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A Survey on the Feasibility of Surface EMG in Facial Pacing

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***Abstract*— A survey on the feasibility of surface electromyography (EMG) measurements in facial pacing is presented. Pacing for unilateral facial paralysis consists of the measurement of activity from the healthy side of the face and functional electrical stimulation to reanimate the paralyzed one. The goal of this study is to evaluate the feasibility of surface EMG as a measurement method to detect muscle activations and to determine their intensities. Prior work is discussed, and results from experiments where 12 participants carried out a set of facial movements are presented. EMG was registered from *zygomaticus major* (smile), *orbicularis oris* (lip pucker), *orbicularis oculi* (eye blink), *corrugator supercilii* (frown), and *masseter* (chew). Most important facial functions that are limited due to the paralysis are blinking, smiling, and puckering. With majority of the participants, crosstalk between the measured EMG channels was found to be acceptably small to be able to pace smiling and puckering based on detecting their contraction intensities from the healthy side. However, pacing blinking based on *orbicularis oculi* EMG measurement does not seem possible due to crosstalk from other muscles, but the electro-oculographic (EOG) signals that couple to the same measurement channel could help to detect eye blinks and trigger stimuli. Futhermore, *masseter* greatly disturbs EMG measurement of most facial muscles, which needs to be addressed in the pacing system to avoid falsely interpreting its activity as the activity of another muscle.**

I. INTRODUCTION

Unilateral facial paralysis causes problems with daily activities such as eating, drinking, and social interaction. Facial pacing refers to prosthetic technology that can reanimate the disabled side of the face. Muscle activations are measured from the healthy side and the corresponding muscles of the disabled one are simultaneously activated, or paced, with functional electric stimulation.

Surface electromyography (EMG) is a measurement method that registers the electrical activity of muscles from the body surface. It produces a stochastic signal whose amplitude reflects the intensity of muscle activations.

The goal of this study is to present a literature survey and experimentally assess the feasibility of surface EMG measurements in facial pacing. Prior work on facial pacing focuses on eye blinks that are a special case of facial movements with limited variation in muscle activation intensity and duration. The presented study provides information whether the crosstalk between facial surface EMG measurements limits the feasibility of EMG in determining activation intensities for the pacing. The study focuses on transcutaneous facial pacing while the measurement and stimulation could also be carried out with percutaneous electrodes.

II. LITERATURE REVIEW

A. Surface EMG

Surface EMG measures the electrical activity of the muscles with a high temporal resolution, enabling detection activity that starts rapidly and has a short duration. Intensities of muscle activations can be determined computationally efficiently [1]. Muscle activity can be detected before it is even visible. However, EMG suffers from crosstalk, i.e. the activity of neighboring muscles and muscles whose fibers interweave with those of the target muscle are also registered [1].

EMG measurements are influenced by several factors that make the interpretation of EMG signal amplitudes problematic. The factors include extrinsic ones, such as electrode configuration and electrode–skin impedance, and intrinsic ones, such as physiological and anatomical characteristics of the muscles. Amplitudes should be normalized to make them comparable between muscles and subjects, and also within subjects at different time instants. Normalization can be carried out by dividing amplitude values with a reference value obtained from the same muscle with the same electrode configuration. The reference value should have a high repeatability. [2]

B. Functional Electrical Stimulation

Functional electrical stimulation operates on the principle that electric charge can activate muscles via their nerves or directly [3], [4]. The nerve is significantly more excitable, and the activation takes place through it whenever possible [3], [4]. The intensity of muscle contraction depends on the amount of charge that is delivered to excite it [3], [4]. Thus, stimulating with a constant-current stimulator that outputs

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the selected current waveform allows controlling the charge and is preferable over a constant-voltage one.

The stimulus waveform has many options from trains of very short (millisecond range) biphasic pulses to longer DC pulses and alternating current waveforms in the kilohertz range [4]–[6]. The stimulation excites sensory nerves the same way as motor nerves, but the sensory threshold is always lower than the motor one [5]. Using waveforms consisting of short, balanced, biphasic pulses is recommended to avoid harmful effects on the skin that monophasic ones may have [4]–[6]. Pulsed currents recruit the muscle fibers through summation, activating only some at first and more when the total amplitude, the pulse repetition frequency, or the pulse width is increased [3], [4].

