Activity Evaluation of Facial Muscles by Surface Electromyography

Nicolò Bertozzi, MD*
Bernardo Bianchi, MD†
Luana Salvagni, MD‡
Edoardo Raposio, MD, PhD, FICS*

Background: Surface electromyography (sEMG) is an easy, noninvasive, and reproducible way to assess spontaneous electrical activity of muscles in real time. In this study, we report data on the correlation between sEMG and mimetic muscle activity during specific tasks so as to create a case–control reference for future studies on acute, chronic, and congenital facial palsy.

Methods: Twelve healthy participants were enrolled (6 women and 6 men) with a mean age of 42.75 (range, 26–58 years) years. sEMG signals were recorded at rest and while performing voluntary and specific tasks that elicited selective contraction of frontalis, orbicularis oculi, zygomaticus major, orbicularis oris, and platysma muscles simultaneously and bilaterally for each muscle group. Statistical analysis was performed to evaluate if there was a statistically significant difference of the average contraction values between left- and right-side data sets and between male and female participants.

Results: No statistically significant difference was found between male and female participants or between the right and left sides at rest and while performing the requested tasks, even though they were not identical. No participant complained about the procedure.

Conclusions: Interindividual and intraindividual variability of the sEMG signal as well as crosstalk between muscles groups were reported downsides that we did not encounter. The absolute noninvasiveness of our procedure makes it feasible to be applied even to young children. This dataset obtained in healthy participants might also be useful in the observation of patients undergoing regeneration/reinnervation procedure following recently acquired facial palsy or mimetic muscle reconstruction for congenital/inveterate one. *(Plast Reconstr Surg Glob Open 2020;8:e3081; doi: 10.1097/GOX.0000000000003081; Published online 29 October 2020.)*

INTRODUCTION

Facial electromyography (EMG) has been always regarded as the standard diagnostic tool to evaluate the mimetic muscles' function during physiological and pathological conditions.[1] Both surface EMG (sEMG) and needle EMG (nEMG) can be used to register the muscular electrical activity, with different advantages and drawbacks. nEMG can record insertional, spontaneous, and voluntary activities with extremely selective detection capability and sensitivity. Furthermore, needle electrodes do not interfere with small movements as much as surface ones do.[2] Nevertheless, needle electrodes need to be moved for a complete assessment of the muscular activity because electrodes can measure only a small area in the muscles.[3] Needle movements can generate discomfort in patients undergoing nEMG recording; furthermore, large movements provoke more pain, making the recording not well tolerated by adults and children especially.[4] Infections, bleeding, and hematoma formation are also potential reported complications.[3]

sEMG registers the spontaneous electrical activity of muscles from the body surface with a high temporal resolution. It produces a stochastic signal whose amplitude reflects the intensity of muscle activations.[5] It is a noninvasive technique because it requires the use of pre-gelled silver chloride electrodes to make the electrical contact between the skin and the sensor. It is usually well tolerated by patients, even youngest ones. sEMG suffers from a crosstalk with neighboring muscles' activity, which can

interweave with that of the target muscle.[6] Furthermore, even the smallest electrode can potentially interfere with the movements of small muscles such as those of the face.

Nevertheless, it is an easy, noninvasive, and reproducible way to assess the spontaneous electrical activity of muscles in real time, particularly suitable for application to an area where nEMG could be of great discomfort for patients.

In this study, we report data on the correlation between sEMG and mimetic muscle activity during specific tasks so as to create a case–control reference for future studies on acute, chronic, and congenital facial palsy.

MATERIALS AND METHODS

Twelve healthy participants were enrolled (6 women and 6 men), with a mean age of 42.75 (range, 26–58 years) years. Exclusion criteria were a clinical history of neuromuscular disease or a botulinum toxin antiaging treatment received within 6 months from the test. All participants were thoroughly informed about the examination and provided written informed consent; no compensation was given to any volunteers in the study.

sEMG signals were recorded at rest and while performing voluntary and specific tasks that elicited selective contraction of frontalis, orbicularis oculi, zygomaticus major, orbicularis oris, and platysma muscles simultaneously and bilaterally for each muscles group. Signals were obtained with 2 recording channels from 2 monopolar and 1 grounding electrode each. The monopolar electrodes were placed according to the guidelines of Fridlund and Cacioppo,[2] while the grounding one was always kept in the paramedian forehead area (Fig. 1).

