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Effects of wearing a customized bite-aligning mouthguard on powerful actions in highly trained swimmers

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ABSTRACT

Background/objectives: The potential advantages of wearing customized bite-aligning mouthguards on several performance parameters such as muscular strength, power and reaction time have been reported. Literature shows that the concurrent activation potentiation phenomenon, elicited by a powered and balanced jaw clenching, can provide athletes with several neuromuscular advantages. The aim of the present study was to investigate the acute effects of jaw clenching while wearing a customized bite-aligning mouthguard on swimming start, countermovement jump and swim bench test, in contrast to two other conditions: non-jaw clenching and jaw clenching without mouthguard.
Methods: A randomized, repeated measure within study design was used to compare the condition effect on eight highly trained elite male and female swimmers.
Results: Statistical analysis revealed a significant increase in the countermovement jump height ($p = 0.041$) when comparing the use of mouthguards with the non-jaw condition. In the swim bench, a significant greater time to peak force ($p = 0.049$) was found when comparing the use of mouthguards with the jaw condition. Although, non-significant effects, small differences were found in the start reaction time and 15-m freestyle swimming when comparing the use of mouthguards with the non-jaw condition.
Conclusion: This study demonstrated that wearing customized, bite-aligning mouthguards had an ergogenic effect on specific measures of vertical jump and swim bench test, whereas non-meaningful but small differences were found in swimming start.

1. Introduction

Sport performance professionals are continuously searching for strategies to improve the athletic potential. However, it's difficult to find suitable and cost-effective techniques maintaining the programmed training loads. In the resistance training context, several authors have suggested the stimulatory effect of the remote voluntary contraction (RVC) as a mechanism to enhance the force output in the main involved muscles of each exercise. This raising phenomenon, known as Concurrent Activation Potentiation (CAP),[1–3] could be promoted by different strategies such as Jendrassik and Valsalva manoeuvres, gripping with the fists or jaw clenching.[1,4]

Over the last years, several theories have been suggested to explain the potential neuromuscular advantages associated with jaw clenching. One theory is based on the integrative function of the cerebral motor cortex and the intercortical connections between the different motor areas of the brain. Thus, when one part of the motor cortex is activated because of jaw clenching, the neural centres of the other parts of the brain are also co-activated. These centres send impulses to the prime movers which initiates the targeted actions. Another theory underlines the increased excitability of spinal motor neurons while an individual clenches the jaw, amplifying the alpha motor neuron activity, gamma loops and muscle spindles, together with descending the cortical input and the stimulus invoked by the afferent input.[1] Furthermore, it is

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established that jaw clenching increases the excitability of the Hoffman reflex (H-reflex). Indeed, greater force levels in jaw clenching produces greater H-reflex facilitation in some muscle groups, which is evoked with both the descending influence from the cerebral cortex and the afferent input from the oral-facial region.[5] The cortical effect, mentioned in the first theory, might be explained by the temporal unmasking of lateral excitatory projections through afferent inputs during voluntary teeth clenching. The spinal effect of the second theory, however, might be explained by the reduction of the presynaptic inhibition and postsynaptic changes in membrane potential.[5]

Studies examining the effects of jaw clenching in prime mover muscle activation or muscular power output have revealed positive results in several forceful actions.[2,6–8] In this vein, Ebben et al.[6] evaluated the neuromuscular activation of the lower limb muscles during an isokinetic test comparing No-RVC versus RVC condition, which included jaw clenching, hand gripping, and Valsalva maneuver. The authors found a higher activation when subjects performed the action under RVC condition. Moreover, these ergogenic effects could be magnified when athletes combined jaw clenching with the co-acctivation of other muscle groups.[9] In fact, several studies[10,11] suggest that during a maximal voluntary occlusion, it is evoked a simultaneous co-activation of the trunk and neck muscles, specially splenius capitis, trapezius, elevator scapulae and sternocleidomastoideus. Other researchers[12] have demonstrated that it is not possible to produce a maximal jaw clenching contraction with uncovered teeth, since depressor muscles are active during clenching to protect the teeth. Additionally, possible imbalances in the temporomandibular structure and musculature could be magnified.[13,14] Therefore, the use of jaw clenching as a mechanism to enhance several performance parameters requires a powered and balanced occlusion. Thus, clenching customized mouthguards may help to settle these issues, promoting a more aligned and powerful clench and further increasing the neuromuscular effects associated with jaw clenching.

The reasons why wearing these intra-oral devices could produce positive effects may remain in the repositioning of the lateral, forward and/or vertical dimension of the jaw and the subsequent muscular rebalancing.[15] It has been suggested that lateral movements of 1–3 mm promote a centric occlusion, increase the mandibular stability and thus, better conditions for a powerful and balanced jaw clenching.[16] This readjustment promotes a better position of the cervical vertebrae and proper cranial signalling, amplifying the neuromuscular output in the prime movers. Moreover, an increase in posterior thickness, will open the lower airway and optimize afferent and efferent signalling from the sensorimotor system.[12] Supporting this findings, Arima and colleagues[17] studied the relationship between the vertical dimension of the occlusion and the activity of the masseter muscle in a healthy population. Results indicated that the optimal distance to achieve the maximum occlusal biting force is around 8-mm between the first molars. Therefore, the use of a certain type of mouthguards might directly affect the contraction patterns during the occlusion.[12]

Although jaw clenching combined with the use of bite-aligning mouthguards seems to provide enhanced neuromuscular responses, the current literature indicates that this combination is not always transferred to more efficient actions in the athletic context. While several studies reported benefits because of jaw clenching and the use of mouthguards in lower limb powerful actions,[2,18–22] other studies showed no significant differences.[23–25] For instance, Ebben et al.,[2] found that jaw clenching improved the Rate of Force Development (RFD) an average of 19,5% during a Countermovement Vertical Jump (CMVJ) test with respect to non-jaw condition. Also Buscà et al.,[20] exposed improvements in CMVJ-height and CMVJ-mean power when collegiate healthy male subjects performed the test using a custom-made mouthguard. The influence of the RVC on the reaction time has also been investigated.[8,16,26] The possible improvements have been associated with stress reduction on the temporomandibular structure, as well as with better neural transmission, higher blood flow and an increased oxygen unloading in other areas of the head and neck.[26] Additionally, Issurin and Verbitsky[8] suggested that factors such as mental concentration, and a more favourable emotional state can also contribute to these motor effects. The authors found positive effects on the reaction time during a swimming take-off in professional and semi-professional male swimmers. Results revealed a shorter start reaction time and a more efficient start in the first 15-m crawl when the athletes simultaneously contract their jaw and abdominal musculature. In contrast, other authors[16,19] observed no significant differences in a visual stimulus reaction task under 3 different conditions (i.e., no mouthguard, customized and self-fitted) in a group of trained subjects.

