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Artificial Eye Blink Pacemaker - A First Investigation into the Blink Production Using Constant-interval Electrical Stimulation

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Abstract— **Facial paralysis due to damage of the facial nerve affects the function of facial muscles, including the muscles responsible for eye blinking. The absence of the eye blink can lead to severe and permanent corneal damage as the protection and lubrication of the eye is decreased. Thus, it would be highly important to provide an aid to sustain the eye health. The present aim was to study the effects of long-term electrical eye blink stimulation using a facial stimulation prototype. Five healthy participants watched a movie for 78 minutes, while the eye blinks were produced to their left eye by pre-programmed, timer-triggered blink stimulation at fixed intervals. We analyzed the functionality of the stimulation prototype, potential changes in the quality of the produced blinks, and the ratings of experiences in terms of pain, discomfort, and naturalness. We also analyzed the acuity of vision before and after the stimulation. The results showed that the stimulated eye blink was rated as not painful, somewhat uncomfortable, and slightly unnatural. With three participants the stimulation evoked a full eye closure throughout the study, and with two participants, the stimulation evoked partial blink after some time. Further, on four of the cases, the vision of the stimulated eye was better after the movie than before it. The participants told that the stimulation did not disturb the movie watching. As the findings were promising, the next steps include more comprehensive tests both with intact participants and with persons having an acute facial paralysis.**

Keywords— **Eye blink, electrical stimulation, facial pacing, facial paralysis**

I. Introduction

Facial paralysis is a condition where the functions of facial muscles become impaired due to nerve damage. In most cases, the paralysis is unilateral, thus paralyzing one side of the face while the intact side functions normally. Yet, in some rare cases, the facial nerve damage can be bilateral. The most prevalent form of unilateral facial paralysis is Bell's palsy [1]. The annual prevalence for Bell's palsy is 20–30 cases per 100,000, thus affecting about one in 60–70 people in their lifetime [1]. Approximately 70% of patients will fully recover within three months, while the rest remain with facial dysfunctionalities of varying degrees [2]. Other causes for facial paralysis leading to continued or permanent facial deficits include trauma, infections (e.g., borreliosis and herpes zoster), tumors, surgical interventions, and congenital paralysis.

Unilateral paralysis results in many problems including asymmetry of social expressions and problems in basic functions such as speaking, eating, drinking, and eye blinking. As the eye blink has a crucial role in enabling clear vision, protecting, lubricating and cleaning the eye, the absence of it can lead to severe and permanent corneal damage. Typically, the treatment consists of the use of lubricant eye drops and in more severe, chronic cases, of surgery resulting in altered facial appearance (e.g., gold weight attached to the upper eyelid or eyelids sewed together). Surgery always includes also a risk of complications.

The aim of this study was to pre-evaluate the functionality and subjective experiences of noninvasive, long-term, timer-triggered blink stimulation with intact participants prior to clinical trials. This type of a system could potentially improve the quality of life especially during the acute phase of the facial paralysis when the prognosis of the recovery is still uncertain.

A. Facial pacing methods

Recently, a method called facial pacing has been studied to regain lost facial functions related facial paralysis. Typically, facial pacing refers to the idea where facial activity is measured from intact side of the face and this measurement is then used to electrically stimulate facial muscles of the paralyzed side to create more symmetrical facial behavior in terms of timing and intensity. These are called as closed-loop methods.

In closed-loop methods, the system detects eye blink -related signals from the healthy side of the face in order to trigger concurrent blink on the paralyzed side eye. The measurement methods include, for example, electromyography (EMG), electrooculography (EOG), and the use of infrared (IR) emitter-sensor pair or gyroscopic sensor in detecting eye closure [3, 4, 5, 6]. Previous studies have shown that stimulation of the *orbicularis oculi* muscle and/or facial nerve branches using transcutaneous electrodes can be useful in restoring eye blink in about 50% of the cases [7]. On the other hand, the results have shown that reliable detection of eye blinks is challenging even in controlled laboratory settings. Further, the proposed closed-loop methods do not function in bilateral paralysis.

