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“MigraineMonitor” – Towards a System for the Prediction of Migraine Attacks using Electrostimulation

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Abstract: Migraine attacks can be accompanied by many different symptoms, some of them appearing within 24 hours before the onset of the headache. In previous work, reduced habituation to an electrical pain stimulus at the head was observed in the pre-ictal phase within 24 hours before the headache attack. Based on these results, this work presents an application to track influence factors on migraine attacks and an Arduino-based control unit which replaces the traditional approach of manual electrical stimulation. The usability of both components of the project was evaluated in separate user studies. Results of the usability study show a good acceptance of the systems with a mean SUS score of 92.4. Additionally, they indicate that the developed control unit may substitute the current manual electrical stimulation. Overall, the designed system allows standardized repeatable measurements and is a first step towards the home-use of a device for establishing a new method for migraine prediction.

Keywords: migraine prediction, migraine tracking, premonitory symptoms, electrostimulation, smartphone application

1 Introduction

About 10% of the population worldwide suffers from migraine [1]. Migraine is characterized by a unilateral, mostly throbbing pain, which arises episodically and can be accompanied by a visual aura. Even though several drugs exist for the treatment of migraine attacks, studies have shown that medication is most effective if taken at an early stage before the first

headache symptoms occur [2, 3]. Therefore, an accurate prediction of an upcoming migraine attack is crucial. As patients describe premonitory symptoms, like loss of concentration, that can occur up to 24 hours before an attack, these symptoms might be used for the prediction of migraine attacks [4].

In the past, research groups used different approaches for the prediction of migraine attacks. For instance, Kropp and Gerber analyzed the increase of contingent negative variation (CNV) amplitude before an attack, recorded in response-time tasks using a warning stimulus [5], whereas Giffin et al. recorded electronic diaries in a three month study, documenting premonitory, non-headache symptoms [4]. Various companies already offer websites or smartphone applications to track these premonitory symptoms and outside influences on migraine attacks. The website “Migräne Radar” e.g. represents a platform where users can report migraine attacks in specific geographic regions [6]. The application “M-sense” implements a diary function, which supports the users in documenting changes in nutrition, sleeping patterns and environmental influences, e.g. weather data [7]. However, since premonitory symptoms, like loss of concentration, are often not specific, a reliable prediction is hard to be made from these data.

Therefore, Strupf et al. introduced a new approach for migraine prediction [8]. Previously, a lack of habituation to a longer lasting heat stimulus was observed as a unique symptom for the time period preceding a migraine attack (pre-ictal phase) [9]. However, standardized heat stimuli are not easy to apply with a small home-use device. Thus, Strupf et al. used adaptation to electrical stimulation to analyze the pain perception in various areas of the head during different migraine phases. Results showed, that the habituation of migraine subjects to the electrical stimulus was absent in the pre-ictal phase differentiating them from healthy volunteers [8]. However, repeated usage showed, that the control of the clinical electrostimulator is complicated and time consuming, and can furthermore only be performed by authorized staff. Therefore, it is necessary to standardize the procedure and at the same time minimize the risk of human error. Additionally, a wearable device has to be developed in order to acquire data in everyday situations and therefore enable a more accurate prediction of migraine attacks by creating a larger dataset.

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Small portable electrostimulators for patients to be used at home, such as TENS devices (transcutane electrical nerve stimulation) are already a commercially available way to reduce pain, for example for acute lower back pain or recurrent headache [10]. Since the devices are not supposed to create pain, the settings, such as current, frequency or pulse width have been restricted [10]. Furthermore, electrostimulation is used by NEMS devices (neuro electrical muscle stimulation) for the stimulation of muscles rather than nerves in order to build up muscles, e.g. during periods of immobilization [11]. However, those devices do not meet the requirements for this application and thus, a new system for electrostimulation needs to be developed.

The aim of this project is to create a new approach of a solid migraine prediction through combining a diary of premonitory symptoms and daily self-administered electrical stimulation measurements. As a first step this work presents an Arduino-based control unit for standardizing the manual electrostimulation. Secondly, an Android application is introduced for the documentation of pain ratings and other parameters from the electrostimulation. By combining it with documentation features from other migraine applications, the acquired data can be set into context in order to provide more meaningful information. Both systems are evaluated in respect to their usability based on the system usability score (SUS) [12].