Although certain beneficial effects are recently reported, literature is still unclear about under which conditions and situations highly trained elite athletes can take advantage of wearing intra-oral devices. Therefore, the purpose of the present study was to analyse the acute effect of wearing customized, bite-aligning mouthguards in swimming start (SS), countermovement vertical jump (CMVJ) and swim bench (SB). It is hypothesized that the use of these kinds of mouthguards increase the CMVJ power and height as well as the SB power and time to peak force. Moreover, a reduced reaction time and faster 15-m SS are expected.

2. Methods

2.1. Study design

A randomized, repeated measure within study design was used to compare the acute effects of wearing a customized, bite-aligning mouthguard (MG) with respect to the two other conditions (JAW and NON-JAW) on swimming start, jump ability and pull arm power test. Conditions were randomly distributed to avoid the influence of fatigue and the test learning effects. In JAW and MG conditions, subjects were encouraged to clench their jaws as powerful as possible whereas in NON-JAW condition subjects were encouraged to relax their mandible muscles. Additionally, swimmers were instructed to wear the MG during one-week in their training sessions, previous to the testing day. Tests were performed in the following order: swimming start test (SS), countermovement vertical jump test (CMVJ) and swim bench test (SB). As dependent variables, rear foot separation (SS_RFS), first water contact (SS_FWC) and start efficiency, evaluated by the time at 15-m (SS_T15), were assessed from the swimming start test. Jump height (CMVJ_height), relative maximal power (CMVJ_RMP) and maximal rate of force development (CMVJ_MRFD) were assessed from the countermovement vertical jump test. Finally, time to peak force (SB_TTPF), peak power (SB_peakpower) and mean power (SB_meanpower) were taken from the swim bench test.

2.2. Subjects

Eight highly trained male and female top-class swimmers (age: 23.25 ± 4.10 years, height: 173.79 ± 8.05 cm and weight: 64.69 ± 7.88 kg), participated voluntarily in this study, one month before the national championship. All participants were involved in the senior Spanish Swimming Team (competing in sprint or half distance disciplines in the Olympic Games) concentrated at the High Performance Centre of Sant Cugat, Barcelona (Spain). A health screening was completed with each subject in accordance with the

American College of Sports Medicine exercise testing procedures. All subjects were also evaluated by an expert dentist before the MG fitting process to guarantee an adequate dental health to participate in the study. The study was approved by the Ramon Llull University Institutional Review Board (reference number 1920003D) and was conducted in accordance with the Declaration of Helsinki (revised in 2013). All swimmers were informed of the purpose and study design, the benefits and the risks of the investigation before signing an institutionally approved informed consent. Additionally, all subjects were asked to refrain from taking part in any activity that would negatively impact the outcome of the assessments. They all refrained to drink alcohol, coffee or any other type of stimulant, 24 h before the testing session.

2.3. Procedures

Swimmers participated in three sessions. The first session was used to provide all the information about the risks and benefits of the study, to obtain the informed consent, to assess anthropometric measurements and to scan the mouth structure by an expert dentist. In the second session, the MG fitting process was finished and a familiarization process was performed for all the testing protocols. In the third session, the test battery was performed and data were collected. In this testing session, all subjects performed three trials of each test (three tests) with the three different conditions (5 min rest between trials). Before the tests, all participants completed a standardized warm-up protocol: a) previous to the SS, participants performed a swim-specific warm up, including 15 min of crawl style combined with three swimming starts +15-m sprint (3 min rest between starts and 5 min before testing); b) previous to the CMVJ and SB, participants performed 15 min' warm-up including: 10 min jogging, 5 min of calisthenic exercises, and 5 min of warm-up tests trials (including 2 sub-maximal intensity repetitions of each test). Furthermore, the same training routine was performed for each subject during the 24 h previous to the testing session. All tests were performed at the same time of the day and all the actions were video recorded to analyse the technique requirements. To identify each video file with the proper condition, participants performed the tests with a different colour bracelet associated to each condition. Additionally, all subjects were encouraged with the same instructions by the same person in all the sets and conditions.

2.4. Performance measures

2.4.1. Swimming start

Subjects were instructed to step up to the block and once in their position, the principal investigator gave the verbal command 'take your mark' which was shortly followed by the starting signal. Then swimmers performed a maximal freestyle sprint until the 15-m finish mark. The starting command was produced by a LED signal, actioned for the same investigator. The time interval between the preliminary command and the starting signal ranged from 2.2 to 3.9 s. In JAW and MG testing conditions, the technique protocol included jaw clenching which was initiated immediately after the preliminary verbal command. In NON-JAW condition, swimmers were asked to relax the mandible and the abdominal muscles during the previous phase to the take-off. All quick-offs were performed from the standard poolside block under simulated race conditions. All sets were filmed by a recording system which consisted of three cameras. The first camera was a GoPro HERO4 (GoPro, Inc., San Mateo, CA, USA) and held in the block to show a close-up view of the swimmers' faces. These images guaranteed that the participants met with the assigned condition. The second one (Casio EX-ZR1000, Casio Computer Co., Ltd., Tokyo, Japan), operated at a sampling rate of 240 Hz, was mounted on a tripod, and was placed 5-m away from the block, to film a sagittal plane of the take-off. This camera filmed simultaneously the light stimulus and the swimmers take-off. And finally, a third camera (Casio HS Camera 60 Hz; Computer CO., LTD., Tokyo, Japan), operated at a sampling rate of 60 Hz was used to record a pool open plane to analyse the 15-m freestyle. The test was performed in a 50-m indoor pool (water temperature: 25–26 °C).