The EMG signals were amplified with the MyoScan and recorded with the ProComp Infinity (Thought Technology Ltd) at a sampling rate of 2048 Hz and visualized in real time with a notebook running the Infiniti BioGraph software (Thought Technology Ltd). An impedance check was performed before each recording session. Electrodes were positioned at a fixed 1-cm interspace between them. The notch filter was enabled at 50 Hz and the signal filtered at 90 Hz. Electromagnetic interferences were minimized by keeping every electronic equipment

3 m from the recording device apart from the notebook used for software analysis. Each participant was employed for one research session, lasting only half an hour. At the beginning, the patient was fully informed about the aim of the study and its design to get his/her written consent. After that the volunteer was taught about the specific task that he/she was asked to perform.

Each muscle group was tested simultaneously and bilaterally. EMG recording was divided into 2 phase for each muscle group: first, a resting task for 10 seconds with a neutral expression and then a voluntary movement task for other 10 seconds specific for the assessed muscle, as reported in Table 1. Before recording phase, patients were asked to perform by their own the voluntary tasks while looking at the mirror 1 minute for each movement. This step was done to improve volunteers' ability to perform selective, isolated activation of individual mimetic muscles. This special training aimed also to produce a maximum voluntary isometric contraction for all the 10 seconds of the recording[7] (Table 1) (Fig. 2).

The skin was properly prepared with alcohol wipes before application of electrodes. Electrodes were placed in line with the muscle fibers in accordance to the guidelines of Fridlund and Cacioppo,[2] making sure that they were firmly attached and had the same electrical orientation bilaterally. The cables were immobilized at the thorax of the patients with tapes to prevent them from being pulled or shaken, thus reducing the risk of artifacts. Coupled muscles were tested in the following order: frontalis, orbicularis oculi, zygomaticus major, orbicularis oris, and platysma muscles.

sEMG signals were viewed as raw signals and root mean square to identify the muscles activation timing, their level of activation, and the presence of potential artifacts. An amplitude analysis was performed for each task, recording baseline/resting level, average contraction, peak level, and variability.

Statistical analysis was performed. The Lilliefors test was used to demonstrate whether the data sets had normal distribution. The Wilcoxon–Mann–Whitney was adopted to evaluate whether there was a statistically significant difference of the average contraction values between left and
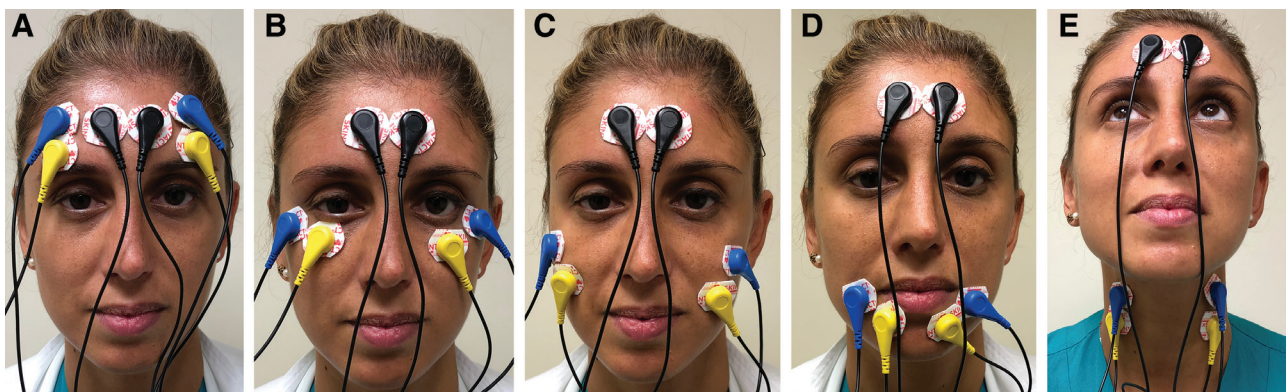

Fig. 1. Monopolar (blue and yellow) and grounding (black) electrodes placement for evaluation of frontalis (A), orbicularis oculi (B), zygomaticus major (C), orbicularis oris (D), and platysma (E) muscles.

