User-Centered Ergonomic Design of a Portable EEG System for Evaluating Dolphin-Assisted Therapy in Children with Neurodevelopmental Disorders

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***Abstract*—Dolphin-Assisted Therapy (DAT) is a therapeutic alternative used in comprehensive neurorehabilitation, aimed at improving the quality of life and social integration of patients with neurodevelopmental disorders through interaction with dolphins. However, the lack of defined standards makes it difficult to objectively evaluate its effectiveness. In this context, it was identified that the electroencephalographic device used to record EEG signals before, during, and after the sessions (based on a TGAM1 sensor) presented both functional and ergonomic limitations, as its readjustment interrupted the therapy sequence and caused discomfort in patients. To address this issue, the present work proposes the redesign of the device, incorporating ergonomic criteria to improve comfort, stability, and ease of use, without compromising the quality of the signal acquired by the TGAM1 sensor. The main objective was to optimize the user experience while also enabling the collection of more consistent and reliable data for analysis. The results show a significant improvement, achieving a 51% increase in signal retention. This made it possible to recover approximately 36 additional seconds of high-quality neural data per hour of therapy, thanks to more continuous and accurate EEG acquisition during interactions with dolphins. Furthermore, patient evaluations indicated greater acceptance of the device, highlighting improvements in comfort and weight perception compared to the previous version, thereby validating both its functionality and ergonomic design.**

***Keywords*—User-centered design; ergonomics; portable EEG system; Dolphin-Assisted Therapy; neurodevelopmental disorders; 3D printing; TGAM1**

I. Introduction

Dolphin-Assisted Therapy (DAT) is an alternative therapeutic method in which the well-feeling of children with various neurodivergent conditions is pursued via interaction between humans and dolphins, typically pregnant or lactating females from the bottlenose species. These therapies act as adjuncts to standard treatments that aim to promote healing and wellness [1]. Some studies have demonstrated that dolphin-assisted treatments accelerated motor skills, improved motivation for learning, benefitted on cardiovascular and respiratory efficiency, increased the flexibility of movement, help to reduce pain and helped in balance [2]. To date, DAT has been studied mainly to prove its efficacy [3].

Currently, DAT lacks established standards. Thus, a standardized approach is necessary to ensure that the therapeutic advantages of FIT are fully realized. According to Rutherford [4], standardization enables the ends of treatment efficacy evaluation. This enables better comparisons of results from different treatments, allowing professionals to determine the most effective techniques for specific diseases. In the case of DAT, for example, one measurement of its efficacy can be made by looking at variation in neurodivergent children's brain waves (as measured through electroencephalographic [EEG] signals) before, during, and immediately after the treatment with DAT. Depending on cerebral cortex region, the 10/20 system [5] defines a set of specific points on the scalp where several electrodes must touch to measure an EEG. This enables the measurement of electrical impulses generated by neurons to study human cognitive activity. Standardization of DAT is a problem, because the approach often differs widely in terms of method, frequency and duration of sessions, training used and species/type of dolphins [6], [7], [8], which can produce great variation in results. Therefore, the existence of measurement methods and instruments to capture EEG signals before, during, and after each session is essential to analyze the effectiveness of DAT.

Repositioning the electroencephalographic apparatus recording EEG signals before, after and during DAT represents a considerable challenge faced in the standardization of DAT.

In this way, the main goal is not to improve on the inherent performance of the sensor which will always be fixed by design, but rather, to obtain a match with its theoretical performance by simulating to some extent the favorable (or ideal) operating conditions where the sensor was initially proven.

In addition, it was determined that the moments of placement and withdrawal of devices are different between the types of conditions of the child being evaluated with DAT, so much so that they interfere with the performance order in which operations were carried out throughout the sessions, generating some discomfort for its use [9].

Research in EEG focuses both on understanding human cognition and on the use of brain signals to interact with the external environment through brain–computer interfaces (BCI).

A large portion of this research is conducted in medical or academic institutions [10].

There are multiple potential applications outside the laboratory environment, including prosthetic control, communication for individuals without motor function, therapeutic rehabilitation, and video games [11]. However, implementing EEG in real-world environments presents several challenges, particularly in uncontrolled contexts such as DAT. In these scenarios, expert personnel are not always available, electrode caps are often complex, and their placement requires a considerable amount of time. Furthermore, considering that patients are often neurodivergent children, it is essential that the device be comfortable and not cause discomfort during use.