2.4.2. Countermovement vertical jump

In this test subjects were encouraged to jump vertically as much as possible doing a previous countermovement. In a standing position with their feet shoulder width apart and with the hands on their hips throughout the measurement, participants were asked to perform an elastic countermovement during the contact phase and landing with a complete leg and ankle extension. Jumps were measured using a force plate (Kistler 9260AA, Winterthur, Switzerland) equipped with a data acquisition system (Kistler 5695 b, Winterthur, Switzerland). Raw data was acquired (sampling rate 1000 Hz) using the MARS software (Kistler, Winterthur, Switzerland) and system calibration was performed according to the MARS software recommendations. Each jump was also recorded using a high speed digital camera (Casio EX- ZR1000, Casio Computer Co., Ltd., Tokyo, Japan) operated at a sampling rate of 240 Hz. All video files were analysed to determine the knee angle of flexion. Only the jumps with maximum deviation of ±5% with respect to a 90° angle of flexion were considered for the analyses.

2.4.3. Swim bench

This test was executed with the swimmer over the bench in a prone position and the hands placed in paddles attached to pull ropes. During execution, swimmers pulled quickly backwards through a complete range of motion with his arms moving in parallel. For a better simulation of the technical action, subjects were instructed to brake the downward acceleration with the arms during the recovery phase.[27] Swimmers were strapped on the swim bench in a constant inclination of 25° and they were allowed to pull two times before being tested. Then, six maximal pull continuous repetitions were performed. Data was recorded using a linear position transducer (Chronojump-Boscosystem, Barcelona, Spain), operated at a sample rate of 500 Hz, and connected to Chronojump Software (version 1.9.0. Chronojump-Boscosystem, Barcelona, Spain). The position transducer was attached in the bench structure to record the complete range of motion on the same incline as the bench. Mean power, peak power and time to peak force were assessed during both concentric and eccentric phases of the movement (entire phase). Only the 2nd to 5th repetitions were considered for the study.

Finally, to obtain the usage and perception rates toward MG, a modified Athletic Mouthguard Attitude Questionnaire was completed by the participants.[28] The questionnaire used Likert item response categories ranging from 1 ("strongly disagree") to 5 ("strongly agree"). The mean rate of each question was assessed being 1 point the strongest negative perception and 5 points the strongest positive perception. A neutral perception was scored as 3.

2.5. Bite-aligning mouthguards

Each subject was provided with a customized, bite-aligning mouthguard (RDMouthguard SL, Terrassa, Spain), designed to promote a stabilization of the mandible arch in a long centric position. Upper-jaw impressions were taken by standard trays using alginate impression material and poured with dental stone to produce working models. Before the models were confected, the impressions were disinfected using 1% sodium hypochlorite. MG were fabricated using a layer of 1.4 mm-thick Ethylen-Vinylacetat-copolymere (EVA) and a layer of 4 mm-thick Polyethylenterephthalat-1 (PETG) with a minimal dentoalveolar discrepancy regarding the morphology of the mouth structure of each participant.

2.6. Statistical analysis

The chosen number of participants was based on effect size 0.41 SD with an α level of 0.05 and power at 0.95, using G Power Software (University of Dusseldorf, Dusseldorf, Germany). The Shapiro-Wilk test was used to confirm that data were normally distributed to approve the use of the parametric techniques. All variables, except SB_meanpower ($p = 0.033$) and SS_RFS ($p = 0.019$), were normally distributed with ranging from $p = 0.075$ to $p = 0.968$. For non-parametric variables, Friedman Test was used to examine the effect of condition on SB_meanpower and SS_RFS. For parametric variables, One-way repeated-measures analysis of variance (ANOVA) were used to assess the effect of the 3 different conditions (Non-JAW, JAW, MG) on the swimming start (SS_FWC and SS_T15), countermovement jump (CMVJ_height, CMVJ_RMP and CMVJ_MRFD) and swim bench tests (SB_peakpower and SB_TTPF). The assumption of sphericity was verified by the Mauchly's test and the Greenhouse-Greisser correction was applied if it was violated. In case of significant main effects, the Post hoc analysis with Bonferroni correction was used in order to test the pairwise differences between conditions. Statistical significance set at $p \leq 0.05$. To compare the magnitude of changes between conditions, Cohen's *d* effect size was calculated and interpreted as <0.2, trivial; 0.2 to 0.6, small; 0.6 to 1.2, moderate; 1.2 to 2.0, large; >2.0, very large.[29] The statistical description was used to obtain the mean and standard deviation of each dependent variable and the results were expressed as mean ± standard deviation (mean ± SD). All statistical procedures were conducted using SPSS software (Version 26.0 for Windows; SPSS Inc, Chicago, IL, USA). Additionally, the typical error of measurement (TE) was estimated, and the smallest worthwhile change (SWC) was calculated as $= 0.2 \times$ between-subject SD, using the between-swimmer standard deviation (SD) of the average within each condition.

3. Results

A significant main effect was found for condition on CMVJ_height ($F_{(2,14)} = 4.01$, $p = 0.042$, $\eta p^2 = 0.36$) and SB_TTPF ($F_{(2,14)} = 3.79$, $p = 0.048$, $\eta p^2 = 0.35$) whereas this effect was non-significant on CMVJ_RMP ($F_{(2,14)} = 2.50$, $p = 0.117$, $\eta p^2 = 0.26$), CMVJ_MRFD ($F_{(2,14)} = 1.21$, $p = 0.326$, $\eta p^2 = 0.14$), SB_peakpower ($F_{(2,14)} = 2.53$, $p = 0.115$, $\eta p^2 = 0.26$), SB_meanpower ($\chi^2_{(2)} = 3.25$, $p = 0.197$), SS_RFS ($\chi^2_{(2)} = 0.85$, $p = 0.651$), SS_FWC ($F_{(2,14)} = 0.92$, $p = 0.421$, $\eta p^2 = 0.11$) and SS_T15 ($F_{(2,14)} = 0.67$, $p = 0.525$, $\eta p^2 = 0.08$).