C. Facial Pacing

The concept of facial pacing, shown in Figure 1, was introduced already several decades ago [7]. Facial pacing systems need to process measured signals and produce stimulation signals in real time. Pacing seems practical only when the facial nerve is only partially paralyzed. Completely denervated muscles might not respond to short biphasic pulses, and are considered to require long DC pulses to be activated [8]. This would result in long delays between the sides of the face. The delay should be minimized in order for the facial expression to be observed as synchronous. Most people notice the delay when it is 33 ms between the sides of the face when observing an eye blink, but longer delays stay unnoticed when the movement is eyebrow lift, lip depression, or smile [9].

Most important facial functions that are limited due to the paralysis are blinking, smiling, and muscle tonus of the oral commissure. Earlier studies have focused on pacing eye blinks based on the EMG measurement of *orbicularis oculi* [10]–[13] or *levator palpebrae* [14] muscle. In addition to detecting EMG activity, these studies also partly rely on detecting baseline changes in the signals, i.e. electrooculographic (EOG) signals and motion artifacts. The stimulation waveforms for activating *orbicularis oculi* to reanimate blinks have been fixed-length trains of biphasic square wave pulses [12], [14]–[16]. Pacing longer eye closures or facial functions that have varying durations and intensities have not been reported.

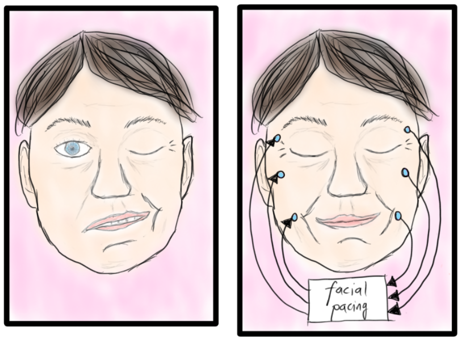


Fig. 1. Principle of facial pacing

EMG measurements in pacing suffer from stimulation artifacts that are distortions caused by the coupling of the stimulation signal to the measurement channels. The artifacts are discussed in studies that deal with pacing eye blinks [10], [12]. Artifacts can be removed with computational methods, and sample-and-hold functionality of EMG amplifiers allow fast recovery after each stimulation pulse [12], [17]. If the EMG amplifiers saturate during stimulation pulses, EMG samples need to be discarded as computational methods can not remove the artifact. The amplitude of the stimulation current affects the amplitude of the artifact, and, thus, it is preferable to use low amplitudes [12], [17]. In pacing, stimulation currents may need to be pulsed to have periods when the stimulation is off and artifact-free EMG can be registered.

III. EXPERIMENTAL STUDY

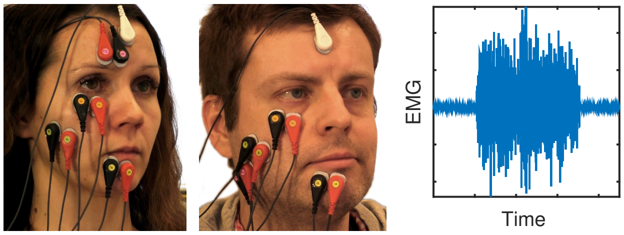
A. Methods

1) Experimental Procedure: Principles outlined in the Declaration of Helsinki of 1975, as revised in 2000, were followed in the experimental study. Twelve healthy volunteer participants (6 females, 6 males) participated in the experiments. Their age ranged between 31 and 55 years (39.3 ± 7.3 years).

The experiments were conducted in two phases. In the first one, the participant performed voluntary smile, lip pucker, and frown movement tasks while EMG signals from *zygomaticus major*, *orbicularis oris*, *orbicularis oculi*, and *corrugator supercilii* were measured. Second phase included the measurement of *zygomaticus major*, *orbicularis oris*, *orbicularis oculi*, and *masseter* while the participant performed smile and pucker movement tasks while chewing a gum. Both phases had resting tasks between the movement tasks. The resting task was a neutral expression in the first phase, but included chewing in the second one. Phases started with a 1-minute-long resting task. Then 10 repetitions of each movement task were performed in randomized order. Each task lasted for 6 seconds. The movements were instructed to be performed as naturally as possible for the time that an on-screen instruction was visible. Instructions regarding movement intensities were not given.

