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Development of an app-controlled simple, wearable teeth grinding sensing device

Abstract: Teeth grinding is, due to its various impacts on the human body, a highly discussed issue in dentistry. It can damage the tooth structure or cause pain due to muscle tension. At the moment, there is neither a satisfactory diagnostic nor a comprehensive treatment option. This paper deals with the development of an app-controlled, small, portable sensor unit that can be used by patients to monitor their teeth grinding in everyday life. It also offers a treatment option due to an implemented biofeedback option. To achieve the most cost-effective device possible, only off-the-shelf electronics and no proprietary software were used. In initial tests, the measuring device showed high level of measurement accuracy when performing measurements without feedback at rest (f_score=-0.025...0).

Keywords: bruxism, teeth grinding, mobile self-diagnosing device, surface electromyography, biofeedback, Android app, microcontroller.

https://doi.org/10.1515/cdbme-2021-2084

1 Introduction

Teeth grinding, so called bruxism, has been defined as repetitive activity of the masticatory muscles, which is characterized by clenching or grinding of the teeth and / or by bracing or shifting of the lower jaw without tooth contact [1]. It is also differentiated into awake and sleep bruxism [1].

The aetiology of bruxism is multifactorial and partly still unknown [2, 3]. It occurs either without an apparent cause or related to psychiatric and neurological illnesses, sleep disorders and psychoactive medication or substances [4]. Emotional stress, anxiety and depression are also mentioned as correlating factors [5]. The consequences of bruxism are multifarious: It can damage the dental system and cause pain in the oro-facial region and beyond [2].

Presently, there is no satisfactory method for diagnosing bruxism. Polysomnography (PSG) is the gold standard, i.e. the recording of several physiological parameters of lower jaw movement and tooth-associated grinding noises in the sleep laboratory [6]. This method however represents a high technical, financial, and time-consuming effort so the need for inexpensive and small, portable diagnostic devices is high [6]. At the moment there is neither a causal therapy for bruxism. The S3 guideline for the diagnosis and treatment of bruxism recommends occlusion splints for the prevention of tooth damage and the monitoring of bruxism activity [6]. The problem, however, is that these can be used symptomatically only. The bruxism activity itself is not changed by these splints, only are the teeth protected from damage. Further therapeutic approaches are therefore necessary. Because of that, some detecting devices offer a biofeedback function: patients should perceive the unconscious, harmful grinding behaviour and, as a result, refrain from grinding [7, 8]. However, this process must be learned [7]. Several clinical studies have confirmed that biofeedback can be used successfully as a therapy for bruxism [8 - 10].

This paper presents the development of an inexpensive device, suitable for everyday use at daytime, which enables reliable (self-) monitoring of teeth grinding activity and offers optional biofeedback: patients can choose to be notified by vibration if teeth grinding is detected in order to decrease their grinding activity. Furthermore, the measurement accuracy is described and potential improvements are discussed.

2 Material and Methods

2.1 Design of the sensor unit

Electromyography is a well-established method for recording muscle activity that has been used for decades. In addition, the significant muscles for teeth grinding are located directly under the skin surface, which enables good signal-to-noise ratio. The surface EMG (sEMG) sensor unit GRV EMG Detector (Seeed Technology Co. Ltd, Shenzhen, P.R.C.) is used to detect teeth grinding in combination with Kendall EKG disposable adhesive electrodes H124SG (Cardinal Health AG, Dublin, OH, USA), which are placed over the *M. masseter*, a muscle involved in the grinding movement, and on the neck. The sensor unit amplifies the potential

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difference arising from muscle tension and outputs signals between 0-5 V. To determine the measurement accuracy of the sensor in general, the output signals were recorded during teeth grinding, yawning, speaking, and when pressure was applied to the electrodes.

A "Beetle" (DFRobot, Shanghai, P.R.C.), a microcontroller board programmed using the Arduino IDE, is used as control unit. A vibration motor GRV VIBRATION (Seeed Technology Co.) is installed for biofeedback. Its vibration frequency is 150 Hz and should thus be easily perceptible through the Vater-Paccini corpuscles behind the ear [11]. In addition, a force sensor (SEN-Pressure10, SIMAC Electronics GmbH, Neukirchen-Vluyn, DE) is used to detect artefacts due to pressure loads onto the electrodes (e.g., if the user sleeps and the electrodes are pressed against a pillow). To enable communication between sensor unit and smartphone, the Bluetooth module "4duino Wireless Modul HC-05 4-Pin" (ALLNET GmbH Computersysteme, Germering, DE) is installed.