2 Methods

2.1 Control Unit

To replace the manual stimulation procedure used by Stupf et al., a control unit was designed to automatically control the stationary clinical electrostimulator. For this work a Digitimer DS5 (Digitimer Ltd, Welwyn Garden City, UK) electrostimulator was used. An external controller can be attached to the analog frontend of the electrostimulator via BNC socket. Therefore, manual handling of the stimulator becomes obsolete and human influence can be minimized. The developed control unit consists of an *Arduino Uno* microcontroller, combined with a 2.8" touchscreen at a resolution of 240 x 320 pixel. The control signal for the electrostimulator is generated by the microcontroller via pulse-wave modulation (PWM) and translated to an analog output signal using a digital-to-analog-converter (DAC) with a resolution of 12 Bit.

Using the touchscreen, the subjects is guided through the stimulation process. All acquired data are stored to an EEPROM. After the study, data can be read out and transferred to a computer via USB for further analysis.

2.2 Smartphone Application

The smartphone application “MigraineMonitor” meets two requirements: Firstly, it collects user-specific data about visual and auditory perception, mood changes and physical stress. Using the Yahoo weather API [13], the application stores weather influences, including temperature and air pressure. Furthermore, the user can report migraine attacks with additional information about duration, localization and strength of the headache. The user can additionally indicate medication and side effects and save the results from the electrostimulation procedure. Acquired data is stored to the smartphone in SQLite databases and can be exported for the study supervisors as csv files. After a large dataset has been collected and recorded by the application, the study supervisors can evaluate factors that may influence individual migraine attacks and verify the assumption that the electrical stimulation of migraine patients can indicate attacks.

3 Evaluation

3.1 Control Unit

The touchscreen-based control unit was evaluated with 15 healthy subjects (44% female, age 32 ± 13 years ($M \pm SD$)). The study consisted of a comparison between the manual system, used by Stupf et al., and the control unit, designed in the course of this work. For the manual procedure, another electrostimulator (Digitimer DS7) was used because it does not possess an analog voltage input and can only be controlled manually through a current regulator. Both stimulators (DS5 and DS7) are employed in the clinical field within studies for electrostimulation and each device operates with different internal impedances. The order of stimulation was randomized between the subjects. The stimulation procedure was similar to the approach of Stupf et al. [8]: A small electrode was applied successively to four different positions on the head (frontal and temporal on each side). At first, the pain threshold was determined by applying rectangular pulses at a frequency of 2 Hz and a duration of 500 μ s. The current was linearly increased starting at 0 mA in steps of 0.08 mA/s until the stimulation was perceived as painful by the subject. The procedure was repeated three times, and the pain threshold was computed as the average current amplitude out of the three iterations. Afterwards, a suprathreshold stimulation was performed by applying the pain threshold in rectangular pulses with a frequency of 100 Hz and a duration of 5 s. Afterwards, the subject rated the pain perception of the suprathreshold stimulation at the beginning and the end of the stimulation on a scale from 0 (no pain)

to 10 (maximum imaginable pain). The whole procedure was repeated for all four electrode positions on the subject's head. The evaluation included a usability survey based on the system usability scale (SUS) [12]. A system's usability is considered above average, if it scores higher than 68 out of 100 [12].

3.2 Smartphone Application

The application's usability was evaluated independently from the control unit within a separate study of 21 subjects (71% female, age 31 ± 13 ($M \pm SD$)), who tested the migraine diary function over a period of two weeks. Users were required to track migraine attacks and to document daily mood changes. At the end of the evaluation period, subjects were asked to evaluate the usability of the control unit by filling out the SUS questionnaire. Additionally, headache sufferers were supposed to rate the usability during a headache attack in comparison to periods without headaches on a scale from 1 to 5 (1 = equal usability compared to pain-free period, 5 = usage impossible).

4 Results

4.1 Control Unit

Results show that ratings at beginning and end of the suprathreshold stimulations of the standard, manual procedure were higher throughout all electrode positions than using the control unit, as depicted in Table 1. Using an ANOVA test with a significance level of 5%, the procedures showed a significant difference regarding the pain rating at the beginning ($p = 4.11 \cdot 10^{-3}$) and the end ($p = 2.71 \cdot 10^{-3}$) of the suprathreshold stimulation. Since all subjects rated the perceived pain higher at the beginning of the stimulation than in the end, the pain rating differences were negative throughout all patients. As visualized in Figure 1, the average differences of the manual procedure show higher deviations than the control unit. However, the ANOVA test did not show any significant differences ($p = 0.651$). For the usability evaluation, the control unit reached a SUS score of 93.16 ± 5.02 ($M \pm SD$).