EMG signals were measured with a NeXus-10 physiological monitoring device (Mind Media BV) at a sampling rate of 2048 Hz. The measurements were bipolar using pregelled, sintered Ag–AgCl electrodes. A separate grounding electrode was used on the forehead, and the electrodes were placed according to the guidelines of Fridlund and Cacioppo [1] as shown in Figures 2a and 2b. *Corrugator supercilii* was left out from the second phase of the experiments because the measurement device only had 4 channels, and the muscle is not as important in facial pacing as the others are. The experiments were recorded with a digital video camera.

2) Data Analysis: The raw EMG signals were processed to compute EMG amplitude estimates. 8th order Butterworth filters implemented as zero-phase forward and reverse ones were used to remove 50 Hz power line noise and to limit the signal frequencies to the range of 20–500 Hz. Root mean



(a) First phase (b) Second phase (c) EMG example

Fig. 2. Electrode placement in the experiments and EMG signal example.

TABLE I

Percentages of participants ($N = 12$) with statistical differences ($p < 0.05$) in the EMG RMS values of the channels between the facial movement tasks.

Task vs. task		*corrugator supercilii*	*zygomaticus major*	*orbicularis oris*	*orbicularis oculi*	*masseter*
smile	neutral	8	100	8	75	-
	pucker	50	100	92	50	-
	frown	100	100	0	67	-
	chew	-	67	92	83	-
	chew & smile	-	92	92	92	-
	chew & pucker	-	75	100	75	-
	eye blink	0	100	8	42	-
pucker	neutral	25	17	92	67	-
	frown	100	25	92	25	-
	chew	-	67	100	67	-
	chew & smile	-	92	92	83	-
	chew & pucker	-	83	92	100	-
	eye blink	50	17	92	8	-
frown	neutral	100	0	0	17	-
	chew	-	92	92	100	-
	chew & smile	-	100	92	92	-
	chew & pucker	-	92	100	92	-
	eye blink	100	8	0	58	-
chew	neutral	-	92	92	100	-
	chew & smile	-	83	42	83	42
	chew & pucker	-	33	92	75	33
	eye blink	-	92	92	67	-
chew & smile	neutral	-	100	92	100	-
	chew & pucker	-	75	92	83	17
	eye blink	-	100	92	92	-
chew & pucker	neutral	-	92	100	100	-
	eye blink	-	92	100	92	-
eye blink	neutral	8	0	0	92	-

square (RMS) values of the filtered signals were computed for each movement and resting task to estimate the EMG amplitudes. RMS values were also computed for the first half (the muscle contraction phase) of each eye blink that was determined based on the video recordings. Only blinks during neutral expressions were included.

Outlier removal was done for the RMS values of the neutral expressions to remove possible unwanted muscle activations in them. RMS values below and above 1.5 times the interquartile range from the lower and upper quartiles, respectively, were removed. Outliers were not removed from the other tasks that had only 10 repetitions or from the eye blinks.

One-way analysis of variance (ANOVA) was used to test for differences between the means of the RMS values of the tasks. This was done separately for each channel of each participant. If the test revealed a difference, multiple comparison procedure with the Tukey-Kramer method was computed to find out which movements had differing RMS values.

B. *Results and Discussion*

An example EMG signal registered during a muscle activation is shown in Figure 2c. Percentages of participants that had statistical differences in the EMG RMS values between the tasks are shown in Table I. The RMS values of all the participants have been combined for illustration in Figure 3 even if the values between subjects are not directly comparable.

The crosstalk between the EMG measurements of the targeted facial muscles can be assessed based on the results. Smiling produced *zygomaticus major* RMS values that differed with statistical significance from the neutral expression and the other movements in all cases when the ones involving chewing are excluded. Some elevated RMS values for *zygomaticus major* were also registered during puckering which indicates that the *orbicularis oris* couples to the measurement or is activated in some cases.

With most participants, puckering produced elevated *orbicularis oris* RMS values compared to the neutral expression and other movements except the ones with chewing.

Crosstalk was not seen to have a major effect on the *corrugator supercilii* measurement. Frowning produced RMS values that differed from the neutral expression and the other movements with statistical significance. Some other movements also produced elevated values. This happened mostly during puckering because the *corrugator supercilii* was sometimes simultaneously activated.