The system is powered by a single-cell lithium-polymer battery (3.7 V, 350 mAh, Jauch Quartz GmbH, Villingen-Schwenningen, DE) which can be recharged via a charging board (TP4056 by NanJing Top Power ASIC Corp, Nanjing, P.R.C.) with integrated protection circuit DW01-P (Fortune Semiconductor Corp, New Taipei City, Taiwan)). A manual switch is used to switch between charging mode and operation mode. Since the Beetle requires a 5 V supply voltage, the battery voltage is converted to 5 V by a step-up module (ME2108, Nanjing Micro One Electronics Inc., Nanjing, P.R.C.). All components used in the prototype and their specific costs are listed in Table 1. The assembled prototype is shown in Figure 1. The housing model was created using CREO Parametric 3D CAD software (Version: 5.0.0.0; PTC Inc., Boston, MA, USA). The shape and dimensions of the earpiece are derived from DIN IEC/TS 60318-7 [43]. The housing of the prototype was printed from PLA filament (PLA Prusa Galaxy Black) using a Prusa I3 (both Prusa Research, Prague, Czech Republic).

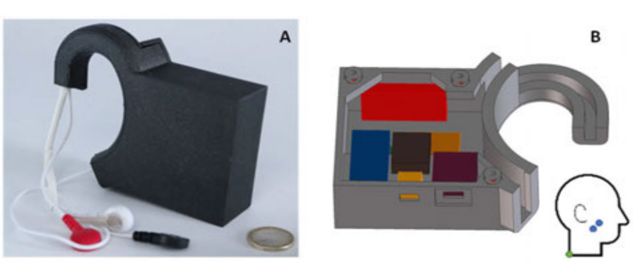

Figure 1: The assembled prototype (A) contains all the parts from Table 1, as shown in the 3D model (B). The positioning of the measuring electrodes (blue) above the *M. masseter* and the reference electrode (green) in the neck above the C4 vertebra can be taken from the schematic drawing.

Table 1: Components used in the prototype and their specific cost.

Component	Cost
GRV EMG Detector	30 €
Kendall EKG adhesive electrodes H124SG	0.4 € / measurement
Force sensor	3 €
Charging board	1 €
StepUp	1 €
Rechargeable battery	14 €
Beetle	9 €
Switch	5 €
Bluetooth module	15 €
In total	**78.4 €**

2.2 Android app to control the sensor unit

To operate the sensor unit and to give the user access to their data, an Android app was developed. The app controls the sensor unit and enables data storage as well as the analysis of the measurement data and is thus intended to enable self-monitoring to the user. To enable evaluation whether biofeedback leads to a reduction in bruxism activity or not, there are two measurement modes provided via the app, namely with feedback or without feedback. The app was developed for the Android operating system (Open Handset Alliance Consortium, Mountain View, CA, USA). The associated program code was written using the Android Studio 4.1 development environment (Google LLB, Mountain View, CA, USA).

Starting from the home page, the user can either continue to a help menu containing information about how the app works, or to the measurement page, where a Bluetooth connection is first established with the sensor unit and then a measurement can be started. Finally, the user can view their measurement data via the measurement data page. For this purpose, the data is permanently stored locally on the user's end device using an SQLite database. The data is displayed in separate tables for each measuring mode (with or without feedback). In addition, both measurement modes can be compared through a bar chart. This helps evaluating, whether the biofeedback reduces the grinding activity.

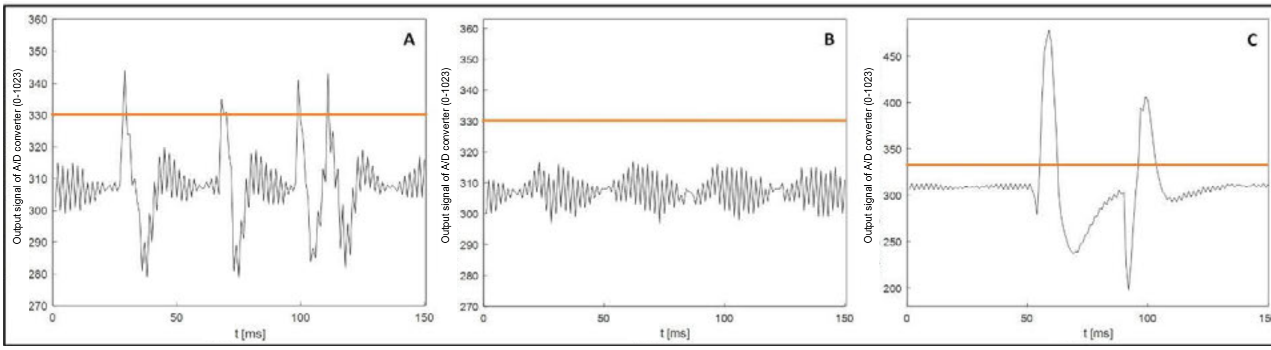

Figure 2: GRV EMG Detector output signals during teeth grindings (A), speaking (B) and during pressure loads onto the surface electrodes (C). To record the signals, adhesive electrodes were placed near the *masseter* muscle on one side of the face and the reference electrode was placed above the C4 vertebra. The orange line at 330 units is the calculated *bruxLimit* threshold value.

