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ORIGINAL ARTICLE

# Effects of 8-week oral splint usage on body flexibility and muscle strength-endurance performance in Pilates practitioners

**Susanna Rampichini**[1] · **Giuseppe Coratella**[1] · **Emiliano Cè**[1,2] · **Stefano Longo**[1] · **Christian Doria**[1] · **Marta Borrelli**[1] · **Johnny Padulo**[1] · **Sheida Shokohyar**[1] · **Giovanni Michielon**[1] · **Eloisa Limonta**[1,2] · **Fabio Esposito**[1,2]

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## Abstract

**Purpose** We investigated the acute and chronic effects of oral splint on muscle strength-endurance performance and body flexibility.

**Methods** Twelve Pilates practitioners (age 49.5 ± 5.8 years; mass 58.6 ± 6.5 kg) were evaluated with (OS) and without (CTRL) oral splint. Before (PRE) and after (POST) 8 weeks of oral splint usage during Pilates activity, muscle strength-endurance and body flexibility were evaluated through a frontal plank exercise and a Toe-touch test in OS and CTRL. Before each test, the highest electrical activation (EMG) of masseter and temporal muscles during maximal occlusion was determined. During frontal plank, the time-to-exhaustion, the maximum voluntary activation of masticatory muscles and the time of muscles activation have been determined.

**Results** No OS vs CTRL and PRE vs POST differences were found in the maximum voluntary activation of temporal and masseter muscles. The time-to-exhaustion in OS was longer than CTRL in both PRE ($P=0.049$) and POST sessions ($P=0.043$). Time of masticatory muscles activation during plank was moderately greater in OS at PRE ($P=0.020$) and POST ($P=0.022$), while no difference between PRE and POST emerged in both conditions. Higher muscular activation was found in OS than CTRL at PRE ($P=0.031$) and POST ($P=0.031$), whereas no difference between PRE and POST appeared. No effect on flexibility emerged neither acutely nor chronically.

**Conclusion** Acute and chronic oral splint usage improved strength-endurance performance but not body flexibility. These findings suggest biomechanical and neural mechanisms influencing the muscle length and the concurrent activation potentiation, but not muscle tone and stiffness.

**Keywords** Mouthguards · EMG · Occlusal splint · Masticatory muscles

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✉ Susanna Rampichini
susanna.rampichini@unimi.it

Giuseppe Coratella
giuseppe.coratella@unimi.it

Emiliano Cè
emiliano.ce@unimi.it

Stefano Longo
stefano.longo@unimi.it

Christian Doria
christian.doria@unimi.it

Marta Borrelli
marta.borrelli@unimi.it

Johnny Padulo
johnny.padulo@unimi.it

Sheida Shokohyar
sheida.shokohyar@unimi.it

Giovanni Michielon
giovanni.michielon@unimi.it

Eloisa Limonta
eloisa.limonta@unimi.it

Fabio Esposito
fabio.esposito@unimi.it

[1] Department of Biomedical Sciences for Health, Università degli Studi di Milano, via G. Colombo 71, 20133 Milan, Italy

[2] IRCCS Istituto Ortopedico Galeazzi, Milan, Italy

## Introduction

Oral splints (OSs) have found a widespread application for protection purpose and therapeutic usage [1–3]. OSs have been introduced during daily activities to obtain a proper alignment of the temporo-mandibular joint, reduce myofascial pain by increasing the interocclusal distance, improve the mandibular stability and distribute the masticatory pressure uniformly at the superior and inferior arch [3–5]. As a consequence, an improvement in muscular performance in terms of maximum strength [6–9], power [9, 10], endurance [11], and posture [12] has been reported. Collectively, the improvement in physical performance has been argued to be induced by different biomechanical and neural mechanisms. The former include the decrease in the myofascial tension and, in turn, of muscle–tendon stiffness of jaw, neck and trunk muscles [13] and an OS-induced elongation of the masticatory muscles [10, 14]. The neural mechanisms involve an amelioration of neuromuscular efficiency, which represents the muscle responsiveness to a neural excitation [15], a decline of undesirable neural afferents from the orofacial area to the brain [3, 16], and a reduction of co-contractions [7, 17, 18]. Nonetheless, these observations have been limited to the force-generating capacity, with no insights on body flexibility [9, 17].

