# Effects of Two Different Self-Adapted Occlusal Splints on Electromyographic and Force Parameters During Elbow Flexors Isometric Contraction

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## Abstract

Limonta, E, Arienti, C, Rampichini, S, Venturelli, M, Cè, E, Veicsteinas, A, and Esposito, F. Effects of two different self-adapted occlusal splints on electromyographic and force parameters during elbow flexors isometric contraction. *J Strength Cond Res* 32(1): 230–236, 2018—The study was aimed at determining the acute effects of 2 types of occlusal splints on maximum isometric strength and fatigue of the elbow flexors muscles. The hypothesis was that splint-induced masticatory muscle repositioning might improve primary muscles recruitment by stretching masticatory muscles especially with the thicker splint. On 9 physically active volunteers with no temporomandibular joint and masticatory muscles disorders, we assessed maximum voluntary contraction (MVC) of the elbow flexors with diurnal ($OS_D$, 1-mm thick) and sport ($OS_{SP}$, 3-mm thick) splints, and without splint (control, Ctrl). On different days, participants performed 60 seconds of isometric contraction at 100% MVC ($100\%_{60s}$) and 80% MVC contraction until exhaustion ($80\%_{exh}$) under $OS_D$, $OS_{SP}$, and Ctrl in random order. Time of force output within target (t-target), force distance from target ($\Delta F$), and force coefficient of variation were calculated. Percentage of force decay ($\Delta_{Fi-Fe}$) was determined during $100\%_{60s}$. From the electromyographic (EMG) signal, root mean square (EMG RMS) and mean frequency (EMG MF) were determined. Neuromuscular efficiency (NE) was calculated as the ratio between force and EMG RMS. MVC contraction and NE were significantly higher in $OS_{SP}$ and $OS_D$ than in Ctrl. During MVC, EMG MF was significantly lower in both splint conditions, and EMG RMS showed a non-statistical tendency to lower values under both splint conditions. During $80\%_{exh}$, t-target was longer in $OS_D$ and $OS_{SP}$

(+7.8% and +5.2%, respectively) than in Ctrl. $\Delta_{Fi-Fe}$ was lower in $OS_{SP}$ than in Ctrl and $OS_D$. These results support the hypothesis of a NE improvement of the elbow flexors possibly induced by acute, splint-induced masticatory muscles repositioning.

**Key Words** strength, endurance, mouthguard, fatigue, EMG

## Introduction

**M**outhguards are considered to be an effective and cost-efficient device recommended by the American Dental Association in various sports to decrease the risk of orofacial injuries (30). Although face and mouth injuries were estimated to affect 50% of the players, this incidence decreased markedly to 1.4% as a result of the mandatory use of mouthguards (27,30). Although mouthguards have been shown to protect against orofacial injuries, many players do not wear them during training sessions and competitions because of the discomfort, difficulty in verbal communication, and breathing, thus interfering with athletic performance (14). For this reason, the effects of mouth appliances on physical performance translated into formal scientific research as early as the 1960s (18,30), uncovering positive effects of oral appliances, which were mainly designed to properly align the temporomandibular joint (TMJ), on maximum strength (28), power (1), endurance (13), expiratory ventilation (12), and posture (2). This improvement in performance needed to be accompanied by structural changes of the devices, with a decrease in vertical amplitude and thickness, to make it more comfortable during sport activities (20,21).

Mainly 2 types of oral device (oral splint, OS) have been designed to optimize the contact and distribution of pressure between the upper and lower dental arch (26) and possibly to induce optimal TMJ placement (7,10): (a) self-adapted, over the counter "boil-and-bite" devices and (b) custom-made splints, manufactured on models cast from individual dental impressions. The latter show optimal comfort and

wearability (9,31) and are the best protection against oro-facial injuries (4,24). However, they are more expensive, and consequently many recreational athletes tend to prefer the first type. Acute OS usage may determine a distancing of the dental arches and create a mandibular stability with an increase in vertical distance between superior and inferior arch (29,32). As described previously, isometric strength was found to increase significantly with the elevation of vertical dimension (5). Indeed, masticatory muscles repositioning in the vertical direction has been shown to induce beneficial ergogenic effects in healthy individuals (23). However, the mechanisms underlying OS effects on physical performance are still a matter of debate.