B. Open-loop stimulation control

In thinking purely the needs of patients from medical perspective, that is, saving the eye, the above type systems may be unnecessarily complex. Still further, creation of symmetrical eye blinking is not the first concern in the acute phase of a paralysis. A realistic alternative for closed-loop systems that has not yet been studied, is to create an open-loop system. The open-loop method is, by definition, more straightforward than its closed-loop equivalent given that the feedback module (i.e., real-time physiological measurement and data analysis apparatus) is replaced by a pre-programmed timer, which triggers the eye blink stimulations at a fixed pace.

In this study, the average biological and neuropsychological blinking parameters were utilized in determining the key parameters for the open-loop stimulation. Average blinking frequency varies individually from less than two up to 30 blinks per minute, being typically about 12–20 blinks per minute under neutral conditions [8]. In addition to individual differences, task related factors affect the blinking rate. For example, conversation may increase the blinking frequency, whereas visual tasking, such as visual terminal display work, lowers the frequency [8]. The duration of blink is also individual, but the duration of a typical blink is approximately 100–400 ms [9].

C. Aims and research questions

The current study investigated the functionality of a constant-interval open-loop (i.e., timer-induced) stimulation in eye blink production. The emphasis was to study the functionality of our stimulation prototype (http://www.uta.fi/sis/tauchi/projects/mimeface.html) and subjective experiences while using a unilateral eye blink pacemaker for a longer time period. In the previous studies, the blink stimulation sessions have been relatively short. To obtain first-hand information on longer periods of stimulation, we stimulated the blink for 78 minutes, which is an average length of a typical movie. The aim was to explore if the quality of the stimulated blink alters as a function of time (e.g., decline due to habituation or muscle fatigue [10]). In addition, we collected ratings of experienced levels of pain, discomfort, and the naturalness of the artificially produced eye blinks.

It has been hypothesized that dry eye syndrome caused by reduced blink rate (e.g., while watching a video display) is associated with situationally impaired visual acuity [11]. Therefore, we were also interested to know whether the visual acuity changes as a result of the forced eye blinks.

II. Methods

Participants: Five healthy male volunteers (including one of the authors) from the staff of the local university took part in the experiment. Their age ranged between 26 and 55 years (mean 39.2 years, SD 11.8 years). Three of them had some previous experience with electrical stimulation of muscles (e.g., transcutaneous electrical muscle stimulation). All the participants use computer display(s) several hours during their normal workday. All participants signed an informed consent form before their participation. The study was accepted by the ethical committee of Pirkanmaa Hospital Disctrict (R15067) and it followed the principles outlined in the Declaration of Helsinki of 1975, as revised in 2000 and 2008. The participation was compensated with a movie ticket.

Equipment and stimulation parameters: Our pacing device includes four amplifiers for EMG measurement and four for functional electrical stimulation. In the current study, we used only the stimulation functionality. The device communicates wirelessly through Wi-Fi connection with PC, which was also used to adjust the stimulation parameters (for details, see [12]). The stimulation waveform used in this study was a biphasic square wave with symmetric positive and negative phases (equal width, equal amplitude) using phase duration of 0.4 ms and 250 Hz pulse repetition frequency. Pulse train duration was 200 ms with ramping time of 80 ms (Fig. 1, left). The commercial, disposable stimulation electrodes made from carbonized rubber were cut approximately to a size of 1.9-cm². The electrodes were attached to the skin above the *orbicularis oculi* muscle. The first electrode was positioned 0.5 cm lateral to the orbital rim and the other was positioned about 0.5 cm from the first one (Fig. 1, right). A Panasonic HC-V750 digital video camera recorded the participants' face at 50 frames per second.

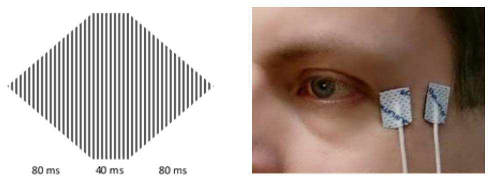

Fig. 1 Left: Illustration of the used stimulation pulse. The current is ramped up to a maximum intensity for 80 ms, it remains at the maximum for 40 ms, and is ramped down for 80 ms. Right: Attachment of the stimulus electrodes.