Positive effects were also found on postural control [13, 19–21], arguing that the convergence of trigeminal afferents and proprioceptive inputs from the temporomandibular region and of the vestibular and proprioceptive afferents from the neck toward the central cervical nucleus of the upper spinal cord may possibly yield to an interaction between the vestibulospinal reflexes and the stomatognathic apparatus [12, 21]. Moreover, the interconnection between the masticatory and postural muscles and the influence of dental occlusion on muscle tone have been proposed as additional mechanisms underlying the enhancement of balance ability [13].

Although many studies have explored the impact of OS usage on the performance in several sports, two main concerns emerge from the literature revision. Primarily, the aforementioned studies focused only on the acute influence, while the chronic effects of OS usage and its impact on the correlates of physical performance have not been yet explored. Considering that the mechanical properties of the muscle–tendon complex require several weeks to adapt to an external stimulus [22], chronic OS usage may disclose long-term effects with possible further ameliorations in muscle performance. Indeed, a strong interrelationship between the biomechanical properties of jaw, neck and back myofascial tissues and the reduction in the tension of the back muscles has been observed [13]. Therefore, long-term OS usage may lead to not only a reduction in myofascial pain but also an enhancement of body flexibility. Second, no studies investigated possible OS influences on strength-endurance, an important aspect of force-generating capacity, which is essential for both sport performance and daily life activities [23]. The possible higher relaxation level or over-involvement of the temporo-mandibular muscles induced by OS usage may conceivably contribute to a better muscular performance while exerting a strength-endurance task.

Therefore, the current study aimed to examine the acute and chronic effects of OS usage on muscle strength-endurance performance and body flexibility. We hypothesized a muscle strength-endurance enhancement with no effects on flexibility after acute OS use, likely because of the longer time to adapt the mechanical properties of the muscle–tendon complex to the OS-induced stimuli. Conversely, we expect that after long-term OS usage, the enhancement in muscle strength-endurance would be accompanied also by an increase in body flexibility.

## Methods

### Experimental design

The pre-post one-group trial aimed at assessing muscle strength-endurance and body flexibility with and without the use of OS. A group of expert Pilates practitioners was recruited because of their long-term experience in muscle strength-endurance and flexibility, so to avoid any possible bias.

The procedures lasted 10 weeks. In week-1 and week-10, the pre- and post-intervention assessment was performed. The OS usage lasted from week-2 to week-9. To assess muscle strength-endurance and flexibility, a frontal plank exercise [24] and a Toe-touch test were selected [25, 26]. During the forearm plank testing, neuromuscular evaluation of masticatory muscles was also performed by recording surface electromyogram signal (EMG) of the temporal and masseter muscles. At the beginning of the testing session each participant performed three maximal voluntary jaw occlusions (maximal voluntary contraction, MVC) with (OS) and without (CTRL) the use of a commercially available OS (Brux Power, Montefarmaco, Italy) suited for sports activity. The trial presenting the highest EMG signal was inserted into data analysis and considered as the maximum. Flexibility and muscle strength-endurance test followed the MVC and were performed in a random order within each testing session before and after the 2 months application period. The testing procedures were executed at the same time of the day to avoid any effect on corticospinal excitability due to circadian rhythms [27]. Moreover, at the day of the testing session, the participants were asked not to alter their physical activity habits to exclude any influence on circadian rhythms [28].

## Subjects

Twelve expert female Pilates practitioners were recruited [age 49.5 ± 5.8 years; body mass 58.6 ± 6.5 kg; stature: 1.65 ± 0.06 m; training frequency: 2 sessions/week; mean ± standard deviation (SD)]. The inclusion criteria were the absence of acute inflammatory conditions, chronic pain from postural issues and the lack of any musculoskeletal pathologies and temporo-mandibular joint disorders. After a full explanation of the experimental procedures, benefits and risks, and the purposes of the study, all the participants signed the informed consent. Subjects habitual to normal occlusal splint were also excluded to the study. The local Ethic Committee of the Università degli Studi di Milano approved the study, which was conducted in accordance with the principles of the 1975 Declaration of Helsinki.