Most of the scientific literature examining the effects of splint-induced jaw repositioning on physical performance focused mainly on dynamic muscular strength (1,6,15,17,34). However, the effects of splint usage, either customized or self-adapted, have been so far poorly investigated on isometric muscle activity.

On these bases, the aim of this study was to determine the effects of 2 different "boil-and-bite" (self-adapted) devices on maximum isometric strength and response to fatigue in recreational athletes. In particular, the effects of diurnal ($OS_D$, 1-mm thick) or sport splint ($OS_{SP}$, 3-mm thick) usage were compared with a condition without any device (control, Ctrl).

## METHODS

### Experimental Approach to the Problem

The repeated-measures study design aimed at assessing isometric strength performance with and without the use of 2 kinds of over the counter, boil-and-bite devices. The study was conducted under 3 experimental conditions: with diurnal ($OS_D$, 1-mm thick) or sport splint ($OS_{SP}$, 3-mm thick) (Dr. Brux, Montefarmaco, Italy), and without any device (control, Ctrl). The pictures of the 2 models of splint are shown in Figure 1. Participants reported to the laboratory 5 times. During the first visit, participants were familiarized with the experimental procedures and the instruments used to reduce the variability of the measurements as much as possible. In the second visit, participants performed 3 trials of maximum voluntary contraction (MVC) under each experimental condition for reliability purpose. In the next 3 sessions, after reassessing MVC, participants were asked to perform 2 different isometric tasks, separated by a resting period of at least 2 hours: 1 isometric contraction at 100% MVC for 60 seconds ($100\%_{60s}$) and 80% MVC isometric contraction until exhaustion ($80\%_{exh}$) under $OS_D$, $OS_{SP}$, and Ctrl condition, respectively, in random order. The last 3 sessions were randomly performed. Subjects were always supervised by a qualified operator during tests. The correct exercise execution was carefully checked and participants were always verbally encouraged and motivated during all tests.
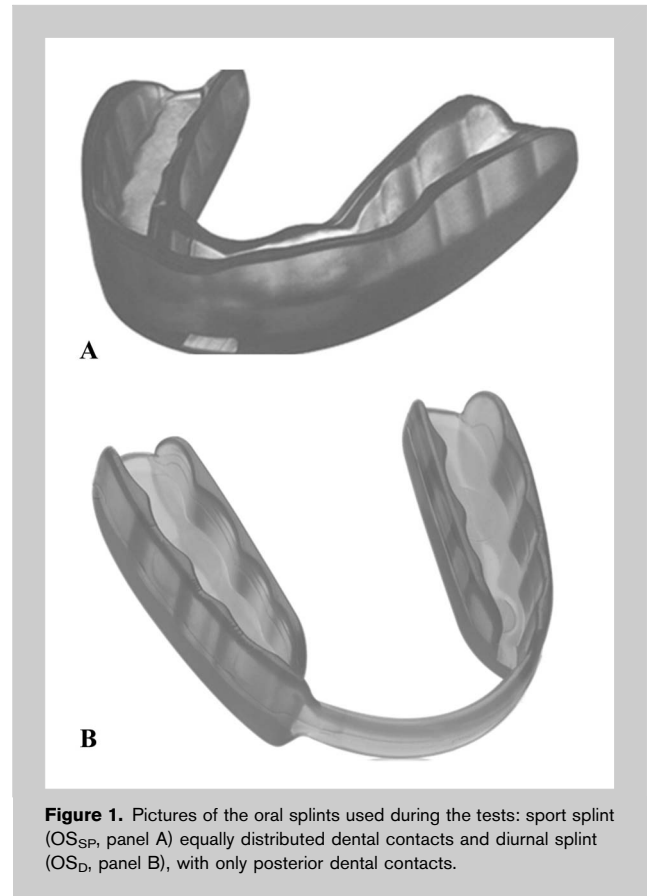


**Figure 1.** Pictures of the oral splints used during the tests: sport splint ($OS_{SP}$, panel A) equally distributed dental contacts and diurnal splint ($OS_D$, panel B), with only posterior dental contacts.