Pairwise comparison revealed significant differences in CMVJ_height ($p = 0.041$) as the result of wearing MG respect to NON-JAW condition, whereas no significant improvements were observed between conditions in both CMVJ_RMP and CMVJ_MRFD. Additionally, non-significant differences were observed in any variable of the CMVJ when comparing MG and JAW conditions (Fig. 1).

A significant difference was found in SB_TTPF when comparing MG and JAW conditions ($p = 0.049$). However, non-significant differences were found in SB_peakpower and SB_meanpower. Additionally, non-significant differences were observed in any variable of the SB when comparing MG and NON-JAW (Fig. 2).

In terms of the SS test, non-significant differences were observed between conditions for any of the variables assessed on the start reaction time neither the 15-m freestyle distance (Fig. 3).

Besides non-significant differences, ES analysis showed small and moderate differences associated with the conditions. When comparing JAW and NON-JAW conditions, small differences in all variables of the CMVJ were observed. For JAW condition, results showed a small increase in CMVJ_height (ES = 0.41) and in CMVJ_RMP (ES = 0.39) whereas there was a small decrease in CMVJ_MRFD (ES = −0.43). In the swim bench test, although small faster differences were found in SB_TTPF (ES = 0.37), worse results in SB_peakpower (ES = −0.45) and in SB_meanpower (ES = −0.13) were found for JAW respect to NON-JAW condition. In the swimming start test, results showed a small difference in SS_RFS (ES = −0.41) and SS_FWC (ES = −0.3), being faster with the JAW condition than NON-JAW condition. Additionally, small differences were found (ES = −0.34) in SS_T15 for the JAW condition (Table 1).

As shown in Table 2, compared with JAW condition, when subjects wore MG they experienced small greater differences in CMVJ_height (ES = 0.58), CMVJ_RMP (ES = 0.4) and CMVJ_MRFD (ES = 0.52). In the swim bench test, the use of MG promoted moderate differences in SB_peakpower (ES = 0.80) and in SB_meanpower (ES = 0.65). In the swimming start test, subjects were faster when they wore MG in SS_RFS (ES = −0.28) and SS_FWC (ES = −0.2), both with a small difference. Nevertheless, only trivial differences were found in SS_T15 (ES = −0.03).

When comparing MG and NON-JAW conditions, results showed moderate differences in CMVJ_RMP (ES = 0.79), whereas only trivial changes in CMVJ_MRFD (ES = 0.09) for MG condition. In the swim bench test, results showed small greater differences in SB_TTPF (ES = −0.59), SB_peakpower (ES = 0.35) and SB_meanpower (ES = 0.51) when wearing MG. Also, small better differences were found in SS_RFS (ES = −0.53), SS_FWC (ES = −0.41) and SS_T15 (ES = −0.37) for MG condition (Table 3).

Results of the modified Athletic Mouthguard Attitude Questionnaire revealed that subjects had an overall positive perception toward the MG. Although 37.5% of participants felt that MG was bulky (mean score of 3.25 ± 1.16) and 12% felt uncomfortable when wearing it (mean score of 2.6 ± 0.74), any of them felt a performance decrease (mean score of 2 ± 0.92) or difficulties to breath (mean score of 2.75 ± 1.28) when wearing it. Moreover, 75% of the participants answered that they usually contract their jaw (mean score of 3.75 ± 0.87) and 50% combine jaw clenching with abdominal contraction (mean score of 3.625 ± 1.06) just before the swimming start. Additionally, 50% of swimmers felt that with MG condition their performance could improve (mean score of 3.25 ± 0.71).

4. Discussion

The main finding of the present study was that customized, bite-aligning MG had a positive effect on certain upper and lower muscular power tasks, basically associated to knee extension and pull arm actions, in highly trained swimmers. Results showed a significantly higher performance in CMVJ_height and moderate differences in CMVJ_RMP when wearing MG respect to NON-JAW condition. However, no significant differences were found in any variable of the CMVJ when comparing JAW and NON-JAW conditions. These findings could suggest that the CAP phenomenon, promoted by the RVC of the jaw muscles, seems to be insufficient to increase CMVJ performance in professional swimmers. Nonetheless, when subjects combined the jaw clenching with the use of MG results reached meaningfully. In the present study, the MG fitting process provides a precise adjustment and comfortable design which promotes better conditions for a more powerful and balanced jaw clenching. Thus, the ergogenic effects of CAP were increased when wearing MG. These differences might be probably