## Procedures

### Maximum voluntary activation

The maximum voluntary activation of temporal and masseter muscles was determined at the beginning of both pre- and post-training assessment. Three 5 s maximum jaw occlusions were performed and the EMG signal of temporal and masseter muscles was acquired unilaterally on the dominant side (sampling frequency: 2 kHz) through bipolar wireless probes (FREE EMG, BTS Bioengineering, Italy), placed in accordance with manufacturer's instructions. Depolarized EMG signal was processed off-line by a 4th order zero-lag Butterworth band-pass filter (10–500 Hz). The root mean square (RMS) was calculated from OS and CTRL EMG raw data on a moving 200 ms window as follows:

$$\mathrm{RMS} = \sqrt{\frac{1}{T}\int_{0}^{T} \mathrm{EMG}^{2}(t)} \tag{1}$$

[29]. The maximum RMS value was considered as the maximum level of activation. The coefficient of variation ranged between 5 and 12%.

### Muscle strength-endurance test

The time-to-exhaustion in maintaining the plank position was used to assess the muscle strength-endurance. This exercise required the participants resting facedown on their palms and toes; the arms were straight and the elbows were aligned below the shoulders. Trunk and lower limbs were placed on the line connecting the shoulder to the feet. In case of wrists pain, participants were allowed to clasp the hands and stay on the forearms (Fig. 1, panel a). The time-to-exhaustion was inserted into data analysis. Additionally, the EMG RMS was determined for the entire duration of the exercise and normalized to the maximum activation. The time above 5% of the maximum activation was also computed and normalized for the plank time-to-exhaustion and inserted in data analysis.

### Toe-touch test

After a full explanation of the testing procedure and 5 min of light warm-up, the participants were asked to stand erect on a wooden box, barefooted, with feet apart at about shoulder width, and with legs completely extended. Then they were invited to slowly bend forward at the waist, stretching the arms towards the toes on a vertical scale placed on the box. Once the final position was reached and held for two seconds, the point on the vertical scale placed on the box was recorded (Fig. 1, panel b). The measurement was repeated two times and the best score was considered for statistical analysis.

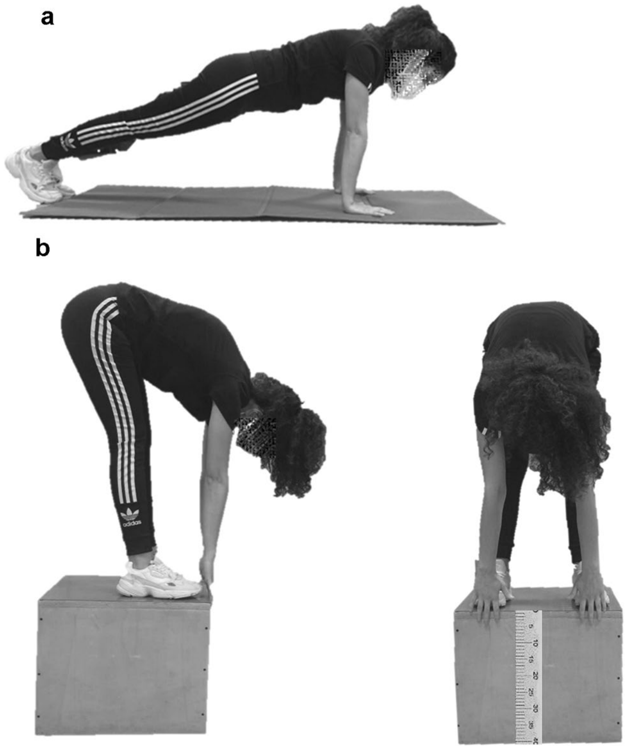

**Fig. 1** The positions adopted for the strength-endurance force tests and for the flexibility assessment are shown

### Intervention

All the participants were instructed to wear the same OS used during PRE and POST tests during each Pilates session for the entire duration of the intervention. A total of 16 sessions was completed.