### Subjects

Nine physically active men (age: 24 ± 2 years (22–26 years); stature: 1.78 ± 0.10 m; body mass: 69 ± 10 kg; training frequency: 2 per week; mean ± *SD*) volunteered for this project. At the time of the study, none of them reported musculoskeletal pathologies of the upper limbs. Participants underwent a private dental visit at their family dental office to exclude the presence of TMJ disorders, acute inflammatory conditions, respiratory problems, and chronic pain from postural issues. Normal occlusal splint users were also excluded. Based on the outcomes, only the subjects exempt from the problems mentioned above were selected to participate in the study. After full explanation of the purpose of the study, the experimental procedures and benefits and risks of the investigation, signed informed consent was obtained from all participants included in the study, which was approved by the University of Milan's Ethics Committee, in accordance with the principles of the 1975 Declaration of Helsinki. Participants were naive about the experimental hypothesis.

### Procedures

Each test was performed at approximately the same time of the day, in a climate-controlled laboratory (constant temperature of 20 ± 1° C and relative humidity of 50 ± 5%). Participants were instructed not to eat for at least

3 hours before tests. They were also asked to avoid ergogenic beverages for at least 8 hours before tests, and to abstain from heavy exercise of the upper limbs in the previous 48 hours. The splints used during the tests had different thickness and allowed for different occlusal contacts: the $OS_D$ was 1-mm thick and had only posterior dental contacts, whereas the $OS_{SP}$ was 3-mm thick and provided a neutral dental occlusion, with occlusal contacts equally distributed along the dental arch (7,19). Participants dipped the splint into boiling water for 20 seconds and then inserted it in the mouth over the lower dental arch using the fingers and the tongue to shape it. If the splint location was unstable or inaccurate, the modeling procedure was repeated.

*Maximum Voluntary Contraction.* During MVC assessment, participants performed 3 maximum trials of the dominant side of elbow flexors each lasting 5 seconds, with 5 minutes of rest in between. The highest value was considered as the closest to the MVC, from which the 80% MVC was then calculated. During each contraction, force (F) and electromyographic (EMG) signals were recorded from the biceps brachii muscle for further analysis. F was recorded at a sampling rate of 128 Hz by a calibrated load cell (mod. SM-1000N; Scottsdale, AZ, USA) operating linearly between 0 and 1,000 N, amplified (gain: ×200) by a 16 bits A/D converter (mod. UM150; Biopac System, CA, USA). The surface EMG was acquired by a multichannel amplifier (mod. EMG-USB; OTBioelettronica, Turin, Italy; input impedance: >90 MΩ; CMRR: >96 dB; EMG bandwidth: 10–750 Hz; gain: ×1,000) with a sampling rate of 2048 Hz. Electromyography was detected in single differential modality by a linear array of 4 electrodes (mod. ELSCH004, OTBioelettronica, Turin, Italy; linear array 45 × 20 mm; electrode 2 × 1 mm; interelectrode distance 10 mm) fixed to the skin by dual-adhesive foam (mod. AD004; OTBioelettronica) filled with conductive gel (Cogel, Comedical, Trento, Italy). The EMG array was oriented with the major axis parallel to the muscle fibers direction and with the EMG electrodes positioned perpendicularly to the major axes of muscle fibers. The skin area under the electrodes was cleaned carefully with ethyl alcohol and gently abraded with a special abrasive and conductive cream (Nuprep; Weaver and Co., Aurora, CO, USA) to achieve an interelectrode impedance below 2,000 Ω. To allow repeated measurements of the signals on different days from the same muscle area, a map with the EMG probe position, together with some landmarks (moles, angiomas and scars), was drawn on a transparency.

From the time and frequency domain analyses of the EMG signal, the root mean square (EMG RMS) and mean frequency (EMG MF) were calculated. From the EMG and F data, the neuromuscular efficiency (NE) was determined as the ratio [F/EMG RMS] at MVC that is how much electrical activity is required to produce a certain level of force output (22).

