Bruxist Activity Monitor System (BAMS): An instrumental approach tool in the assessment of Bruxism

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***Abstract*— The magnitude of harmful effects on dental structures, periodontium, masticatory muscles, and the temporomandibular joint, derived from temporomandibular disorders, specifically from sleep Bruxism, generates evidence that needs to be objectively collected. This paper introduces a portable device aiming at extracting and analyzing parameters (like timestamp, duration, or latency) from recordings obtained from the monitoring of occlusal activity, throughout a complete sleep cycle. An electronic device embedded in a mid-density medical grade silicon occlusal splint detects the moment in which the subject exerts sustained force, and records the time and length of the event, keeping the device on hold until a new event arises. The electronic device, based on a microcontroller, identifies occlusive events from an array of two piezo-resistive sensors and has a storage capacity of up to 36 hours of continuous activity. The collected data is wirelessly transmitted to an external module that is connected via USB to a PC. In the PC, the data is decoded, processed, analyzed, displayed, and stored in ordered files for case subjects, updating every recorded test for a complete history review. The proposed Bruxist Activity Monitor System (BAMS) was tested in one subject for more than 40 hours (5 sessions in 7 days). Preliminary results show the oral appliance endure without any significant damage over its surface nor undermining its functionality.**

I. Introduction

Bruxism is a repetitive muscular and mandibular activity characterized by clenching or grinding of the teeth and-or bracing or thrusting the mandible against the maxilla [1]–[3]. It is a behavior or an oral habit in otherwise healthy subjects. At some point in their lives, 80 % to 95 % of the global population has suffered from Bruxism. [3], [4]. Prevalence of Bruxism range from 14 % to 20 % in infants, 12 % in young adults, 8% in adults, and 3 % in elderly [2], [4]–[8].

The etiology of sleep Bruxism is not entirely known and obeys a multi-factorial model. Sleep functions, such as awakenings from the neuro-cardio vegetative system, and rhythmic muscular masticatory activity (RMMA), are the primary association.

Clinical assessment of the damage in dental structures and tissue, in combination with self-assessment, self-reports, or questionnaires, are the essential and most widely used instruments in the Bruxism diagnosis [9], [10]. The objective detection of the RMMA is obtained only through electromyography (EMG), derived from a polysomnography study (PSG), which is the "gold standard" for the diagnosis of this behavior and all sleep disorders [2], [4], [8]–[11].

The sensitivity of the PSG study in detecting sleep Bruxism in severe cases is moderate to high, and low in less severe cases due to the night-to-night variability of the RMMA. PSG is characterized by a low diagnostic specificity due to the absence of audiovisual recordings (there is a 20 % overestimation in event detection) [2]. Finally, PSG is not performed routinely in otherwise healthy individuals or individuals with no evident sleep disorders.

Other approaches have been proposed to study the individual in their habitual environment through ambulatory monitoring [12]–[16]. These alternatives are less invasive than PSG, aiming at reducing discomfort to the test subject by eliminating cables and electrodes through a portable device that allows the recording of occlusal activity in their respective resting places without using EMG.

The proper assessment of Bruxism contributes to facilitating: a multidisciplinary treatment, the control of this behavior/disorder, and the improvement of the bruxist's quality of life. Therefore, the development of new techniques, or the strengthening of existing ones, using modern procedures and technology, represents valuable knowledge to understand the morphological and functional changes that this phenomenon causes in the stomatognathic system [17].

II. Bruxist Activity Monitor System

This paper introduces BAMS (Bruxist Activity Monitor System), which integrates the three modules depicted in Fig. 1. A User Interface creates and store results tables and display occlusive episodes previously recorded and transmitted throughout a recording session, using a Communication Module and an Oral Appliance, consisting of an occlusal splint that encapsulates the circuitry necessary to detect Bruxism events.