The OS used for the present study presented posterior dental contacts and was 3 mm thick with a maximum border height of 10 mm. The occlusal contacts were equally distributed along the dental arch. Before the first experimental session, the OS was adapted to the subject mouth by being dipped into boiling water for 20 s and successively inserted into the mouth over the lower dental arch. The OS placement was then adjusted to optimally fit the dental arch. In case of an unstable positioning, the shaping procedure was repeated.

### Statistical analysis

Data are presented as mean [standard deviation, SD)] and 95% confidence interval (CI) was also calculated. Normal distribution was checked by Kolmogorov–Smirnov's test. A two-way ANOVA for repeated measures was used to detect the pre-post and the between-group (OS *vs* CTRL) differences in: (i) plank time-to-exhaustion; (ii) time of muscles contraction period (above 5% maximum RMS) during plank; (iii) normalized RMS during plank; and (iv) Toe-touch test. Moreover, for each statistical analysis of variance the Cohen's *d* effect size (ES) was calculated, defined as the difference between two means divided by SD for the data; the magnitude of the effect was interpreted based on the Cohen's rule of thumb, namely, ranges 0–0.1 no effect, 0.2–0.4 small effect, 0.5–0.7 intermediate effect, and $>0.8$ large effect [30]. The statistical analysis was performed through SPSS (ver.25, IBM Statistics, IBM Corporation, Armonk, NY). The level for a statistical relevance was chosen as $\alpha=0.05$.

## Results

### Maximum voluntary activation

No PRE-POST (temporal muscles: $P=0.283$; masseter muscles: $P=0.334$) and OS-CTRL (temporal muscles: $P=0.974$; masseter muscles: $P=0.131$) difference in the maximum voluntary activation of temporal and masseter muscles was found.

### Muscle strength-endurance test

No time X group interaction was found in the time-to-exhaustion ($P=0.251$). Compared to CTRL, the time-to-exhaustion in OS showed a moderate longer duration in both PRE and POST sessions (PRE: $P=0.049$, $d=0.61$, $\text{CI}_{95\%}=0.04$ to 1.18; POST: $P=0.043$, $d=0.67$, $\text{CI}_{95\%}=0.07$ to 1.27). No PRE-POST changes were observed in OS ($P=0.671$) and CTRL ($P=0.353$) (Fig. 2, panel a).

Compared to CTRL, temporal muscle contraction period in OS was moderately greater at PRE ($P=0.020$, $d=0.61$, $\text{CI}_{95\%}=-0.29$ to 1.51) and POST ($P=0.022$, $d=0.88$, $\text{CI}_{95\%}=-0.04$ to 1.79). Within-group analysis showed no difference between PRE and POST in both OS ($P=0.730$) and CTRL ($P=0.348$; Fig. 3, panel a). Compared to CTRL, masseter muscle contraction period in OS was greater at PRE ($P=0.024$, $d=0.41$, $\text{CI}_{95\%}=-0.47$ to 1.30) and POST ($P=0.029$, $d=0.69$, $\text{CI}_{95\%}=-0.21$ to 1.59). Within-group analysis showed no difference between PRE and POST in both OS ($P=0.484$) and CTRL ($P=0.286$; Fig. 3, panel b).

Compared to CTRL, temporal muscle RMS in OS was greater at PRE ($P=0.031$, $d=0.61$, $\text{CI}_{95\%}=-0.29$ to 1.51) and POST ($P=0.031$, $d=0.80$, $\text{CI}_{95\%}=-0.12$ to 1.71). Within-group analysis showed no difference between PRE and POST in both OS ($P=0.565$) and CTRL