In this way, the main objective on signal retention in an aquatic therapeutic environment, where conventional EEG devices face ergonomic challenges from patient movement and signal interference from the physical setting, addresses a specific and underexplored design problem, and the quantified improvement in signal retention provides a concrete metric of engineering value.

Therefore, the primary goal is the maintenance of the signal in a therapeutic water setting; traditional EEG devices are ergonomically complicated with behaviors such as patient movement and physical environment signals. It addresses a concrete design problem that has thus far been underdiscussed and the measured improvement in signal retention quantifies an engineering value.

Ergonomics is the applied science that studies interactions between human beings and other elements of a system. This is done by applying theories, principles, data and design methods whose end aim is improving human well being and system performance [12], [13], but only few studies include ergonomic aspects in the design of electroencephalographic devices [14], [15]. The current research describes the re-design of an electroencephalographic device utilized for EEG signals acquisition incorporating specific ergonomic concepts. In this redesign, we aim to create an instrument that is not only comfortable, functional, and aesthetically appealing for the patient, but also decreases applicable downtime identified in the DAT standardization [9], so as to maximize stable data collection which will allow multi-site analysis protocols or cross-instrument comparison of study conclusions as well as support the development of new evidence-based therapeutic strategies.

The structure of this study is as follows: Section II provides the fundamentals of electroencephalography and ergonomics that made it possible to redesign the electroencephalographic equipment employed pre-, peri- and post-DAT. Section III illustrates the methodology applied in this study. Section IV describes the Redesign and Development Process of Electroencephalographic Device. Section V provides the results and discussion of analysis. Lastly, the conclusion and future work is given in Section VI.

II. Theoretical Framework

A. Electroencephalography

Electroencephalogram (EEG) signals can be measured non-invasively through electroencephalography, which is widely used to obtain electrical impulses generated from human cognitive actions [16]. For research purposes this technique has been utilized for neuroscience, psychology etc.; designing brain-computer interface applications for diagnosis of several disorders including epilepsy, Attention-Deficit/Hyperactivity, etc. [17], [3]. EEG enables the recording of electrical potentials via several electrodes touching the scalp at designated locations on the cerebral cortex, as defined by an international system known as 10/20 system (see Fig. 1; [5]).

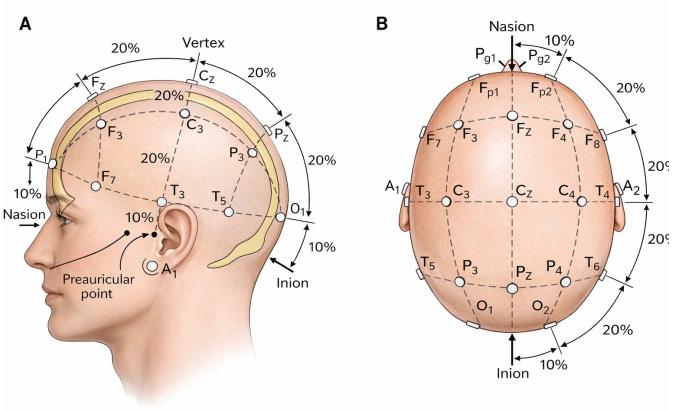

Fig. 1. International 10-20 system for the hydration of extracranial electrodes (Fp: Fronto-polar; F: Frontal; C: Central; P: Parietal; T: Temporal and O: Occipital), based on [5].

Electroencephalography has several advantages over other imaging and behavioral observation methods such as Magnetoencephalography and Magnetic Resonance Imaging, including its excellent temporal resolution and low maintenance cost [3]. Dry electrodes do not require the application of an electrolyte, making their manipulation and cleaning easier. In addition, they enhance ergonomics and comfort designed especially for non-expert users [18]. At the moment, new materials are enabling the production of wireless, miniaturized systems for enhanced applicability [15]. If established this technology adaptation and enhancement might allow its employment beyond scientific labs or hospital, and possible studies around real world situations, domestic health usage as well as the analysis, treatment and supervision of patients with neurodevelopmental problems [19], [20]. However, the implementation of EEG systems in real-world environments presents several challenges, particularly in uncontrolled contexts such as DAT. In these scenarios, specialized personnel are not always available, electrode caps are often complex to handle, and their placement requires a considerable amount of time. Furthermore, since the patients are often neurodivergent children, it is essential that the device provide comfort and not cause discomfort during its use.