*100%$_{60s}$.* Subjects were asked to reach as quickly as possible the 100% MVC and to maintain that intensity for 60 seconds, trying to drop the force output as little as possible. During contraction, F and EMG signals were acquired and subsequently analyzed. From the F signal, the percentage of force decay ($\Delta_{Fi-Fe}$) during 100%$_{60s}$ was determined. From the time and frequency domain analyses of the EMG signal, the EMG RMS and EMG MF were calculated.

*80%$_{exh}$.* Participants performed an isometric effort at 80% MVC to the point of fatigue, i.e., when they were no longer able to keep the force level constant within ±5% of the target. This intensity was chosen because during this level of effort all motor units should be recruited and active (3). Also during this task, F and EMG signals were acquired and analyzed subsequently. From the F signal, the time of F within the target (t-target), the distance of F from the required target ($\Delta F$), as an index of muscle contraction accuracy, and the coefficient of variation (CoV) of F were calculated. Coefficient of variation was estimated as the ratio between the SD of the F in a considered time window and F average value in the same window (CoV = SD/mean). This parameter can be considered as an index of muscle contraction stability (33). From the time domain analyses of the EMG signal, the EMG RMS was calculated.

In all testing protocols, participants were given specific instructions not to focus their attention on OS and teeth clenching while performing the requested isometric motor tasks to avoid any external influence on their usual teeth clenching behavior during physical efforts.

### Statistical Analyses

Statistical analysis was performed using a statistical software package (SigmaPlot for Windows; v12, Systat Software Inc., San Josè, CA, USA). To check the normal distribution of the sampling, a Kolgomorov–Smirnov test was applied. A sample size of 9 participants was selected to ensure a statistical power higher than 0.80. A 1-way (condition) analysis of variance (ANOVA) was used for MVC, and a 2-way (condition × time) ANOVA for repeated measures was applied to determine possible differences in F and EMG variables during the different experimental conditions for 80%$_{exh}$ and 100%$_{60s}$ tests. The post hoc Holm–Sidak test was applied when necessary to establish the location of the differences. The level of significance was set at $\alpha < 0.05$. A 2-way, mixed model intraclass correlation coefficient (ICC) was used to assess intersession reliability of MVC assessment between visit 2 and 3, 4, or 5. Intraclass correlation coefficient values were considered as very high if >0.90, high if between 0.70 and 0.89, and moderate if between 0.50 and 0.69. Unless otherwise stated, values are expressed as mean ± *SE*.

## RESULTS

### Maximum Voluntary Contraction

Absolute MVC was significantly higher ($p = 0.012$) in $OS_{SP}$ (378.5 ± 39.9 N; $p ≤ 0.05$) and $OS_D$ (361.8 ± 42.9 N) than in control condition (345.7 ± 30.7 N). Neuromuscular efficiency also showed higher ($p = 0.048$) values in $OS_D$ and $OS_{SP}$ (1,031.9 ± 206.8 N/mV and 1,222.4 ± 182.3 N/mV, respectively) with respect to Ctrl (822.4 ± 109.3 N/mV, Figure 2, panel A and B). Both EMG RMS and EMG MF showed lower values ($OS_D$: 0.37 ± 0.08 mV and 131.9 ± 4.2 Hz and $OS_{SP}$: 0.34 ± 0.09 mV and 131.3 ± 5.2 Hz for EMG RMS and EMG MF, respectively) than Ctrl (0.38 ± 0.06 mV and 147.6 ± 6.6 Hz for EMG RMS and EMG MF, respectively). The difference reached statistical significance in MF ($p = 0.001$) while indicated only a trend in RMS (Figure 2, panel C and D). Reliability for MVC measurements was between high and very high. Indeed, ICC values were 0.985, 0.880, and 0.915 under Ctrl, $OS_D$, and $OS_{SP}$, respectively.

### 80%$_{exh}$

During 80%$_{exh}$, t-target was 16.6 ± 7.4 seconds, 16.2 ± 5.3 seconds, and 15.4 ± 4.4 seconds in $OS_D$, $OS_{SP}$, and Ctrl, respectively. The differences were not significant.