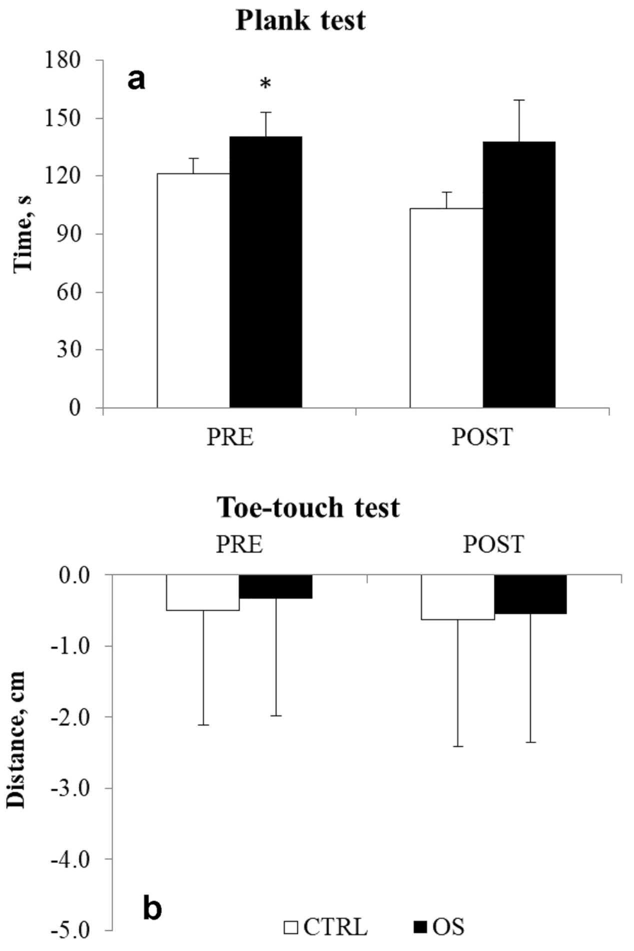

**Fig. 2** Panel **a** PRE and POST mean (SD) values of time-to-exhaustion during plank test. Panel **b** PRE and POST mean values (SD) determined during Toe-touch test. White bars: CTRL and black bars: OS. $^{*}P<0.05$ vs CTRL