Procedure: When a participant arrived, the experimenter explained the aim of the experiment and the participant filled out an informed consent form, consent form for the use of video material, and a background questionnaire. Then, a vision test was performed with a three-meter eye chart. After the vision test, the participant was seated in a comfortable armchair and stimulation phase begun. Before the *orbicularis oculi* stimulation, the muscle of the thenar eminence of the left hand was stimulated in order to familiarize the participant to the stimulation, and the rating scales were explained. Following this, the stimulation electrodes were attached above the *orbicularis oculi* muscle. The stimulation was started from 0.5 mA and it was repeated five times at each amplitude level. The amplitude of the stimulation was increased in 0.5 mA intervals until an eye closure (i.e., a complete blink) was evoked. After this, it was ensured from the offline video that a full eye closure was evoked. Then, using this personal amplitude level, the stimulation was repeated five times with the five-second inter-stimulus interval and the participant was asked to evaluate the painfulness and discomfort of the stimulation, and the naturalness of the movement evoked by the stimulation. The pain and discomfort rating scales ranged from 0 (not at all painful/discomfortable) to 10 (extremely painful/discomfortable). The movement naturalness scale was an eleven-point bipolar rating scale varying from -5 (unnatural) to +5 (natural), with 0 representing the neutral point (neither unnatural nor natural) of the scale.

Then, the participant watched a movie for 78 minutes from an 18.5" Samsung SyncMaster 933HD LCD television, which was centered approximately at the participants' eye level and set at one-meter watching distance. During the movie, the *orbicularis oculi* was stimulated at five-second intervals resulting in a total of 900 stimulations. After the movie, the participant evaluated again the painfulness, discomfort, and the naturalness of the stimulation. Finally, the vision test was performed again. Before leaving, the participant was interviewed about the following topics: did he notice the stimulation, did it disturb watching, did the feeling about the stimulation change over the time, and was the stimulated blink rate appropriate. The experiment took approximately two hours in total.

III. Results

The stimulation functioned reliably for every participant for the duration of the whole experiment. The average current to evoke a complete eye blink was 3.2 mA (range 3.0–3.5 mA) in the beginning of the experiment. Offline frame-by-frame analysis of the video recordings for every ten minutes showed that with three participants the stimulation evoked a full eye closure throughout the study. With one participant, the stimulation evoked a full eye closure at the beginning, but after twenty minutes the blink was partial so that eyelid covered the pupil. With another participant, the stimulation evoked a complete blink only at the beginning of the study. Already after ten minutes, the stimulated blink was incomplete, reaching the pupil center, and after 50 minutes, the stimulation evoked only a twitch blink, meaning a small movement of the upper eyelid. After the experiment, these two participants spontaneously reported that the stimulated eye blink felt somewhat incomplete towards the end of the movie.

The Figure 2 shows the averaged pain and discomfort ratings for the blink stimulation. At the beginning of the experiment, the participants rated the stimulation as not painful but somewhat uncomfortable. Both the discomfort and pain ratings were lower after the movie than before it.

On average, the participants rated the movement evoked by the stimulation as mildly unnatural before the movie. After the movie, the ratings were somewhat lower as can be seen from the Figure 3.

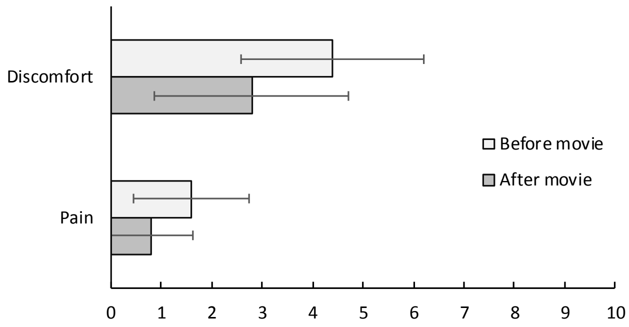

Fig. 2 The average discomfort and pain ratings (±SDs) for blink stimulation before and after movie.