A. Oral Appliance

The Oral Appliance consists of a mid-density medical grade silicon occlusal splint that coats in and isolates the electronic circuitry. This circuitry is in charge of acquiring,

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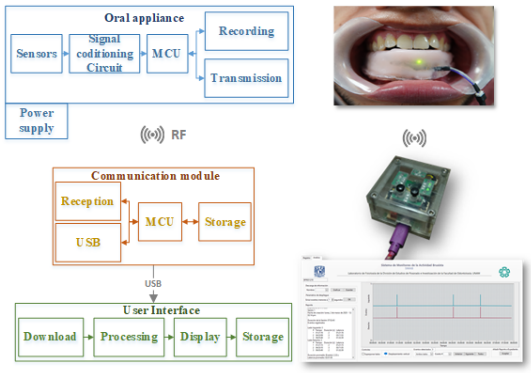

Fig. 1. Block diagram of the Bruxist Activity Monitor System (BAMS).

storing, and transmitting the signal from two piezo-resistive sensors located over each second molar (right and left) of the mandible (see Fig. 2-a and 2-b). This device is powered by a 3100 mAh 3.7 V Li-Ion rechargeable battery externally wired to a dc/dc linear regulator (ADP122 from Analog Devices).

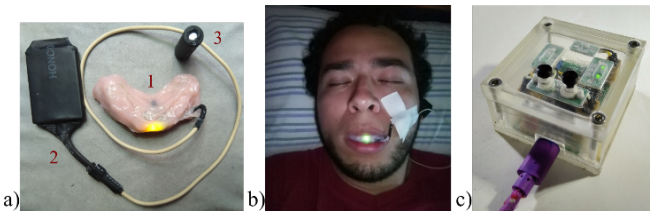

Fig. 2. a) Oral Appliance: Occlusal splint (1), Battery (2), and Magnet (3); b) Test subject wearing the Oral Appliance during a recording session; c) Communication Module.

The Oral Appliance carries out two possible tasks selectable by the user hovering a magnet for a few seconds over a reed switch which generates an external interrupt in the PIC18F25K20 microcontroller from Microchip (MCU).

The Recording task starts when the MCU detects a high state input for four continuous seconds. Through an internal timer, the MCU acquires 1 sample/s from each channel (right and left). The two channels comprise a 0.2" diameter force-sensing resistor (FSR) from Interlink Electronics as the ground-referenced element of a non-inverting amplifier with a 300 mVdc input voltage. This first stage is followed by a first-order active low-pass filter, with a cutoff frequency of 0.28 Hz. Then, a non-inverting open-loop comparator with a reference voltage of 810 mV (see Fig. 3) generates the signal that enters the MCU. The MCU stores timestamps only while holding active-high either or both recording channels. This data is temporarily stored in 8-byte buffers per channel and written in a 2-Mbit SPI EEPROM (M95M02 from ST, endurance more than 4 million write cycles) when the buffer is full. In this configuration, the memory is capable of storing at least 36 hours of continuous activity. This task concludes when hovering the magnet for 2 seconds (or more, and less than 4 seconds) in the same way used to start it.

The Transmission task starts when the magnet reaches the surroundings of the reed switch for 2 seconds (or more) and less than 4 seconds. The MCU reads the content of

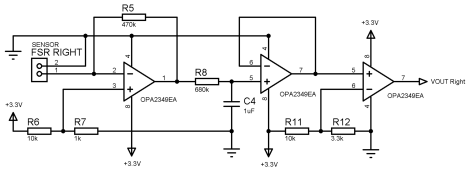

Fig. 3. Signal Conditioning Circuit (right channel).

the external EEPROM and temporarily stores it in 16-byte blocks. Then, the MCU sends the data, by SPI, to a radio frequency transceiver (nRF24L01+ from Nordic) that links to the Communication Module, which receives and stores such data. This process repeats until the information from memory is finished reading and ends when the Communication module receives the last data block, see Fig. 4. After the data transfer completes, both devices return to the Standby Mode.

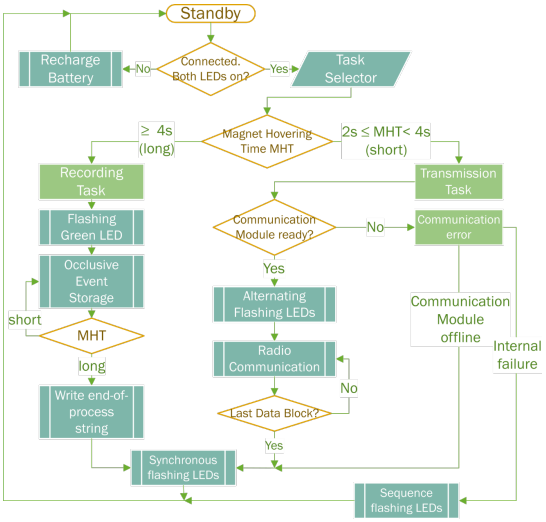

Fig. 4. Oral Appliance diagram flow.