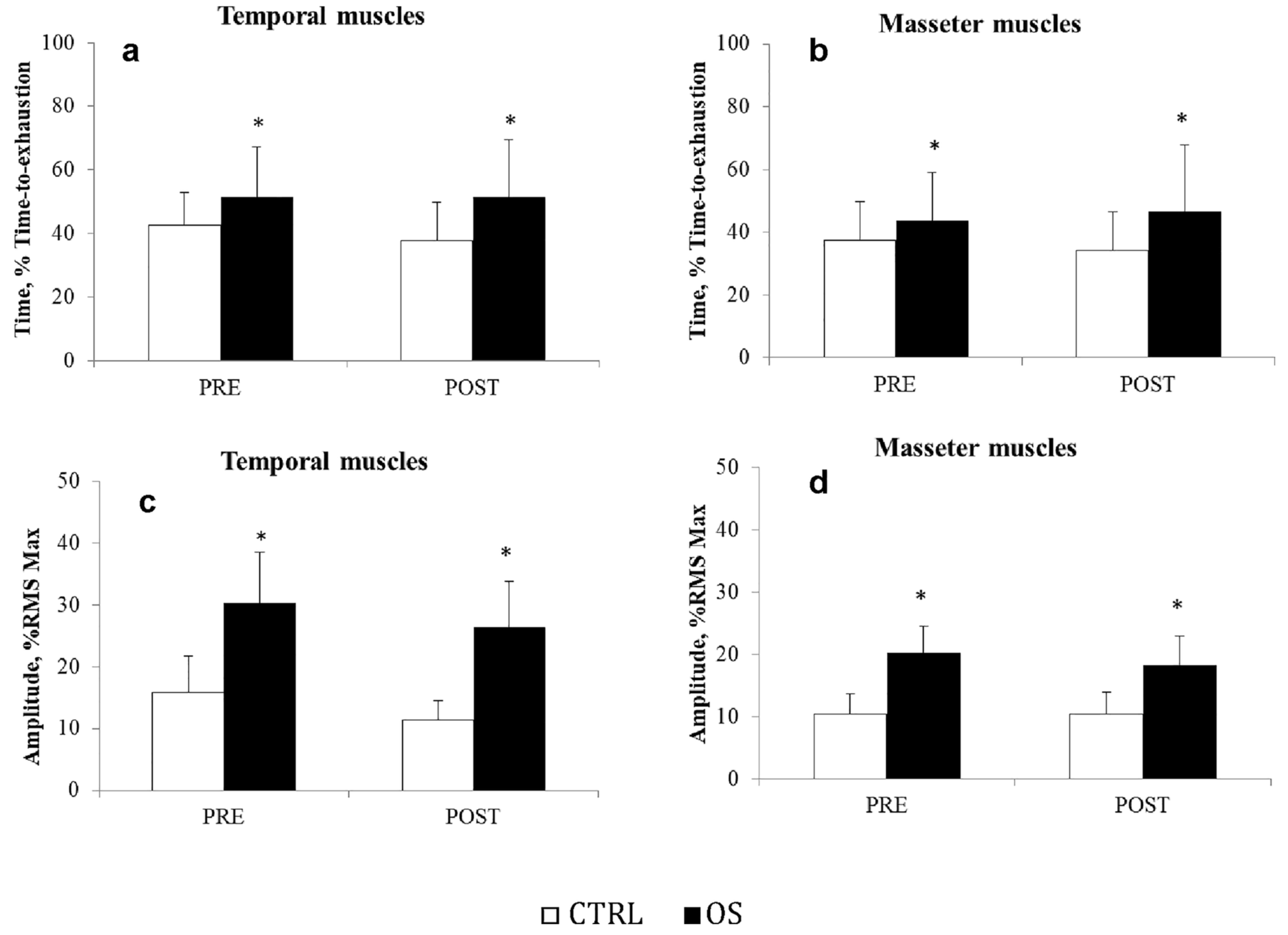

**Fig. 3** The temporal (panel **a**) and masseter (panel **b**) muscles contraction period, expressed as the percentage of the time-to-exhaustion, during Plank test is shown. The temporal (panel **c**) and masseter (panel **d**) muscle RMS during Plank is reported as the percentage of the maximum value determined during MVC. White bars: CTRL and black bars: OS. *$P<0.05$ vs CTRL

($P=0.307$; Fig. 3, panel c). Compared to CTRL, masseter muscle RMS in OS was greater at PRE ($P=0.021$, $d=0.74$, $\mathrm{CI}_{95\%}=-$ 0.16 to 1.65) and POST ($P=0.006$, $d=0.58$ $\mathrm{CI}_{95\%}=-$ 0.31 to 1.48). Within-group analysis showed no difference between PRE and POST in both OS ($P=0.663$) and CTRL ($P=0.844$; Fig. 3, panel d).

### Toe-touch test

Figure 2 (panel b) shows the mean PRE and POST values of the toe-touch test determined during CTRL and OS. No time X group interaction was found ($P=0.886$). Statistical analysis showed no differences between OS and CTRL neither in PRE ($P=0.689$) and POST ($P=0.803$) sessions. No difference was found between PRE and POST in both OS ($P=0.460$) and CTRL ($P=0.425$).

## Discussion

The novel findings of the present study demonstrate that acute OS usage increased the time-to-exhaustion, the duration of masticatory muscles contraction, and their EMG amplitude during the strength-endurance test, while no changes occurred in body flexibility. After 8 weeks of OS usage, the improvements in strength-endurance performance persisted but no effects on body flexibility were observed. The present data may suggest that acute and chronic OS utilization influences positively the strength-endurance performance by acting predominantly on neural factors. Differently, the OS use seems not to affect the mechanisms underpinning the flexibility, such as mechanical (muscle tone and stiffness) and neural factors (proprioceptive afferents), neither acutely nor after 8 weeks of intervention.