Table 1. Summary of the Muscles that Were Tested and the Movement Tasks that Patients Were Asked to Perform for Selective Muscle Activation

Muscles Assessed	Movement Task
Frontalis muscle	Lift brow
Orbicularis oculi muscle	Close eye
Zygomaticus major muscle	Smile
Orbicularis oris muscle	Lip pucker
Platysma	Wrinkling neck skin

right-side data sets within all the population study and between women and men participants.

RESULTS

sEMG signals were recorded at rest and while performing voluntary and specific task from frontalis, orbicularis oculi, zygomaticus major, orbicularis oris, and platysma muscles among 12 healthy participants (6 women and 6 men) whose mean age was 42.75 (range, 26–58 years) years. None had a clinical history of neuromuscular disease, while only 2 reported previous botulin toxin injection to the upper-third of the face (not within the previous 6 months).

The recording sessions were well tolerated by all participants, with no reported discomfort apart from electrode removal from the lid (Figs. 3, 4).

Given the fact that some data sets did not display normal distribution, the nonparametric Wilcoxon–Mann–Whitney test was adopted.

No statistically significant difference was found between right and left side at rest and while performing the requested tasks, even though they were not identical. Furthermore, no statistically significant difference was found between male and female participants. All the data and the statistical analysis are summarized in the tables attached, while the values reported in the histograms represent the average measurements at each session (Tables 2, 3) (Fig. 5).

Fig. 2. Each muscle group was tested simultaneously and bilaterally by asking the patient to produce a specific movement task for selective muscle activation, starting from the rest position (A), lifting the brows for frontalis muscle activation (B), closing the eyes for orbicularis oculi activation (C), smiling for zygomaticus major activation (D), lip puckering for orbicularis oris activation (E), and wrinkling neck skin platysma activation (F).
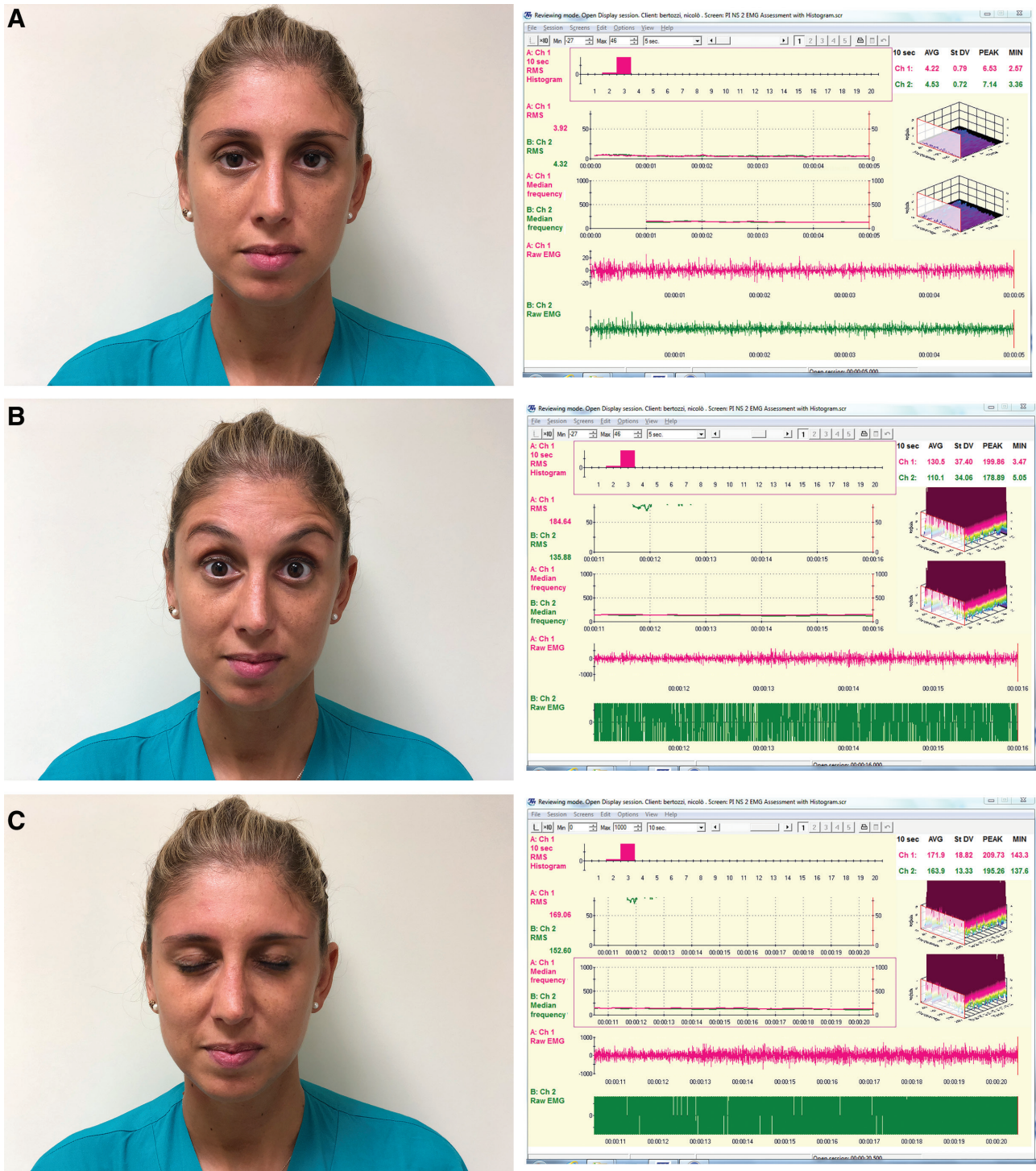
Fig. 3. Examples of sEMG patterns recorded at rest (A) and while lifting the brows (B) and closing the eyes (C).