Orbicularis oculi results show that the electrical activity of other muscles disturb the measurement. Thus, *orbicularis oculi* EMG can not provide a reliable detection of eye blinks, but simultaneously measured low-frequency EOG signal could help. This is supported by earlier findings where eye blinks have been detected with a good performance from EMG/EOG measurement with electrodes positioned on the superomedial quadrant of the *orbicularis oculi* muscle orbit [13].

Chewing introduced a crosstalk from the *masseter* muscle to the *zygomaticus major* measurement so that RMS values higher than those caused by smiling alone were registered. Crosstalk was also significant in *orbicularis oris* and *corrugator supercilii* measurements. However, the experimental setup did not provide information about the coupling of *masseter* activity to *corrugator supercilii* measurement.

IV. CONCLUSIONS

The literature review shows that studies on facial pacing have focused on normal blinking, but ones on pacing other facial movements that have more variety in intensities and durations have not been reported.

The experimental results show that EMG measurements can provide the necessary information for pacing other move-

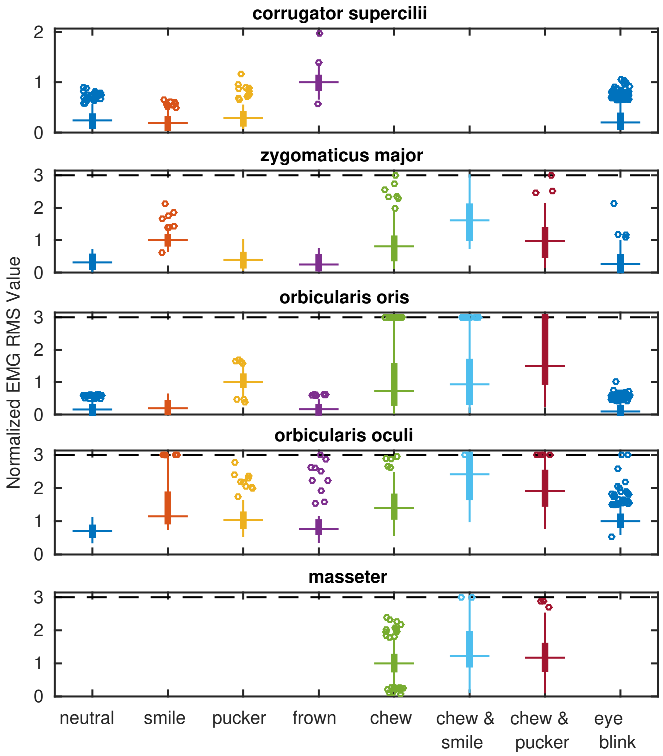


Fig. 3. Normalized EMG RMS values during the facial movement tasks, all participants combined. The values are normalized separately for each muscle and each participant by dividing them with the median value computed for the reference movement that was: frown for *corrugator supercilii*, smile for *zygomaticus major*, pucker for *orbicularis oris*, eye blink for *orbicularis oculi*, and chew for *masseter*. Horizontal lines are the medians, boxes extend from lower to upper quartiles, whiskers reach the maximum value not considered an outlier, and circles are outliers (below and above 1.5 times the interquartile range from the lower and upper quartiles, respectively). The extreme values were clipped at the dashed line and are shown right after it.

ments than blinking. The crosstalk between EMG measurements of facial muscles during smile, lip pucker, and frown movements was found to be acceptably small. However, in line with earlier findings [18], chewing produced strong crosstalk from the respective muscle to the measurements of other facial muscles. This sets requirements for the pacing system to avoid falsely stimulating other muscles while chewing.

A limitation of the presented study is that EMG signals were compared by using the per movement RMS values. In practice there may be short periods of time when there is more crosstalk than the computed RMS values reveal.

Future research includes developing real-time pacing of other movements than blinking. The pacing should be reliable and unaffected by stimulation artifacts. Pacing blinks is a special case that can be carried out by triggering a fixed stimulus waveform, but pacing other movements could be carried out by continuously stimulating with a stimulation waveform that is amplitude or frequency modulated based on detected muscle contraction intensities.

OPEN DATA

The experimental data and its processing are available at http://urn.fi/urn:nbn:fi:csc-kata20160519232206569792.

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