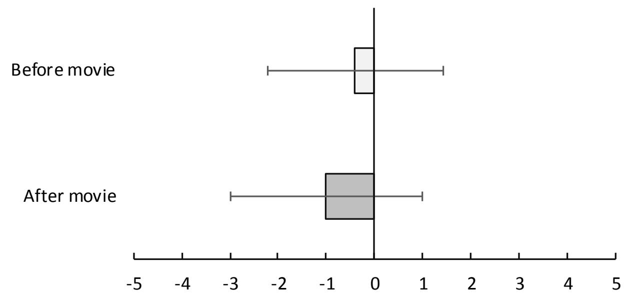

Fig. 3 The average naturalness ratings (±SDs) for blink stimulation before and after movie.

Table 1 presents the results of the vision tests before and after the movie. For four of the participants, vision of the left (i.e., stimulated) eye was better after the movie than before the movie. The vision of the right (i.e., reference) eye remained the same (three participants) or was decreased (two participants) during the movie.

In the semi-structured interview, the participants reported that they noticed the stimulation but it did not disturb the watching. In addition, they told that they got used to the stimulation, and sometimes they even forgot the stimulation. Two participants experienced the stimulated blink rate as too frequent, while the others thought that the rate was appropriate.

Table 1 Vision test results before and after watching the movie.

Participant	Left (stimulated) eye vision		Right (reference) eye vision	
	Before movie	After movie	Before movie	After movie
1	0.7	0.9	1.0	0.9
2	0.7	0.8	0.7	0.7
3	0.7	1.1	0.9	0.9
4	0.9	1.1	1.1	1.1
5	0.9	0.8	1.0	0.9

IV. Discussion and conclusions

The present findings from using open-loop eye blink stimulation were promising. The results confirmed the earlier findings that transcutaneous electrical stimulation can evoke an eye blink without painful sensation [7]. However, the present study was the first to examine longer period stimulation. Interestingly, the results showed that the ratings of painfulness and discomfort caused by the stimulation did not increase over the time. On the contrary, these ratings got even slightly lower after the movie than before it. The participants' comments after the experiment supported this finding. They told that they got used to the stimulation and sometimes it was even unnoticed. The participants rated the naturalness of the stimulated blink as mildly unnatural. One cause for this may be that some participants experienced the stimulated blink rate as too frequent as compared with their own natural blinking frequency.

Previous studies have shown that visual tasks lower the blinking frequency [8]. Further, excessive evaporation of tear fluid caused by decreased blinking has been proposed to be a major cause for visual task -associated drying of eyes [11]. Dry eyes further cause corneal discomfort and blurred vision [8]. Curiously, our results showed a tendency in which the vision of the non-stimulated eye remained the same or decreased during the movie watching whereas the vision of the stimulated eye got better. All of the participants were video display terminal workers, thus, belonging potentially to the group with higher incidence of dry eyes [8]. The number of the participants was small and further studies are needed, but it is possible that the stimulation-evoked eye blinks helped to keep or even restore the normal corneal lubrication affecting further the visual acuity.

The results revealed that with three out of five participants the stimulation evoked a full eye closure throughout the study. With two participants, the stimulation evoked attenuated (i.e., partial) blink after some time. Further studies are needed to investigate the reason behind this. However, possible explanations include, for example, changes in the electrode contact or muscle fatigue. The involvement of motor units evoked by electrical stimulation contractions differs significantly from the spontaneous blink activation, causing greater and earlier muscle fatigue [10]. In the future, it is possible to study the effects of the longer inter-stimulus interval allowing longer recovery time for the muscle fibers or the effects of other type of the stimulation waveform.

In conclusion, the open-loop blink stimulation method was found functional and it was experienced primarily positively after a relatively long visual task. Our next steps include more comprehensive tests both with intact participants and with persons having an acute facial paralysis.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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