For a more precise assessment of the differences among the 3 conditions in terms of electromechanical response, we decided to compare only the first 10 seconds of the isometric task, i.e., the maximum amount of contraction time that was reached by all participants at 80% MVC. Electromyographic RMS, $\Delta F$, and CoV values during 80%$_{exh}$ are shown in Figure 3. The initial values of EMG RMS were 0.374 ± 0.081 mV; 0.406 ± 0.024 mV; and 0.340 ± 0.092 mV for Ctrl, $OS_D$, and $OS_{SP}$, respectively. In the first 10 seconds, EMG RMS showed a progressive increase in all experimental conditions. $\Delta F$ starting values were 0.384 ± 1.580% (Ctrl), −0.647 ± 1.972% ($OS_D$), and −1.827 ± 1.734% ($OS_{SP}$). The values during the first 10 seconds showed stability in the target force maintenance. Last, CoV started at 0.039 ± 2.980 (Ctrl), 0.025 ± 3.310 ($OS_D$), and 0.033 ± 4.950 ($OS_{SP}$) and showed a decrease in the considered interval. As depicted in Figure 3, the 2-way ANOVA for repeated measures retrieved no differences for all variables among Ctrl, $OS_D$, and $OS_{SP}$. A time effect was observed in EMG RMS from the fifth second, in EMG MF from the sixth second, and in CoV immediately after the start of the test. There were no interactions between the 2 factors.

### 100%$_{60s}$

The $\Delta_{Fi-Fe}$ of maximal contraction was similar in Ctrl (66.38 ± 4.05%) and $OS_D$ (67.64 ± 3.87%), but
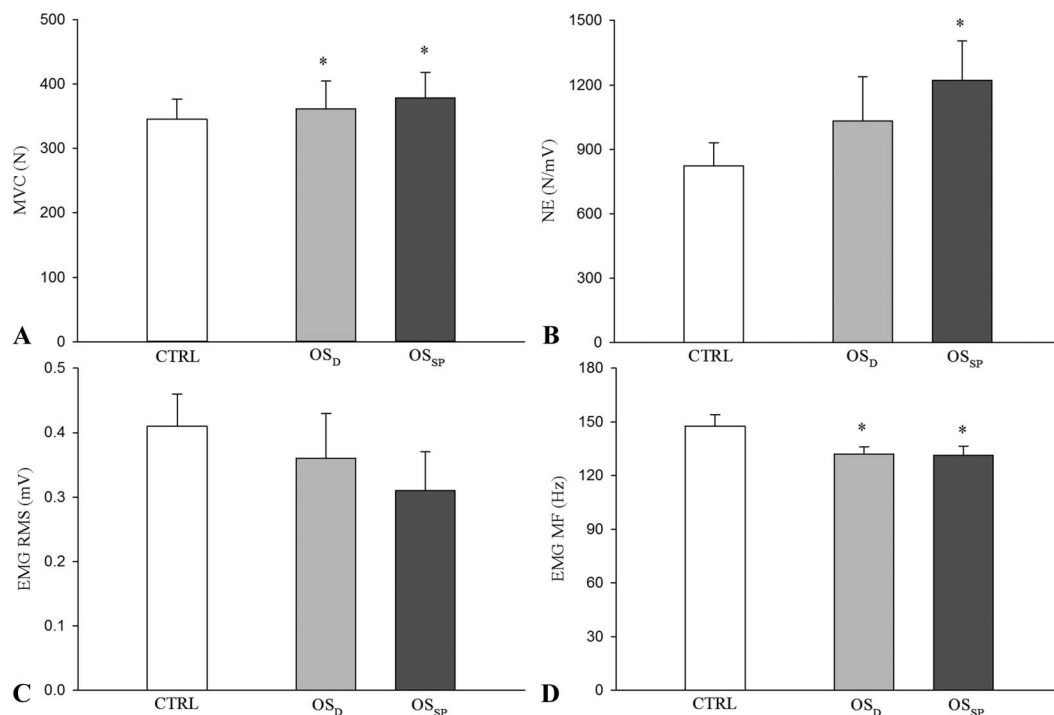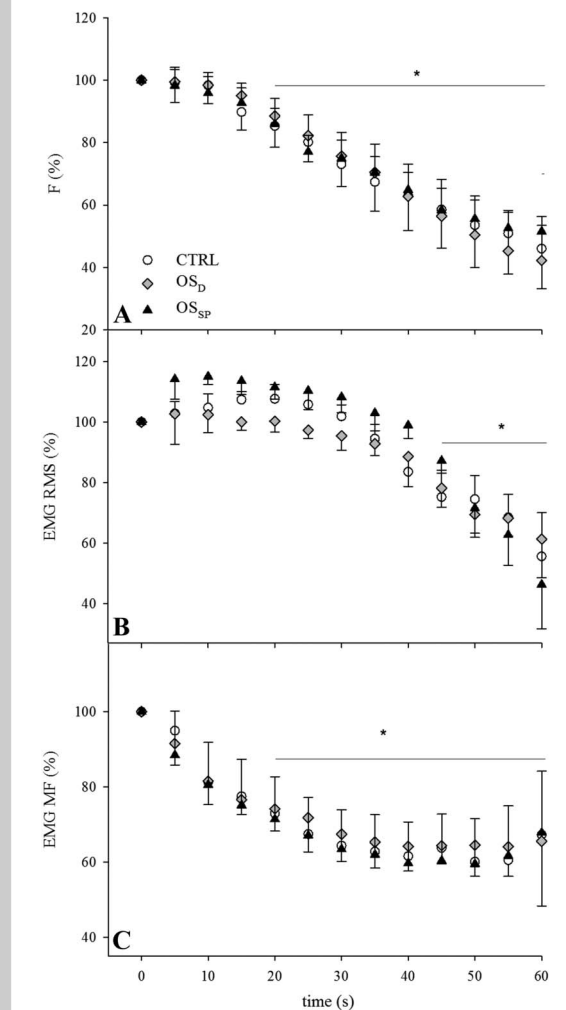