B. Communication Module

The Communication Module is a USB-powered device, which is in charge of receiving and storing transmitted data from the Oral Appliance, and send them to the User Interface (see Figs. 1 and 2-c). Similar to the Oral Appliance, this dongle can perform two tasks by holding down the selection button. This button is on the upper face of the acrylic box that encloses the circuit.

The Reception task starts by pressing for 2 seconds (or more) and less than 4 seconds. A PIC18F25K50 MCU configures via SPI the nRF24L01+ transceiver to remain in Rx (reception) mode until the Oral Appliance begins the data transfer. The MCU commands the RF module to send back acknowledgment packets every 16-byte successful reception and temporarily stores 256-byte blocks before writing them down to the external EEPROM (M95M02). Communication ends when the MCU reads the end-of-process character string, and the task completes by writing the last received data block into memory. As well as the Oral Appliance, a

sequence of flashing lights indicates the status of the transfer before returning to Standby Mode.

The USB task begins by pressing the button for four seconds. The MCU performs the USB enumeration routine, and when it succeeds, a green led remains lit on the front face of the device, and the PC displays the BAMS on the Operating System Device Manager. Otherwise, a red led lights up. Upon receiving the instruction, the MCU continuously reads 256-byte pages from the external EEPROM and streams them down to the User Interface. This process repeats until the last block of data is reached.The task ends when the MCU performs the USB detached routine, and the device returns to Standby Mode.

C. User Interface

A LabVIEW User Interface that enables the download, process, analysis, and store of the Oral Appliance collected data was programmed. It has two sections. Firstly, the File Tab allows accessing or entering new clinical information for each subject. Secondly, the Analysis Tab extracts the quantitative data (Event Timestamp, Event Duration, Time Between Events, also referred to as Latency, Events Per Hour, Average of Events, Duration and Latency per side or both sides) and plots the location of the found events. Also, the Analysis Tab allows the user to filter, compare, and display the detected events, one by one or as a whole (see Figs. 5 and 6).

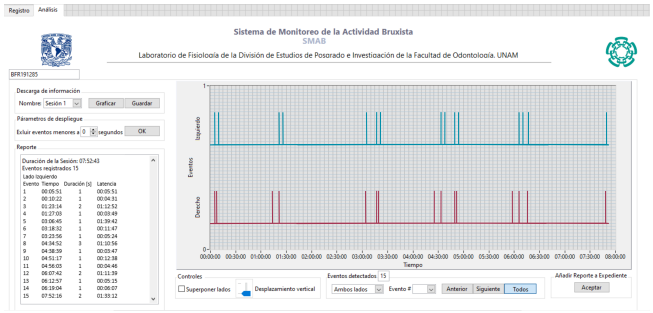

Fig. 5. User Interface Analysis Tab. Graph and results report of raw data.

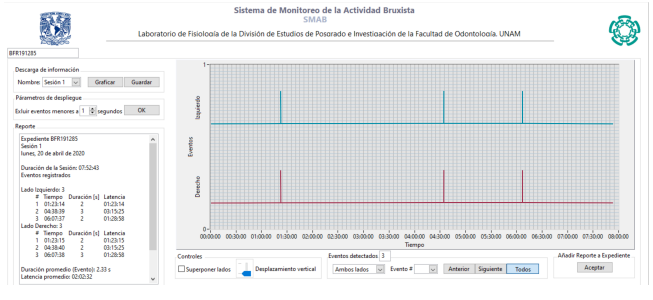

Fig. 6. User Interface Analysis Tab. Graph and results report of events greater than one-second.

In the download task, the User Interface inquires the Communication Module for the available data, and the transfer begins. A background routine decodes and processes this information by filling in the empty spaces between events throughout the entire record, generating a time array whose size is equal to the duration in seconds of the session, and assigning each event to its respective timestamp.

The display task generates and stores in text file result tables based on the selected Deployment parameter (tool to exclude events shorter than the one chosen by the user, e.g., a value of 2 will exclude events whose duration is less than two seconds). Regardless of the selection made, the user can use visualization tools to compare events on both sides (overlay), individually identify events and consecutively navigate between them, or modify time markers to visualize specific periods of the recording session.

III. Pilot Test

A pilot test was performed during 5 complete sleep cycle recording sessions in 7 days (two every other day during 4 days and three consecutive from the 5th day on). The pilot test was conducted in the usual place of rest, on a 34 years old male subject, 100 kg, without personal or family Bruxism history. The test subject was instructed in the handle of the Oral Appliance. A dentist took control of the Communication Module and the User Interface. To reduce the discomfort manifested by the patient before the test, multiple adjustments on the occlusal splint surface were made.