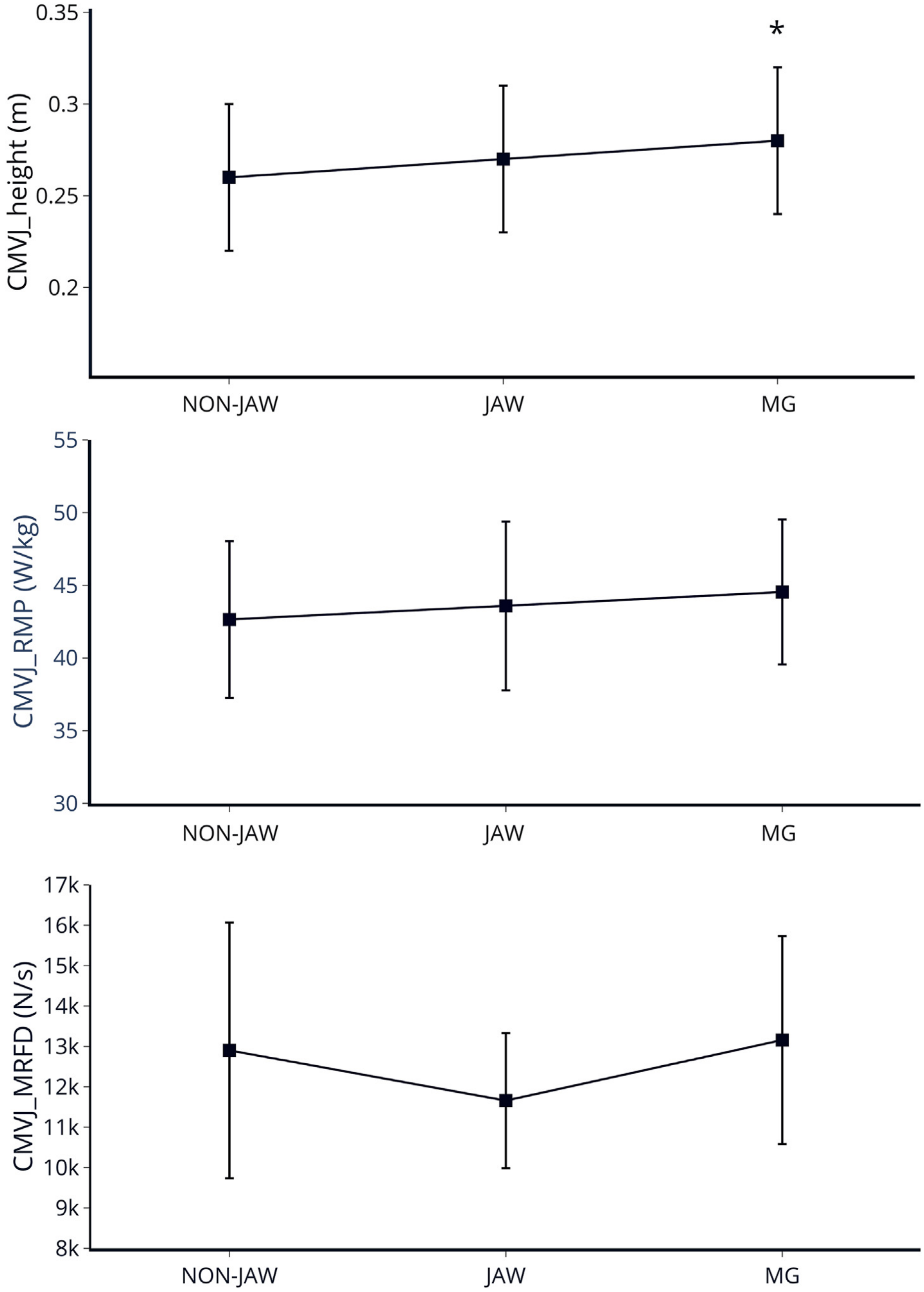

Fig. 1. Comparisons of countermovement vertical jump between the 3 conditions. *Indicates a statistical difference ($p \leq 0.05$).

due to modifications on stimulus-invoked afferent input, resulting in higher excitatory cortical projections, postsynaptic changes in membrane potential and greater motor neuron activity. As a result, an enhanced H-reflex activity and a higher motor overflow to the prime movers could be elicited.[2] These findings are consistent with previous literature describing the potential ergogenic effects of customized MG on CMVJ height in recreational trained subjects[14,20,21] and in high-standard athletes.[18,22]

Several studies found a positive correlation between CMVJ with the starting efficiency.[30–32] Thus, improvements in lower limb power and jumping ability might be important factors reducing starting time and overall race time, which could encourage professional swimmers to wear MG as an additional factor to optimize their athletic potential. Although meaningful advantages were found in CMVJ_height and moderate differences in CMVJ_RMP, non-significant effects were observed in CMVJ_MRFD when compared MG and NON-JAW conditions. In fact, according to previous research[2,20] it was suspected to reach a higher MRFD because of the use of MG, however, only trivial differences (ES = 0.09) were observed in the present study. These findings are consistent with the study of West et al.[32] which reported significant greater CMVJ_height and CMVJ_peakpower but not greater CMVJ_MRFD in highly trained swimmers. It could be speculated that the high amount of training loads into the water, where the weightlessness conditions affects the neuromuscular system, could alter the activation patterns in professional swimmers.[33] Additionally, it should be considered that swimming starts do not depend entirely on the power and reaction time of the swimmers, since other factors such