**Figure 2.** Maximum isometric strength (panel A), neuromuscular efficiency (NE, panel B), and electromyographic (EMG) parameters (panels C and D) during maximum voluntary contraction (MVC) in the 3 experimental conditions ($OS_{SP}$ = sport splint; $OS_D$ = diurnal splint; and Ctrl = control). *$p ≤ 0.05$ vs. CON. Data are expressed as mean ± SE. EMG RMS = electromyographic root mean square; EMG MF = electromyographic mean frequency.
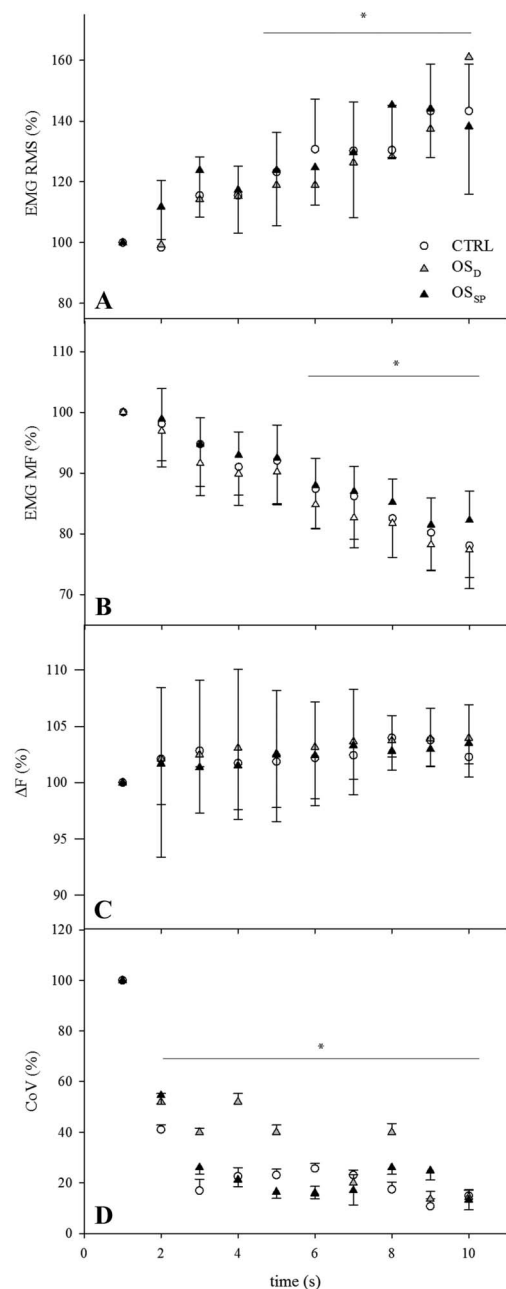
**Figure 3.** Electromyographic root mean square (EMG RMS, panel A) and mean frequency (EMG MF, panel B), distance of force output from the required target (ΔF, panel C), and coefficient of variation (CoV, panel D) of F during the first 10 seconds of 80%_exh in the 3 experimental conditions (OS_SP = sport splint; OS_D = diurnal splint; and Ctrl = control). Data are expressed as a percentage of the initial value (=100%). *$p \leq 0.05$ vs. initial value. Data are expressed as mean ± *SE*.