4.2 Smartphone Application

Overall, the application reached a SUS score of 91.67 ± 6.96 ($M \pm SD$). During the two week evaluation of the smartphone application, 11 out of 21 users indicated to suffer from headaches regularly, including five participants with migraine attacks. All subjects suffering from headache rated the usability of the application during an attack similar to a headache-

Tab. 1: Pain ratings of suprathreshold stimulation ($M \pm SD$)

	beginning		end	
	Arduino	Standard	Arduino	Standard
<i>temple left</i>	4.5 ± 1.5	5.5 ± 1.7	2.3 ± 1.0	4.4 ± 1.8
<i>temple right</i>	4.7 ± 1.8	5.3 ± 1.9	2.5 ± 1.1	2.9 ± 1.6
<i>forehead left</i>	4.3 ± 1.5	5.2 ± 1.9	2.2 ± 0.9	3.3 ± 1.5
<i>forehead right</i>	4.3 ± 1.8	5.2 ± 1.7	2.5 ± 1.2	2.7 ± 1.7

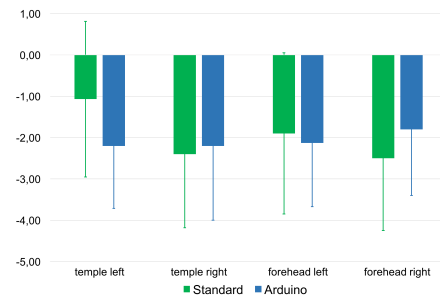


Fig. 1: Differences between pain ratings at end and beginning of suprathreshold stimulation

free period. Among subjects suffering from migraine, the difference in usability between periods with headaches and periods without headaches was 1.6 ± 0.8 . In comparison, users with regular headache rated the difference 1.83 ± 0.69 . Results of the SUS questionnaire showed that the average responses to the question "I think that I would use this system frequently" were considerably worse (2.71 ± 1.41) compared to the average score of all other questions (3.77 ± 0.52).

5 Discussion

5.1 Control Unit

As visible from the results, clear differences were observed between the manual and the standardized procedure. On average, the five second suprathreshold stimulation was rated higher and therefore more painful for the manual stimulation than using the control unit, as depicted in Table 1. According to the feedback of the subjects, the stimulation current increased more rapidly when controlled by the study nurse and therefore subjects were not able to stop the stimulation at the right time due to physiological reaction times and low conduction velocity of nociceptors (1 m/s). As shown in Figure 1, variations in the pain rating differences of the control unit are smaller than for the manual procedure. Furthermore, results showed that a lower pain level habituation within the suprathreshold stimulation was observed throughout all subjects although less current was applied. Lower pain levels would be desirable for

measurements in migraine patients, in which a reduced habituation in the pre-ictal phase is observed.

5.2 Smartphone Application

Since the question about the motivation to use the smartphone application frequently scored low results, the user's motivation needs to be improved. Naturally, the motivation to use this application regularly is low for healthy volunteers, since the application was designed for migraine tracking purposes. For migraine patients a combination of the application and the electrical stimulation through the control unit is expected to increase the motivation by giving the impression of having an influence on their own health and taking an active part in increasing the therapeutic effect.

6 Conclusion and Outlook

The purpose of this work was to develop a control unit to replace manual electrostimulation, combined with an application to record migraine data at home on a daily basis for further analysis by domain experts. Results showed, that the control unit has the ability to substitute the manual standard procedure and can guide the patient through the process. Furthermore, the smartphone application supports the user in tracking individual factors that can influence migraine attacks. Regarding the usability, both systems have proven their applicability during daily-life situations.

To confirm the thesis that electrical stimulation can be used to predict migraine attacks, more data need to be acquired in a more realistic, daily life setting. Therefore, a small and wearable electrostimulator, integrated into a headband with electrodes, for daily stimulation needs to be designed. With more data becoming available, more accurate migraine prediction algorithms based on machine learning approaches can be developed. Those algorithms can then be used to generate an active feedback through the application about the probability of an attack within a certain time frame.

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