DISCUSSION

sEMG measures the electrical activity of the muscles with a high temporal resolution and in a noninvasive manner.[1] It can detect the muscle activity before it is even visible and it is directly related to the intensity of the contraction, and the thickness of the muscle belly.

Facial EMG has been always regarded as the standard diagnostic tool to evaluate the mimetic muscles, and sEMG has proved to be a valuable, noninvasive tool in many research and clinical applications.[8–13]

Giving its accuracy, studies are being carried out to create closed-loop facial pacing systems able to detect early the blink activity for real-time pacing via rapid triggering
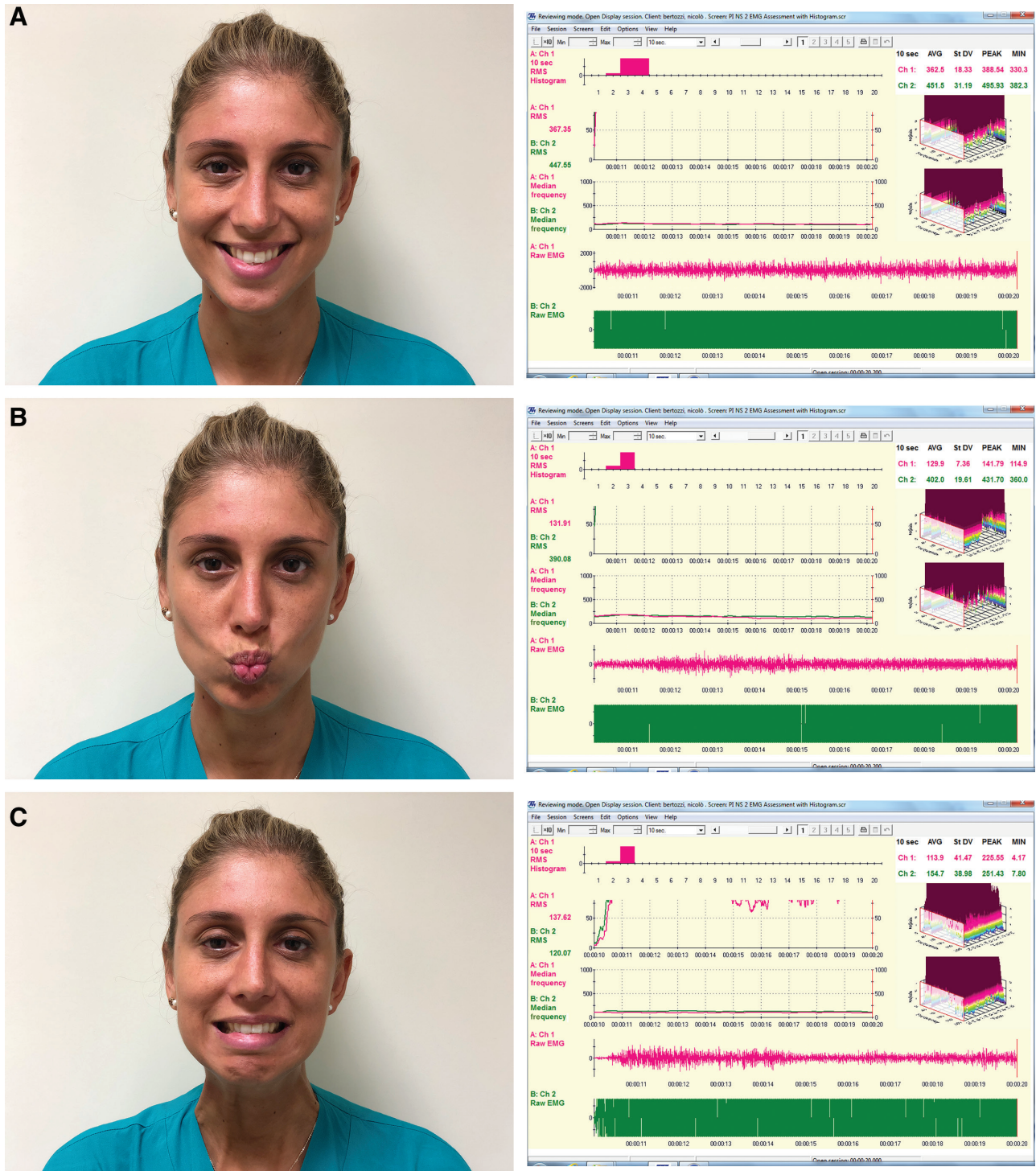
Fig. 4. Examples of sEMG patterns recorded while smiling (A), lip puckering (B), and wrinkling the neck skin (C).

of contralateral muscles in patients suffering from facial palsy.[14–18]

However, sEMG suffers from crosstalk: indeed the electrical activity of neighboring muscles can interweave with those of the target muscle, creating electrical noise, potentially reducing its accuracy.