## Acute OS usage

The moderate increase in time-to-exhaustion during plank with OS was accompanied by a higher masticatory muscle contraction time and electrical activation. Taken together, these findings indicate that during prolonged isometric actions, the increase in the masticatory muscle contraction may help to maximize prolonged tasks. Indeed, the reduction in the myofascial tension and the elongation of the masticatory muscles consequent to the mandibular joint adjustment in forward and vertical direction could have triggered an ergogenic effect and, in turn, an enhancement in strength performance [7, 10, 17, 18, 14]. Moreover, when a high effort is required, people tend to clench their jaw to increase the muscular tension at the neck, thus evoking a modified Valsalva maneuver and increasing the muscle force at the core [14]. Additionally, the simultaneous occurrence of the remote muscles (masticatory muscles) voluntary contraction and the cortical motor overflow has been demonstrated to trigger a neural mechanism known as "concurrent activation potentiation", i.e., an increase in strength performance [14]. The former occurs when the muscles not directly involved in a given task are remotely recruited. Such a recruitment is associated with an enhancement in the amplitude of the spinal and consequently overall neural excitability, thus increasing the force-generating capacity of the agonist muscles [31, 32]. The cortical motor overflow relates to a potentiation of the cortical centers as a consequence of the activation of the motor cortex area [33], which may increase the connections to other cortical areas through a motor overflow of intercortical-communications from one hemisphere to the other [14, 33]. The combination of these two mechanisms may have resulted in an enhancement in the neural drive and an improvement in the strength-endurance performance.

Although OS usage was hypothesized to decrease the muscle tone and the muscle–tendon stiffness of jaw, neck and trunk muscles, with a consequent positive effect on the mechanoreceptors afferents and increase in muscle elasticity [13], the current outcomes do not support such hypothesis as no significant effect on back myofascial tissues was found neither at PRE nor POST. This finding confirms what was previously reported acutely [9, 17] and rules out a possible acute influence of OS on the biomechanical characteristics of trunk muscles and proprioceptive factors.

## Chronic OS usage

The acute OS-induced improvements in the strength-endurance performance found before the intervention occurred to a similar extent after the 8 weeks of chronic OS appliance. This novel finding suggests that the neuromuscular mechanisms involved in OS use, like the concurrent activation potentiation that is likely responsible of these enhancements, do not vary throughout the intervention period neither in a positive nor in a negative fashion. Being this study the first that evaluated the effects of OS appliance on strength-endurance performance throughout a significant time frame, any comparison with previous literature is not possible.

The OS-induced reduction in the neck and trunk muscles tone after the OS intervention may have induced alterations in the mechanical properties of the back myofascial tissue and, similarly to the effect found on postural mechanisms [13], also significant changes in neuromuscular factors, such as a reduction of the afferent feedbacks from muscle spindles, and from the mechanoreceptors. Collectively, these changes might have favored a decrease in back myofascial stiffness and, in turn, an enhancement of the flexibility. However, the lack of any changes in the flexibility test rejects any influence of OS on mechanical or neuromuscular mechanisms underpinning body flexibility characteristics.

The present findings indicated that the acute use of OS positively influences isometric endurance tasks whereas is ineffective to improve body flexibility. An 8 week intervention of OS appliance led to a similar improvement in strength-endurance performance and continued to be ineffective on body flexibility.

## Practical applications

OS appliance has been shown to be a valid aid for promoting biomechanical and neural mechanisms responsible for a strength-endurance performance enhancement. However, no OS impact on body flexibility was observed neither acutely nor after long period usage in expert Pilates practitioners. OS use might therefore be encouraged during the practice of sport activities characterized by these kind of tasks without detrimental effects.

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**Author contributions** Conceptualization: SR, EL, GM, and FE; Literature Review and data collection: SR, EL, MB, and SS; Data analysis: MB, SS, and CD; Statistical analysis: SR. Results Interpretation: SR, GC, SL, JP; Figures Preparation: SR, GC, and MB; Manuscript Preparation: SR, GC, GM, and FE; Manuscript Revision: EC, EL, SL, CD, and JP.

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## Declarations

**Conflict of interest** The authors disclose no professional relationships with companies or manufacturers who will benefit from the results of this study.

**Ethical approval** The local Ethic Committee of the Università degli Studi di Milano approved the study, which was conducted in accordance with the principles of the 1975 Declaration of Helsinki.

**Consent to participate** Informed consent was obtained from all individual participants included in the study.

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