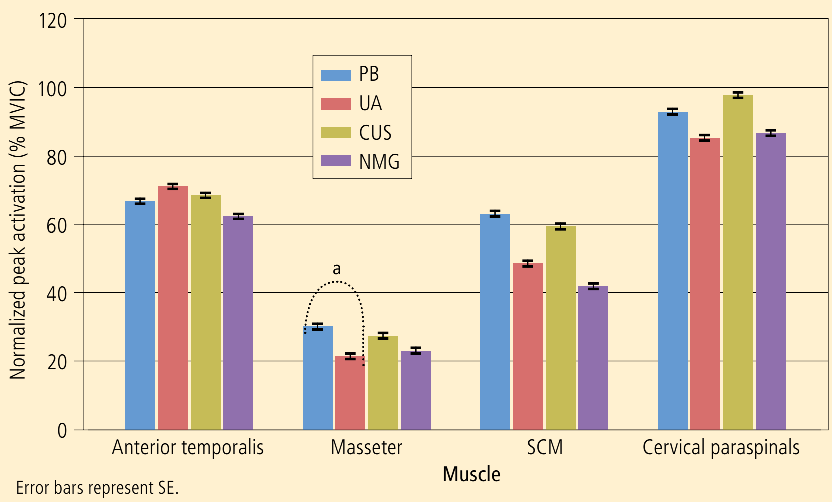
Chart 1. Mean muscle activation during power clean lift, by mouthguard type.



Error bars represent SE.
$^{a}P \leq 0.05$, $^{b}P \leq 0.01$

Abbreviations: CUS, custom mouthguard; MVIC, maximum voluntary isometric contraction; NMG, no mouthguard (control); PB, Power Balance POWERUP Mouthgear; SCM, sternocleidomastoid; UA, Under Armour ArmourBite Mouthguard.

Chart 2. Peak muscle activation during power clean lift, by mouthguard type.



Error bars represent SE.
$^{a}P \leq 0.05$

Abbreviations: CUS, custom mouthguard; MVIC, maximum voluntary isometric contraction; NMG, no mouthguard (control); PB, Power Balance POWERUP Mouthgear; SCM, sternocleidomastoid; UA, Under Armour ArmourBite Mouthguard.

and mouthguard perceptions and preferences among healthy, athletic individuals using different types of mouthguards.

The desire to transform a protective mouthguard for contact sports into a specialized appliance for performance and strength has prevailed among coaches and athletes seeking a competitive edge.[24,30,31] Performance mouthguards such as the commercially available maxillary mouthguards tested in this study are designed with the premise that an increase in posterior thickness will open the lower airway and optimize afferent and efferent signaling from the sensorimotor system. It has been recommended that, for contact sports, a mouthguard that is 6 mm thick be constructed if the interocclusal distance is 5 mm.[1]

The custom mouthguard used in this study was dual laminated with a pressure laminator and was bilaterally balanced on a dental articulator in accordance with the athlete's habitual occlusion. This design allowed for an even distribution of biting forces along the mouthguard and had a final posterior thickness of approximately 3.0-3.5 mm. Measured from the mouthguard to the mandibular incisors, the mean vertical openings induced by the mouthguards in this study were CUS, 3.69 mm; PB, 5.33 mm; and UA, 3.52 mm. Control, the measurement taken without a mouthguard, was 3.54 mm.

Lindauer et al showed that increases in muscle activity for both the masseter and temporalis muscles are associated with increases in voluntary maximum occlusal force between 9 and 11 mm of opening (measured at the first molar).[32] Arima et al studied the effect of vertical dimension on occlusion and EMG activity of the masseter muscle in healthy participants.[33] Their results indicated that the greatest force during maximum clenching occurred when the vertical distance between the first molars measured 8 mm. As the vertical dimension increased and approached 20 mm, both the EMG activity of the masseter muscle and the occlusal force generated decreased. It is important to note that the distances measured by Lindauer et al and Arima et al would have been greater had they measured between the maxillary and mandibular incisors instead of between the molars.[32,33] The goal of the present study was to observe the activation of the anterior temporalis, masseter, SCM, and cervical paraspinal muscles in response to a change in mandibular position during a dynamic and practical sport-oriented anaerobic movement while controlling for baseline (seated, maximum-force) activation. Surface EMG provides a reliable, noninvasive approach that indirectly measures nervous signaling and muscle fiber recruitment in a way that was suitable for the purposes of this study.[34] Other neuromuscular pathways, such as decreasing joint loading and improving TMJ proprioception, are difficult to measure and cannot be determined through noninvasive measures.[35,36] If an increase in overall muscular performance should be expected through the use of a specially designed mouthguard, then the mechanism should include concurrent activation potentiation of muscles directly affected by the oral appliance as well as muscles around the head and neck complex. This relationship has been described as the *craniocervical-mandibular system.*[12] A recent meta-analysis describing this association found only articles of poor quality that generally lacked consideration for practical significance.[16]

Subtle changes in the position of the mandible can have significant effects on muscle function.[35,37] During explosive movements such as the power clean lift, variations in technique as well as starting and ending posture (neutral head posture vs extended neck posturing) could also affect muscle activation trends. The fibers of the anterior temporalis muscle run nearly perpendicular to the occlusal plane, which make them particularly responsive to changes in vertical dimension of the mandible.[38] The superficial masseter muscle runs at a slightly oblique angle from its attachment at the inferior border with the zygoma, which helps stabilize the maxillomandibular relationship during explosive athletic movements.