[19,20] Multielectrode sEMG grids can potentially overcome or at least lessen this issue, being able to better correlate muscle activation with its movement. However, the relatively large area occupied by these grids may interfere with muscle contraction. Some authors stated that sEMG is appropriate for superficial muscles recording and that its signal was better than analyzing muscle activity with intramuscular electrodes.[21–27]

Table 2. The Raw sEMG Values Observed and the Results of the Wilcoxon–Mann–Whitney (WMW) Test Performed by Comparing Left- and Right-side Data Sets Obtained from the Study Population

Task	Frontalis Muscle				Orbicularis Oculi Muscle				Platysma Muscle				Zygomaticus Major Muscle				Orbicularis Oris Muscle			
	Rest		Contraction		Rest		Contraction		Rest		Contraction		Rest		Contraction		Rest		Contraction	
	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left
Average	6.9	7.2	85.1	83.5	7.1	7.2	118	118	5.5	6.1	76	65	5.9	5.7	119	147	8.8	7.7	135	194
Median	6.4	5.8	83.1	80	6.2	6.3	98	11.4	5.7	6.3	70.1	48.3	5.5	5.7	97.7	132	6	7.3	97.3	157
SD	4	4.7	42.2	37.6	2.9	2.6	61.2	62.7	2.1	2.7	49.9	39.3	2.9	2.4	67	82.2	7.6	3.9	87.1	135
Min	0.8	3	28.8	32.7	3.4	4	25.8	30	2.1	2.1	15	19.8	2.2	2.7	41.4	50.8	2	2.4	51.8	58.3
Max	15.9	17	174	150	12.5	12	246	261	9.4	9.2	160	131	11.2	11	270	314	29.4	17	316	557
P WMW	>0.05		>0.05		>0.05		>0.05		>0.05		>0.05		>0.05		>0.05		>0.05		>0.05	