The data collected in the Oral Appliance was downloaded to the User Interface after each recording session, clearing memory space from both EEPROM devices. After Session 3, to prevent the loss of a whole recording session, the Oral Appliance battery was recharged.

During Session 1 the test subject reported events that do not obey a constant manifestation of occlusal force or known bruxist behavior (false positives), see Fig. 5. These are natural masticatory events (swallowing saliva, jaw adjustment when changing body position) whose duration does not go beyond one second in most cases. The number of isolated events on each side decreased by modifying the Deployment parameter in the User Interface. Also, it was perceptible when both sides exert uniform force (see Fig. 6). It is important to note that as part of the procedure for each recording session, the test subject performs a sustained occlusion for 2 seconds at the beginning and end of the session to generate auxiliary markers that allow the specialist to determine the length of the session.

In Session 2 there are slight differences between the start timestamp on each side (one-second variation). The results show an early start of the left side compared to the right side in all the events. This response can have different explanations. Firstly, the test subject initiates a dominant (left) side occlusal contact. Secondly, the relief edges of the occlusal splint are slightly higher on the left side. Thirdly, the response of the sensors is different. Finally, there are different depths in the Oral Appliance. It is necessary to evaluate the patient's occlusive behavior in further sessions to ensure or rule out any of these possibilities.

Previous to Session 3, the edges of the Oral Appliance were softened. In Session 3 the previously mentioned variations remain between the start time of each event and

its duration. No tendency is visible towards either side. Such behavior can derive from the movement of the splint when being clinch between the dental cusps. This session enlisted the largest number of events that may correspond to the session length, which was the longest. Another reason may be the test subject's habituation to the Oral Appliance, allowing more profuse periods of sleep without interruptions.

Finally, in Session 4 and 5 single occlusive events without their respective counterpart appear near the end of both sessions. According to the test subject report, this may be due to fatigue of using the Oral Appliance, or to the change of position of the device within the oral cavity remaining misaligned near the contact areas. The subject also reports less discomfort at the beginning of the session and conciliates sleep effortlessly.

Table I sums up the quantitative parameters generated throughout five recording sessions, excluding less than one-second events (false-positives).

TABLE I

PILOT TEST SUMMARY. THE TIME FORMAT IS HH:MM:SS.

Session	Total Length	Number of Events (both sides)	Event Duration (s)	Latency
1	07:52:43	3	2.3	02:02:32
2	07:43:12	4	2.6	01:43:41
3	08:39:20	5	2.7	01:44:34
4	09:17:36	4	3.0	01:48:27
5	08:57:24	4	2.6	01:48:03

IV. CLINICAL RELEVANCE AND CONCLUSIONS

An occlusive event monitoring system capable of generating quantitative results was designed, manufactured, and tested. During more than 40 hours of operation, the system did not present evident data loss and sustained its structural and operational integrity. Dents were only visible over the surface of the silicone at the molars, which did not affect the performance of the piezo-resistive sensors.

The adaptation to the usage of an external element during sleep varies between users (e.g., braces, mandibular advancement splints). Using an electronic device inside the Oral Appliance increases the vertical dimension of the subject's bite and its side effects, mainly at the temporomandibular joint level. On the other hand, while performing multiple recording sessions, the test subject reports less discomfort or higher tolerance to the presence of the occlusal splint. This habituation suggests an increase of systemic origin occlusive events, ruling out the presence of false-positive events that tend to arise towards the end of the session, caused by the usage of the occlusal splint.

This system requires evaluation and validation in clinical conditions on control groups with and without Bruxism diagnosis, comparing the results generated with established reference standards, in this case, the EMG activity of masseter muscles in a PSG study. The expected outcomes will constitute evidence that supports the BAMS as a reliable complementary instrument to determine the magnitude of disorder suffered by the patient. Instrumental proposals, questionnaires, or reports in conjunction with the clinical evaluation of the patient are essential in the correct diagnosis of Bruxism as a pathology. The integration of the Oral Appliance, a Communication Module, and a User Interface as an exploration unit constitute a sturdy examination system capable of delivering quantifiable results, which well do not replace those obtained by other means but represents an alternative assessment tool in the stomatological field with potential use in Sleep Medicine.

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