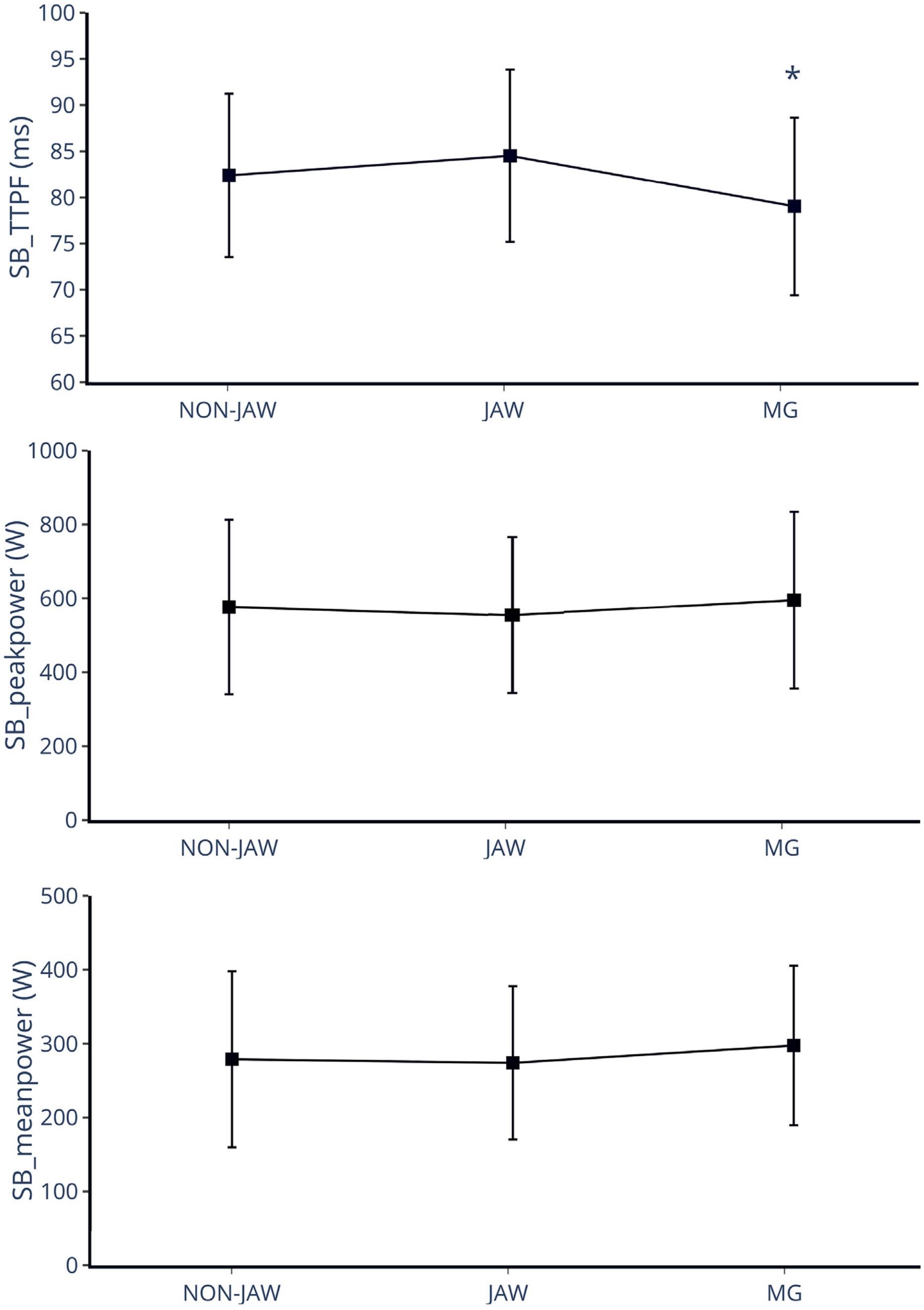

Fig. 2. Comparisons of swim bench test between the 3 conditions. *Indicates a statistical difference ($p \leq 0.05$).

as the angle of projection at take-off, body position during flight and water-entry angles also contribute to the start performance.[34]

Swim bench results revealed significant differences in TTPF comparing MG and JAW conditions. Moreover, moderate differences were observed in peak power and mean power. Swim bench is the most widely used dry-land device in swimming research to assess the arm power as well as other factors such as cardiopulmonary responses to exercise.[35,36] In fact, several research reported a high relationship between the pull arm power and sprint swimming performance.[36–38] Thus, significant results found in TTPF and moderate differences in peak and mean power could encourage professional swimmers to wear MG during training sessions and competitions. Nevertheless, no-significant differences were observed in any variable of the swim bench when compared JAW and NON-JAW conditions. These results are consistent with other studies which reported non-significant improvements on maximal strength of the upper limbs because of the remote voluntary contraction of the jaw muscles. For instance, Buscà and colleges,[20] did not find significant differences between JAW and NON-JAW conditions in a maximal isometric back row test with recreationally trained subjects. The authors argued that the difficulties to keep the mandible muscles relaxed during all the test could be the main argument to find non differences between both conditions. Additionally, the duration of the action and the coordinative requirements forced subjects to open the mouth for breathing, making impossible the jaw clenching maintenance throughout the test. For this reason, the potential effects of CAP could be mitigated. These results agreed with other studies reporting no significant

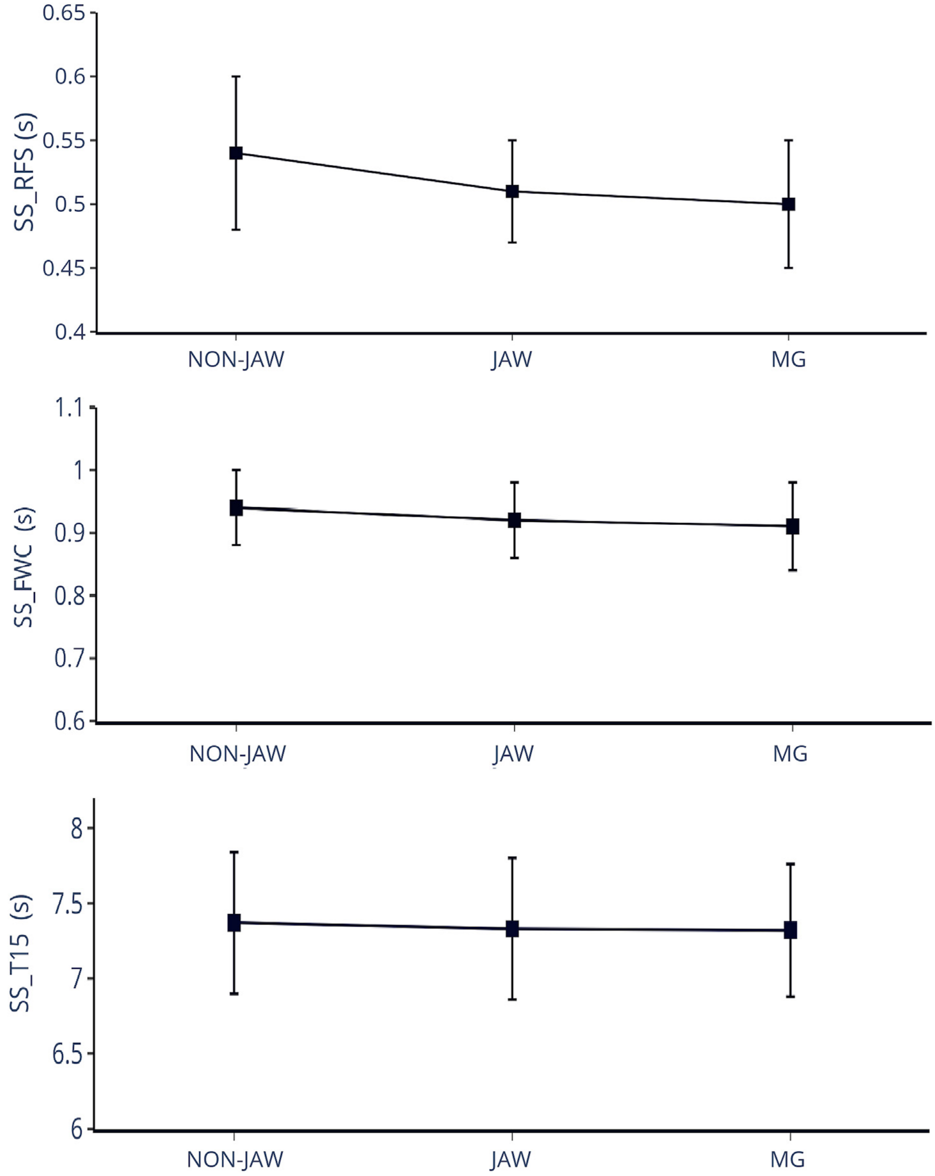

Fig. 3. Comparisons of swimming start test between the 3 conditions.