The interindividual and intraindividual variability of the sEMG signal is another downside. Indeed, it can differ greatly between subjects (age and type of skin), muscles, electrode placements (on the same muscle), and even from day to day with the same subject.[2,6,28] This interindividual and intraindividual difference can also be related to the variability in location and morphology of mimetic muscles mostly correlated to the complex interindividual variation in facial size and shape.[28] Nevertheless, we found a good correlation between facial muscle positions and fiber orientations in accordance with anatomical textbook.[29,30]

The study we have performed aimed at overcoming the issue of the interindividual and intraindividual variability in the prospective of future clinical application. Indeed, our protocol is an extremely simple, fast (30 minutes), and easy method to assess the mimetic muscle activity. Furthermore, the absolutely noninvasiveness of our procedure makes it feasible to be applied even to young children who otherwise might never undergo nEMG at an early age because of the fear of needles. This dataset obtained in healthy participants might also be useful in the observation of patients undergoing regeneration/reinnervation procedure following recently acquired facial palsy or mimetic muscle reconstruction for congenital/inveterate one. As previously state, sEMG is able to detect also the muscle activity before its contraction. Thus, it might also be able to detect the reinnervation of mimetic muscles following maxillofacial surgical reconstruction even before this becomes complete and able to generate an effective

Table 3. The Raw sEMG Values Observed and the Results of the Wilcoxon–Mann–Whitney (WMW) Test Performed Comparing Left- and Right-side Data Sets Obtained from the Male and Female Populations

Task	Rest				Contraction			
	Right Male	Right Female	Left Male	Left Female	Right Male	Right Female	Left Male	Left Female
Frontalis muscle								
Average	7.3	6.5	6.5	7.9	85	86.1	82.9	84.5
Median	62	6.4	5.2	5.7	79	83.7	74.1	83.5
SD	2.6	1	2.3	1.1	19.1	15.9	17	17.2
Min	4.3	3.9	4.4	5.7	46.7	54.2	55.2	43.2
Max	15.7	10	14.1	11.6	131.2	113.6	99.7	104.2
P WMW		>0.05		>0.05		>0.05		>0.05
Orbicularis oculi muscle								
Average	7.1	7.1	7.2	7.3	128	108.4	135.7	116.6
Median	6	7.6	6.1	6.8	67.3	58	71.2	62
SD	1.9	2	1.9	1.8	24.6	8.8	23.1	10
Min	4.3	4.7	15.2	4.7	882	72.8	100.3	81.1
Max	14.7	19.2	4.05	14.4	187.7	108.5	196.7	121
P WMW		>0.05		>0.05		>0.05		>0.05
Zygomaticus major muscle								
Average	5.9	5.8	5.7	5.7	118.7	119	151.6	142.7
Median	5.5	5.1	5.1	6	101.8	95.5	131.7	124.1
SD	2.3	1.7	2.8	0.9	18.8	20.7	26.2	25.6
Min	12.8	3.7	3.4	3.3	81.35	76.7	95	92.5
Max	2.6	12.3	14.4	8.6	160.6	152.7	193.5	190
P WMW		>0.05		>0.05		>0.05		>0.05
Orbicularis Oris muscle								
Average	10.2	7.38	7.4	7.9	127.8	141.4	163.27	178.1
Median	6.7	5.1	8	6.3	96.3	120	156.6	155.6
SD	2.3	2.5	2.4	2.7	53	25.8	27.3	49.3
Min	6.5	4.2	4.3	4.1	110	88.6	116.28	121.5
Max	18	17.1	18.3	17.1	208.5	220.4	228.7	295.01
P WMW		>0.05		>0.05		>0.05		>0.05
Platysma muscle								
Average	5.6	5.3	6.2	6	78.1	73.9	67.6	62.4
Median	5.1	5.7	7.2	6	63	7.5	58.03	48.3
SD	0.9	1.9	0.8	2.4	20.7	12.8	11.3	11.1
Min	4	3.6	3.5	3.8	56	31.85	46.8	41.2
Max	8.2	12.1	8.2	13.5	135.7	80.5	88.8	85
P WMW		>0.05		>0.05		>0.05		>0.05