In the present study, mean muscle activation of the anterior temporalis and masseter muscles was significantly influenced by mouthguard type, leading toward an increase in activity during the power clean lift compared to control. In a similar sample of healthy participants, a 2-mm vertical increase of the mandible caused EMG activity of the masseter, temporalis, and SCM muscles to decrease during seated rest and maximum clenching efforts.[12] The earlier results differ from those in the present study, likely due to the functional demands on the head and neck during the power clean lift. As far as the authors of the present study are aware, this is the first study to measure muscle activation in athletes using maxillary mouthguards during a powerlift.

The SCM is a bilateral flexor and unilateral rotator of the neck. Mean SCM activation was significantly influenced only by PB, which had the greatest mean vertical repositioning effect. Increases in isometric strength of the cervical flexors have been reported in deep bite patients with TMJ dysfunction who are provided with a bite-elevating appliance that creates a vertical dimension 24%-42% greater than habitual occlusion.[7] In healthy patients, arbitrary increases in vertical dimension from 2-12 mm have been reported to increase isometric cervical flexion while the individual is seated clenching in a mandibular orthopedic repositioning appliance; a decrease in flexion is noted as vertical dimension is increased further.[17] It is unclear how the functional demands of the power clean lift would influence activation of the SCM and why only 1 mouthguard had a significant influence on its activation.

The cervical paraspinal muscles make up vertical fibers of the upper trapezius and erector spinae muscles involved with neck extension. In the present study, the presence of a mouthguard had no significant effect on cervical paraspinal muscle activation, which suggests that further research is needed to determine if these muscles are modulated by oral appliances during a powerlift.

The authors are not aware of any long-term observation of healthy athletes using performance mouthpieces or mouthguards similar to those used in the present study. It is possible that prolonged use could lead to transient muscle deprogramming, as has been observed with continuous splint wear.[39]

The present study compared qualitative data on 2 commercially available self-fit mouthguards (UA and PB), 1 custom-fabricated mouthguard (CUS), and no mouthguard (NMG) while athletic adults performed submaximum power clean lifts. Participants perceived that they were strongest (mean rank 1.9 out of 4.0) and reported that the lifts were easiest (rank 2.1) while using CUS. Design features of CUS allowed consistent vestibular adaptation rather than the variable adaptation common with self-fit mouthguards. In addition, the participant's occlusion was indexed on the biting surface of CUS with a dental articulator, while PB and UA had flat surfaces. These design features may have contributed to overall preference for CUS but did not contribute to statistically significant differences in comfort during the power clean lift.

The majority (37.5%) of participants were likely to use 1 of the mouthguards provided during regular practice. However, when the athletes were asked the likelihood of using a mouthguard during competition, the majority (41.7%) were neutral. The participants were largely inexperienced with mouthguards in general, and their responses indicated some level of hesitation to compete while wearing an unfamiliar appliance. Only 16.7% reported that they were not likely to use the provided mouthguards.

When asked to rank overall preference for the mouthguards, 54.2% of participants said they preferred CUS while lifting, 25.0% preferred PB, and 16.7% chose UA. A similar preference for custom mouthguards has been previously reported.[40] The remaining 4.2% of the participants stated that they would not use a mouthguard. While the PB was preferred by one-quarter of the participants, it was ranked as the mouthguard type that made lifting the hardest (mean rank 3.1 out of 4.0). The overall fit of the mouthguard was not reported as more uncomfortable than that of other mouthguards, but participants frequently reported that the design features of PB were uncomfortable or the mouthguard was difficult to bite. Some participants using PB reported that they could not clench properly during the lift. PB consistently induced a greater vertical opening of the mandible, suggesting that vertical repositioning in the range of 5 mm, measured at the incisors, may cause athletes to perceive that they are working harder during submaximum power clean lift attempts.

Conclusion

During the power clean lift, maxillary mouthguards can affect activation of head and neck muscles, specifically the anterior temporalis, masseter, and SCM muscles, through a mechanism related to changes in vertical dimension. These findings demonstrate that muscle activation during the power clean lift is related to length-tension relationships within muscles of mastication that may not affect other areas, such as the cervical paraspinal muscles. Participants, who indicated a nearly 2:1 preference for the custom mouthguard over UA and PB mouthguards, perceived that they were stronger and less encumbered when using a custom mouthguard during power clean lifts.

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Manufacturers

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