**Figure 4.** Force (*F*, panel A), electromyographic root mean square (EMG RMS), and electromyographic mean frequency (EMG MF) (panels B and C) during 100%_60s in 3 experimental conditions (OS_SP = sport splint; OS_D = diurnal splint; and Ctrl = control). Data are expressed as a percentage of the initial value (=100%). *$p \leq 0.05$ vs. initial value. Data are expressed as mean ± *SE*.

N, and 378.5 ± 39.9 N for Ctrl, OS_D, and OS_SP, respectively.

Electromyographic RMS started with values of 0.38 ± 0.06 mV (Ctrl), 0.37 ± 0.08 mV (OS_D), and 0.34 ± 0.09 (OS_SP), then increased slightly in the first 30 seconds respect to initial values with a subsequent decline. Conversely, EMG MF started at 147.56 ± 6.57 Hz (Ctrl), 131.94 ± 4.17 Hz (OS_D), and 120.74 ± 4.16 Hz (OS_SP), decreased during the first 30 seconds, then reaching a plateau (Figure 4, panel B and C).

The 2-way ANOVA for repeated measures disclosed no differences in all variables among the 3 experimental conditions. A time effect was observed in Δ_Fi-Fe and EMG MF from the twentieth second, and in the last seconds of

significantly lower in OS_SP (60.88 ± 5.46%; $p = 0.013$) (Figure 4, panel A).

F decreased progressively during the entire task. The initial values were 345.7 ± 30.7 N, 361.8 ± 42.9

contraction in EMG RMS. There were no interactions between the 2 factors.

## DISCUSSION

The aim of this study was to assess the effects of 2 different kinds of occlusal splints (diurnal, $OS_D$ and sport splint, $OS_{SP}$) on the neuromuscular activation and isometric F output of the elbow flexor muscles. The response to fatiguing tasks was also evaluated. The main finding was that $OS_{SP}$ had a positive effect on maximum isometric strength capacity. During MVC, indeed, higher values were observed in $OS_{SP}$ than in Ctrl. Furthermore, a lower decline in F was observed with $OS_{SP}$ during a sustained MVC for 60 seconds. These results, together with EMG parameters, support the hypothesis of an improvement in NE of the elbow flexors (primary muscles) possibly induced by acute jaw repositioning through splint usage.

Unfortunately, at the time of the study, neither surface EMG activity nor force output of the masticatory muscles were recorded during the tests due to technical problems. Future studies implementing and quantifying neuromuscular activation and force output of masseter and temporalis anterior muscles during primary muscles contraction may provide further support to the interpretation of the present findings.

In the recent years, OS usage has raised questions about positive effects of this device not only on injury prevention but also on dynamic exercise performance. The possible mechanisms underlying this hypothesis involve potential postural readjustments and muscular rebalancing after chronic splint employment (6,16). Indeed, jaw repositioning may correlate with postural control, functional proprioception, and spinal alignment. Changes in spinal alignment and proprioception may promote changes in physical movement and performance (16). The application of an OS may therefore result in a better redistribution of the clenching load, supporting the role that dental occlusion has on posture through the neuromuscular system (6).