Therefore, the development of systems that are easier to use and allow more precise electrode placement could significantly expand real-world BCI applications [21], [22]. In this regard, several studies recommend the design of more ergonomic EEG devices that better adapt to the diversity of head shapes and sizes, as well as to anatomical reference points [23]. To improve usability and accuracy, devices should be designed so that the electrodes are positioned as close as possible to

their ideal locations according to the 10–20 system, while also ensuring repeatability between measurement sessions. This aspect is particularly relevant in DAT sessions, since, as previously mentioned, this field still lacks fully defined standards for data measurement and analysis. Therefore, having a device capable of adapting to the specific conditions of the environment in which this therapy takes place is essential for advancing research in this area.

B. Ergonomics

Ergonomics is a scientific fields devoted to the study of interactions among humans and their elements of a system. It is done by applying theories, principles, data and design methods to enhance human well-being and the overall system performance [12], [13]. Product ergonomics studies the needs of users and the conditions surrounding use. Taking into account ergonomic factors enables product design which allows adapting a product to the features of end users to ensure direct efficiency, safety and productivity in its operation so that it does not cause health problems for people [24].

Disparities between individuals such as gender, race, and abilities can cause product design to fall short. When a device fulfills both the functional and emotional needs of its users [25], it becomes more attractive. As previously mentioned, much of the research on brain–computer interfaces (BCIs) has focused on different technical aspects, such as data acquisition, signal processing, the theoretical foundations of BCIs, as well as the development of conceptual applications or innovative prototypes [26], [27]. Although these research lines are essential to ensure the reliability of BCI technology, studies focused on the ergonomics of these devices remain limited. In particular, further research is needed to analyze how factors such as comfort, usage limits, and the physical characteristics of users influence the suitability of BCI systems for implementation in experimental environments and real-world applications. Such studies are essential to fully exploit the potential of these technologies in a wide variety of contexts.

Despite the progress achieved, the benefits of BCI systems are often limited by several factors, including low signal reliability [26], [28], fatigue associated with prolonged device use, and, in some cases, difficulties related to usability. These limitations raise questions about the suitability of these devices for both research purposes and practical applications. In the case of physiological measurement devices such as EEG systems, ergonomic design becomes particularly important, since the equipment must remain in direct contact with the user's head during signal acquisition. For this reason, it is essential to consider factors such as weight distribution, the pressure exerted by the electrodes, ease of placement, and the ability to adapt to different cranial morphologies [10]. An appropriate design not only improves user comfort but also contributes to obtaining more stable and reliable recordings.

In the context of DAT, the design of the EEG device must also consider the specific conditions of the environment in which the sessions take place. Factors such as user mobility, interaction with an environment close to water, and the need to maintain electrode stability during the therapeutic session require the development of specialized ergonomic solutions. Therefore, designing a device that combines comfort, stability, and ease of use is essential to ensure both the quality of electroencephalographic recordings and an appropriate user experience during therapeutic sessions.

C. Electronics Behind EEG

1) Acquisition: The TGAM1 (ThinkGear ASIC Module) is a single-channel low-power biosensor chip designed by NeuroSky for embedded electroencephalography. The module combines the TGAT chip and is intended to be used in portable and portable BCI devices, as shown in Fig. 2. The TGAM1 works in a voltage range of 2.97 V to 3.63 V and consumes a maximum current of 15 mA @ 3.3 V, leading to very low power consumption as necessary for battery operated applications like the EEG for Dolphin-Assisted Therapy application. It shows an extra-small size of $27.9mm \times 15.2mm \times 2.5mm$ and weighs only around 130 mg, making it suitable for use in headset applications where the module will not interfere with user comfort. It has a 12 bit analog to digital converter which supports 512 Hz sampling rate, and it can capture EEG signals in the range of 0.5 Hz to 100 Hz. The module needs three dry contact electrodes, an electrode for EEG signal registration, and a second as a reference; the solution is to connect the third electrode as the ground. The TGAM1 also has 4 kV of contact discharge and 8 kV of air discharge resistance for built-in electrostatic discharge protection, allowing it to operate reliably under a variety of environmental conditions.