Table 1
Mean difference between NON-JAW and JAW conditions in Countermovement Vertical Jump, Swim Bench and Swimming Start.

	NON-JAW		JAW							
	Mean	SD	Mean	SD	t	*p*	SWC	TE	Diff	ES
CMVJ_height (m)	0.26	0.04	0.27	0.04	1.17	0.787	0.01	0.02	0.01	0.41 (small)
CMVJ_RMP (w/kg)	42.65	5.39	43.58	5.80	1.11	0.861	1.12	1.44	0.94	0.39 (small)
CMVJ_MRFD (N/s)	12902.38	3167.14	11657.25	1673.25	−1.21	0.741	506.57	2168.74	−1245.13	−0.43 (small)
SB_TTPF (ms)	82.38	8.85	84.50	9.35	1.06	0.927	1.82	4.46	2.13	0.37 (small)
SB_peakpower (w)	576.86	235.93	553.73	211.96	−1.26	0.683	44.85	34.62	−23.12	−0.45 (small)
SB_meanpower (w)	278.87	119.15	274.03	103.69	0.50	1.000	22.34	16.96	−4.84	−0.13 (trivial)
SS_RFS (s)	0.54	0.06	0.51	0.04	0.00	1.000	0.01	0.04	−0.02	−0.41 (small)
SS_FWC (s)	0.94	0.06	0.92	0.06	−0.84	1.000	0.01	0.04	−0.02	−0.30 (small)
SS_T15 (s)	7.37	0.47	7.33	0.47	−0.96	1.000	0.09	0.06	−0.04	−0.34 (small)

NON-JAW = non-jaw condition; JAW = jaw condition; CMVJ = countermovement vertical jump; SB = swim bench; SS = swimming start; RMP = relative maximal power; MRFD = maximal rate of force development; TTPF = time to arrive at peak force; RFS = rear food separation; FWC = first water contact; T15 = time at 15 m; m = meters; w = watts; kg = kilograms; N = newton; s = seconds; ms = milliseconds. $*p \leq 0.05$.

differences between the use and non-use of MG on similar length power tests in high-standard athletes.[22,24] Although isolate CAP phenomenon did not have a relevant effect on the swim bench test, the use of MG elicited small positive effects respect to NON-JAW condition. This is probably because the use of customized MG increased the posterior thickness of the mouth, opening the lower

Table 2
Mean difference between JAW and MG conditions in Countermovement Vertical Jump, Swim Bench and Swimming Start.

	JAW		MG							
	Mean	SD	Mean	SD	t	*p*	SWC	TE	Diff.	ES
CMVJ_height (m)	0.27	0.04	0.28	0.04	1.65	0.362	0.01	0.02	0.01	0.58 (small)
CMVJ_RMP (w/kg)	43.58	5.80	44.54	4.99	1.32	0.830	0.10	2.23	0.96	0.40 (small)
CMVJ_MRFD (N/s)	11657.25	1673.25	13158.25	2576.94	1.46	0.502	434.52	2150.56	1501.00	0.52 (small)
SB_TTPF (ms)	84.50	9.35	79.00	9.64	−2.73	0.049	1.90	3.05	−5.50	−0.97 (moderate) *
SB_peakpower (w)	553.73	211.96	594.93	239.47	2.25	0.124	45.23	32.12	41.2	0.80 (moderate)
SB_meanPower (w)	274.03	103.69	297.57	107.88	1.25	0.695	21.16	31.69	23.54	0.65 (moderate)
SS_RFS (s)	0.51	0.04	0.50	0.05	0.81	1.000	0.01	0.03	−0.01	−0.28 (small)
SS_FWC (s)	0.92	0.06	0.92	0.07	−0.57	1.000	0.01	0.03	−0.01	−0.20 (small)
SS_T15 (s)	7.33	0.47	7.32	0.44	−0.09	1.000	0.09	0.12	0.00	−0.03 (trivial)

JAW = jaw condition; MG = mouthguard condition; CMVJ = countermovement vertical jump; SB = swim bench; SS = swimming start; RMP = relative maximal power; MRFD = maximal rate of force development; TTPF = time to arrive at peak force; RFS = rear food separation, FWC = first water contact; T15 = time at 15 m, m = meters; w = watts; kg = kilograms; N = newton; s = seconds; ms = milliseconds. *$p \leq 0.05$.

Table 3
Mean difference between NON-JAW and MG conditions in Countermovement Vertical Jump, Swim Bench and Swimming Start.

	NON-JAW		MG							
	Mean	SD	Mean	SD	t	*p*	SWC	TE	Diff	ES
CMVJ_height (m)	0.26	0.04	0.28	0.04	2.82	0.041	0.01	0.01	0.02	1.00 (moderate) *
CMVJ_RMP (w/kg)	42.65	5.39	44.54	4.99	2.24	0.126	1.04	1.26	1.90	0.79 (moderate)
CMVJ_MRFD (N/s)	12902.38	3167.14	13158.25	2576.94	0.25	1.000	577.43	1848.33	255.88	0.09 (trivial)
SB_TTPF (ms)	82.38	8.85	79.00	9.64	−1.67	0.347	1.85	4.41	−3.38	−0.59 (small)
SB_peakpower (w)	576.86	235.93	594.93	239.47	0.99	1.000	47.54	42.43	18.08	0.35 (small)
SB_meanPower (w)	278.87	119.15	297.57	107.88	1.75	0.306	22.73	26.29	18.69	0.51 (small)
SS_RFS (s)	0.54	0.06	0.50	0.05	0.810	1.000	0.01	0.05	−0.03	−0.53 (small)
SS_FWC (s)	0.94	0.06	0.92	0.07	−1.17	0.841	0.01	0.05	−0.03	−0.41 (small)
SS_T15 (s)	7.37	0.47	7.32	0.44	−1.05	0.940	0.09	0.08	−0.05	−0.37 (small)