However, whether acute splint usage affects maximum isometric strength and endurance has not been examined yet. In this study, we found higher MVC values in $OS_{SP}$ than in $OS_D$ and Ctrl. Together with the tendency toward a lower EMG RMS, this phenomenon implies a higher NE (ratio between F and EMG RMS) in $OS_{SP}$. These effects were detected acutely during isometric muscular tasks, given that regular splints users were excluded from the study. Therefore, postural adjustments that require long time to take place cannot be claimed to have had a role in these findings. Conversely, acute OS usage may have determined a distancing of the dental arches and a resulting elongation of the masticatory musculature that has been shown to induce beneficial ergogenic effects in healthy individuals (23), possibly by altering the proprioceptive feedback from the masticatory muscles. This feedback change in this study may have improved the muscle force generating capacity of the elbow flexors in terms of a better NE.

Moreover, some studies observed that the synchronous co-activation of more muscles (e.g., during handgrip) produces a maximum force expression lower than the sum of the maximum force capacity of the single muscles involved (e.g., single fingers) (11,35). A recent study (25) may provide additional evidence for the functional coupling of the craniomandibular system and muscular control, by observing an improvement in postural control through a reduced intervention of co-agonist secondary muscles with respect to the primary movement.

Overall, our and others' data may confirm the hypothesis that an amelioration of neuromuscular control of the primary muscles may have occurred during $OS_{SP}$ and $OS_D$ conditions, with a lower interference of ancillary feedback and, consequently, an improved contraction effectiveness. According to our data, mandibular stability through acute boil-and-bite splints usage may have induced a better stretching and realignment of masticatory muscles that led to higher MVC with a similar EMG activity, i.e., to a better NE, which represents the muscle responsiveness to a neural excitation (8). Neuromuscular efficiency is based on the relationship between the force generated by a muscle and its EMG activity. Hence, the NE can be interpreted as the ability to produce higher levels of strength within a similar or lesser muscle activation (8).

A lower strength decline between the beginning and the end of the prolonged maximum contraction ($60s_{max}$) was observed in $OS_{SP}$. Moreover, t-target during $80\%_{fatigue}$ showed a tendency to be longer in both $OS_{SP}$ and in $OS_D$ compared with Ctrl. However, EMG parameters during both fatiguing tests showed no significant differences among the 3 investigated conditions. Overall, these findings seem to indicate an enhancement in NE, the previously described ratio between EMG activity and force output, rather than a modification of the motor unit recruitment strategy.

These responses were more evident in $OS_{SP}$ than in $OS_D$ possibly because of the different thickness and shape of the 2 splints (see Methods), allowing 2 very different kinds of occlusal contacts. Anterior dental contacts as in $OS_{SP}$, indeed, produce a higher TMJ load because of a longer lever arm. Moreover, the thicker $OS_{SP}$, by creating a greater distance between the 2 dental arches, may have induced a higher lengthening of the masticatory muscles and a possible consequent reduction of proprioceptive feedback from them.

In conclusion, acute splint usage had positive effects on maximum isometric strength and endurance. Force results, together with EMG parameters behavior, supported the hypothesis of an improvement in NE of the elbow flexors (primary muscles) possibly related to acute jaw repositioning. This response was more evident in $OS_{SP}$ than in $OS_D$ probably because of the different thickness of the 2 splints.

## PRACTICAL APPLICATIONS

Splint usage unveiled some positive effects on maximum isometric strength and endurance tasks. The concurrent

tendency for a decreased central drive (lower EMG RMS during MVC) and the increase in maximum force output (higher MVC values) led to a significant improvement in NE when wearing $OS_{SP}$. Moreover, $OS_{SP}$ reduced force decay during prolonged maximum isometric contraction. Acute splint usage is therefore not only not detrimental for exercise performance but it may also improve it under certain circumstances, such as maximum isometric tasks.

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