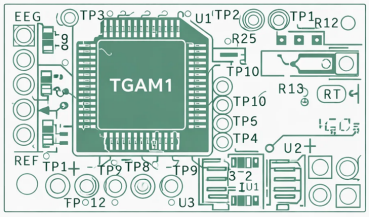

Fig. 2. ThinkGear ASIC Module: Single-channel low-power biosensor chip designed by NeuroSky for embedded electroencephalography.

TGAM1 is a UART serial device with configurable baud rates of 1200, 9600, and 57600 bps; the factory setting for normal data exchange is after booting, having it fixed at the value of 9600 bps. The module also has a built in notch filter to remove power line interference, which can be switched by connecting *the M* pin: connecting it to Vcc enables 60 Hz filtering for countries with 60 Hz AC, such as Mexico or USA; while connecting it to ground filters at 50 Hz for those using 50 Hz AC like Spain or France. The module also has configuration pads (B_0 and B_1) on the back that settle the baud rate and data output mode for a permanent configuration. The TGAM1 is designed to output raw EEG data at 512 Hz and processed parameters, including proprietary NeuroSky Attention and Meditation meters scaled from 0 to 100 percent, along with efficient eye blink detection. These processed outputs are particularly useful for therapeutic applications, as they offer real-time indicators of patient cognitive states without a need for sophisticated signal processing algorithms on the host device.

2) Wireless communication: The first device you will need for a wireless EEG system used in Dolphin-Assisted Therapy is the HC-05 Bluetooth module, Fig. 3, which allows the patient

to transmit their brain activity data over the air to a monitoring station without being tethered by heavy wires. In addition, The TGAM1 EEG sensor captures the neural signals needed to transmit with this module through the HC-05 Interface wirelessly in real-time while children have free interaction with dolphins.

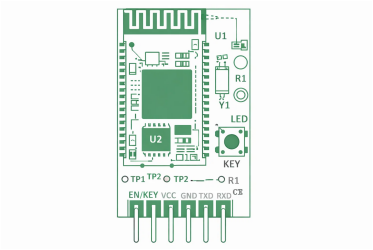

Fig. 3. HC-05 Bluetooth serial module: indicating it's onboard PCB antenna, its main controller ICs and some supporting components.

In this way, HC-05 is a traditional Bluetooth module based on the Bluetooth specification V2.0 and Enhanced Data Rate (EDR) for transparent wireless serial communication. It works on the 2.4 GHz ISM frequency band with GFSK modulation, and CSR's BC417 chip is used to provide reliable wireless connectivity. It has an RF transmit power of +4dBm and reception sensitivity of -85 dBm, allowing communication up to 10 meters in open space. The HC-05 measures just $27mm \times 13mm \times 2mm$ and weighs about 3.7 grams, and includes a PCB antenna with its interface covered by a connector design featuring the following pin layout on a 2.54 mm pitch header: STATE, RXD, TXD, GND, VCC, and EN. This module runs with a supply voltage of 3.6 V to 6 V and consumes 40 mA when pairing and 8 mA when connected. An onboard LED indicates the module's operational status: fast blinking for no connection, slow blinking for AT command mode, and double blinking for successful connection.

The HC-05 communicates via a UART interface, with adjustable baud rates of 4800, 9600, 19200, 38400, 57600, 115200, 230400, 460800, 921600, and 1382400 bps, with factory default settings of 38400 bps, 8 data bits, 1 stop bit, and no parity. The module has two operational working modes: 1) at command response mode for AT command configuration and automatic connection mode for data transmission, it can work as Master, Slave or Loopback roles; and 2) AT_COMMAND_MODE: This mode can be accessed by powering on the module while holding down the enable button, which will make the LED blink slowly during start up (The default baud rate for AT command mode is 38400 bps) Some key configurable parameters (AT+NAME= for Name, AT+ROLE=0 for Slave and 1 for Master, AT+PSWD; default is "1234" or "0000", etc.). It can all be done via serial port (AT+UART). The STATE pin shows whether a connection is active or not; it will output HIGH when connected and LOW when disconnected, allowing the microcontroller to track the status of the connection. Supported features, the module supports power-on auto-connect last paired device and adaptive frequency hopping to minimize interference.

III. Methodology

The methodology (Fig. 4) used for the redesign of the electroencephalographic device that retrieves the EEG signals before, during and after DAT with ergonomic concepts in order to bring comfort, functionality and beauty for the patient. Applied methodology: Soft Systems Methodology from the study proposed by Coria et al. [9] to demonstrate the B2 Model of relevant activities for the development of DAT-specific measurement tools.