Frontalis muscle

Orbicularis Oris muscle

Orbicularis Oculi muscle

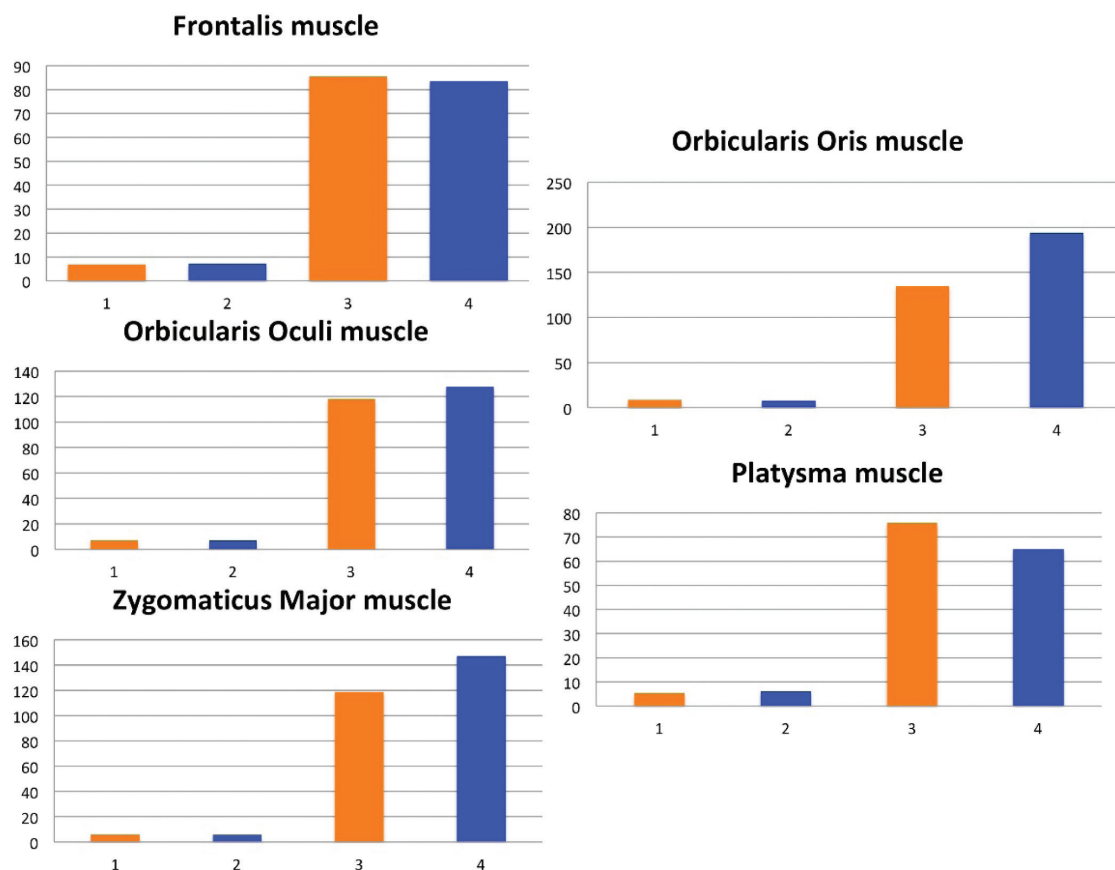## Platysma muscle

Zygomaticus Major muscle

Fig. 5. Mean raw sEMG values. Orange columns, right side; blue columns, left side; 1–2, rest task; 3–4, movement task.

muscle contraction. This capability might have a tremendous impact on the rehabilitation phase because it could anticipate the timing to start logopedics treatment, hence potentially reducing the time required and improving the outcome at the same time. Further studies may be needed with larger volunteer groups; nevertheless, our work can be the starting point to standardize future studies so as to make results comparable.

Edoardo Raposio, MD, PhD, FICS
Plastic Surgery Chair
Department of Surgical Sciences and
Integrated Diagnostics (DISC)
University of Genoa
Plastic and Reconstructive Surgery Division
"San Martino" Hospital
L.go R. Benzi 10
16132 Genova, Italy
E-mail: edoardo.raposio@unige.it

CONSENT
The volunteer provided written consent for the use of her image.

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