2.3 Interaction between device and app

To perform a measurement, the device must be attached to the ear and the electrodes over the *masseter* muscle and the neck. Then, a measurement can be started via the app. By clicking on a button, the patient first selects whether the measurement is to be performed with or without the feedback option. To increase the reliability of the measurement, the sensor unit is then calibrated to the respective user. This is necessary because the basic EMG signal varies from measurement to measurement and from person to person due to different positioning of the electrodes or varying skin impedance. During the calibration process, which lasts 30 seconds, the current EMG value of the sensor is read in continuously and checked whether it is greater than the currently stored maximum value (*emgMax*). If so, the current value is saved as the new *emgMax* value. The user must not move during this time as the resting line, i.e., the superficially measurable resting potential of the muscle, is to be recorded. Subsequently, the threshold value for a grinding event (*bruxLimit*) is calculated with the aid of the experimentally determined coefficient k_{brux} (see eq. 1).

$$\mathbf{bruxLimit} = \mathbf{emgMax} \cdot (\mathbf{1} + \mathbf{k_{brux}}) \qquad (1)$$

After calibration, the actual measurement begins. Every Millisecond, the current output voltages of the force sensor and the EMG sensor are read. If the EMG voltage is above the *bruxLimit* and the reading of the force sensor is below a pre-defined value, the signal is interpreted as a grinding event and the grinding count is increased by one. If feedback mode has been selected, the feedback function is also called, turning on the vibration motor for 500 ms. The measurement is stopped if a command to transmit the data and quit the measurement is sent through the app.

Initial tests were performed to verify the functionality of the sensor unit and the app. Therefore, the device was tested on three different test subjects (male, 23 years; female 55 years, female 25 years). Each test person used the device for one hour while watching television, i.e., almost at rest, once in feedback mode and once in non-feedback mode. They were instructed to deliberately grind 40 times at irregular intervals during this period.

Table 2: Results of testing the sensor device at three different subjects with feedback or without (*g.e. = grinding events).

	Subject No.	**Detected grinding events out of 40**	**Relative deviation f** $f = \frac{detected\ g.e. - actual\ g.e.}{actual\ g.e.}$
With feedback	1	41	+2.5%
	2	43	+7.5%
	3	40	0%
Without feedback	1	40	0%
	2	39	-2.5%
	3	40	0%

3 Results

The measurement results from Figure 2 show that the output signals of the sensor during a grinding event can be clearly distinguished from other movements of the muscle, such as yawning or speaking due to the characteristic amplitude. A bruxism event occurs when the amplitude is in the range 320 to 350 units. In Figure 2 (A) four grinding events have been detected. The sensor unit used is therefore in principle able to detect grinding events.

The results of the first test with three different subjects, displayed in Table 2, confirm this too. The sensor unit detects almost all grinding events when performing measurements without feedback at rest, the relative deviation of measurement accuracy *f* for these measurement cases is low (f_score = -0.025…0). The relative deviation in feedback mode is slightly higher (f_score = 0…0.075), false positive grinding events are detected. A possible reason and solution are discussed below.

4 Discussion

The sensor unit at hand detects conscious teeth grinding due to measurement of muscle activity reliably when used without feedback at rest. The slightly increased values of detected grinding events when used in feedback mode may be due to the electrodes being moved by the vibration, causing a deflection of the EMG line, which is counted as an additional but false grinding event. One possible solution is to adjust the vibration intensity. From this small series of measurements, an accuracy of maximum ± 10% can be expected, but this would have to be confirmed by further measurements. In addition, it would be interesting to expand the test subject experiment to include a recording of the created grinding events so sensitivity and specificity can be calculated more accurately. Calibration enables the use by the layperson, as it reduces the influence of the effects on the measurement signals due to electrode positioning and individual physiological differences.

The functionality of the device needs to be further tested and compared to grinding activity recorded in a sleep laboratory as a gold standard. To evaluate its use at night, the housing must be adapted. The placement behind the ear is reasonable, as it is not directly noticeable by other people. However, it is necessary to improve the fit. The currently used disposable adhesive electrodes are quite conspicuous due to their design and placement on the cheek. So-called tattoo electrodes developed by other research groups could remedy this. Those are ultra-thin and flexible electrodes which can be placed on the skin like peel-off tattoos [12].

The app makes it easy to operate the unit. Thanks to the permanent data storage, the user can easily access the recorded data at any time and monitor themselves independently over a long period of time.

For 78 € material cost, the device offers a cost-effective and reliable way to detect teeth grinding by measuring muscle activity of the *M. masseter* via sEMG. Further work on increasing the usability by miniaturization of the electronic circuits and the housing along with testing on subjects affected by bruxism is still pending.

Author Statement
Research funding: The author state no funding involved. Conflict of interest: Authors state no conflict of interest. Informed consent: Informed consent has been obtained from all individuals included in this study.

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