NON-JAW = non-jaw condition; MG = mouthguard condition; CMVJ = countermovement vertical jump; SB = swim bench; SS = swimming start; RMP = relative maximal power; MRFD = maximal rate of force development; TTPF = time to arrive at peak force; RFS = rear food separation; FWC = first water contact; T15 = time at 15 m; m = meters; w = watts; kg = kilograms; N = newton; s = seconds; ms = milliseconds. *$p \leq 0.05$.

airway and promoting a better airflow.[12,39] As a consequence, the subjects could maintain the powered and balanced jaw contraction during a longer period. In this vein, Morales et al.,[39] found higher airflow dynamics when comparing the use and non-use of mouthguard on anaerobic ability test (Wingate) in both forced and unforced conditions.

In the start reaction time, participants experienced non-significant differences for any variable and condition. Also, non-significant differences were found in the 15-m freestyle. These findings are in contrast with Issurin et al.[8] who found significant ergogenic effects due to jaw clenching combined with abdominal contraction in the start reaction time (average difference = 0.05 s, $p = 0.003$) and in the 15-m distance (average difference = 0.08 s, $p = 0.013$). The authors supported that the possible effects of CAP such as cognitive input, beneficial mental concentration and a more favourable emotional state might be the main contributors to these motor effects. Other authors like Garner and Miskimin[26] attributed the improvements on the reaction time to a stress reduction on the temporomandibular structure, as well as to a better neural transmission, higher blood flow and an increase of the oxygen unloading in other areas of the head and neck. However, other studies[16,19] observed no significant differences on visual reaction time because of the use of MG in trained team-sport subjects. In the present study, one possible reason to explain the absence of advantages associated with jaw clenching and the use of MG could be that swimmers held a maximal contraction of the mandible muscles for several seconds before to the quick off. It is possible that the jaw clenching protocols used by this test were too long in duration. In this vein, Furubayashi et al.[40] demonstrated that cortical facilitation occurs just after the onset of jaw clenching and the spinal facilitation occurs only at a later time. Thus, it could be hypothesized that the RVC should affect the reaction time only at the beginning of the maximal jaw muscles contraction.

Start performance in swimming is a combination of reaction time, vertical and horizontal force off the block, and a low resistance during underwater gliding.[32] In this study we observed significant effects in CMVJ height whereas only small differences were found in the start reaction time because of wearing MG. However, it is interesting to note that small effects may have a large impact in high-level athletes.[41] For instance, at the last 2019 FINA World Championship held in South Korea, the time distance between the 2nd (21.45 s) and the 5th (21.55 s) in the men's 50 m freestyle final was only 0,1 s. In the women's 50 m freestyle the time distance between the 1st (24.05 s) and 4th (24.12 s) was only 0.07 s. Therefore, reducing several split seconds might enable swimmers to win a medal. In 15-m distance it was observed that swimmers resorted almost all the distance gliding underwater and using only a few pull arms. For this reason, potential improvements detected in the pull arms test couldn't be observed in this test. Additionally, we reminded the corresponding condition before each trial and we corroborated it through a posterior video analysis. Nonetheless, once in the water we couldn't ensure the condition was maintained during all the test.

Another important factor to take into consideration when wearing MG in the real sport context is the perception of the athletes. In the present study, despite one of the participants felt that the device was so bulky and also one of them worded a light discomfort when wearing it, any participant argued potential performance limitation because of the MG. Indeed, 50% of the participants felt performance improvements when wearing the oral device. Additionally, 75% of them exposed that they used to contract their jaw just before the start reaction whereas 50% used to contract both the jaw and the abdominal musculature. The mean attitudinal score was 3.25 ± 0.71, indicating an overall positive attitude towards the oral devices. Moreover, in the present research, participants were instructed to wear the MG during one-week in their training sessions. They reported 7,13 ± 3,83 h during the previous week of the tests. For future research, it should be considered a longer period of training to elicit a better familiarization with the devices.

Beyond the sample size of the study, commonly observed among studies with Olympic athletes, several limitations should be considered. Firstly, the difficulties to control the jaw clenching under the water. This limitation could explain the lack of differences in 15-m swimming. Secondly, the lack of a longer familiarization with the MG, which is difficult in this type of studies with a group of athletes training and competing for the most prestigious goals with their own beliefs, habits and obsessions. And thirdly, the inability to explain part of the variance in the swimming start performance through the analysis of the different biomechanical variables (technique).

4.1. Practical applications

The present study is the first in studying the effects of wearing a customized jaw-aligning MG on high-standard swimmers' performance. In this sport, factors such as reaction time and muscular power might be crucial to improve the athletic potential. Although the sample is necessarily reduced, the competitive standard of the participants might contribute to approach the potential effects of this oral appliances in the professional sport contexts. Considering the present findings, the use of customized bite-aligning MG is recommended for highly trained swimmers. Although no significant improvements were observed in some of the studied variables, no negative effects were found. Thus, swimmers can benefit in the most common powerful actions in their discipline. In the high-standard sport context, the use of all resources to improve the performance has to be considered not only in competitive events but also in training sessions, because powerful jumps, pushes, pulls and swimming starts can be benefited of CAP promotion wearing a customized bite-aligning MG. The lack of detrimental effects in ventilatory parameters reported in literature, and the mentioned benefits, could also encourage the athletes in using the devices into the water training sessions, especially for the possible potentiation during the flip turns.

5. Conclusion

This study demonstrated that the use of custom-made bite-aligning mouthguards had an ergogenic effect on jump and pull arm performance. Moreover, although no significant effects were found in start reaction time and 15-m freestyle distance, high-standard swimmers may consider the use of customized mouthguards as a way not only to improve the quality of their occlusion even to improve their athletic potential in powerful actions throughout the training process.

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Declaration of competing interest

The authors have no conflicts of interest relevant to this study.

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