Stage 1: In this stage, the elements that make up the electroencephalographic device were developed using Computer-Aided Design (CAD) tools. The objective was to generate a detailed digital representation of the device at a 1:1 scale, allowing precise visualization of the shape, dimensions, and arrangement of each component. During this phase, structural aspects such as the support base, electrode placement points, adjustment mechanisms, and fastening elements required to keep the device stable during use were defined. Additionally, the digital modeling made it possible to anticipate potential interferences between components and carry out preliminary adjustments before the physical prototype was manufactured.

Stage 2: In this stage, the main ergonomic factors that needed to be considered for the redesign of the device were identified and analyzed. These factors included aspects such as system weight distribution, the pressure exerted by the electrodes on the scalp, ease of placing and removing the device, and adaptability to different cranial morphologies. Criteria related to user comfort, system stability during movement, and interaction with the therapeutic environment were also evaluated. This analysis made it possible to establish design guidelines aimed at improving the user experience and ensuring that the device could be used during therapy sessions without causing discomfort or interfering with EEG signal acquisition.

Stage 3: In this stage, the results obtained from Stages 1 and 2 were integrated through analysis sessions and brainstorming activities, in which different design alternatives were evaluated to meet both the technical requirements and the previously identified ergonomic criteria. Based on this integration, the device design was developed using SolidWorks, which enabled detailed three-dimensional modeling of the system. During this phase, the final dimensions of the device, the precise location of the electrodes, the adjustment mechanisms, and the structural elements required to ensure stability, comfort, and functionality during use were defined.

Stage 4: Once the digital design of the device was completed, the physical prototype was manufactured using 3D printing. This process allowed a tangible version of the device to be produced quickly and at low cost, facilitating early evaluation of the proposed design. The use of additive manufacturing technologies made it possible to accurately reproduce the geometries created in the CAD model, while also allowing rapid modifications if necessary. The prototype was printed in resin to obtain a lightweight and resistant structure suitable for initial functionality testing.

Stage 5: In this step, various tests were carried out to evaluate the performance of the developed prototype. These tests included verifying the overall functionality, user comfort during use, system stability when placed on the user's head, and the proper distribution of the components' weight.

Additionally, the ease of placing and removing the device was analyzed, as well as its ability to maintain the position of

the electrodes at the anatomical points required for capturing EEG signals. The results obtained at this stage made it possible to identify strengths of the proposed design and potential areas for improvement.

Stage 6: Finally, in this stage the results obtained during the tests performed in Stage 5 were analyzed in order to identify possible modifications or adjustments required in the device design. This analysis made it possible to detect aspects that could be optimized, such as adjustments in the structure, improvements in fastening mechanisms, or modifications in the distribution of components. The process then returns to Stage 3, where the identified improvements are incorporated to generate a new version of the design. In this way, an iterative cycle of continuous improvement is established, allowing the device to be progressively refined until a design that meets the functional, ergonomic, and operational requirements for its application in DAT sessions is achieved.

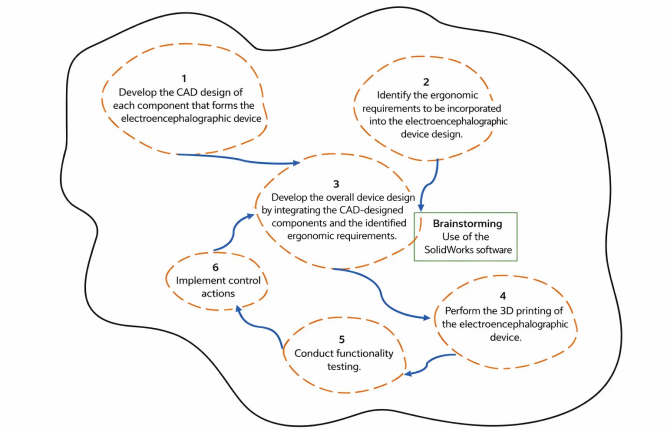

Fig. 4. Methodology used for the design of the electroencephalographic device.

IV. Experimental Results

A. Experimental Setup

The methodology used in this research was approved by the Ethics Committee of the National Polytechnic Institute of Mexico, according to Confidentiality Commitment Letter D/1477/2020. This document endorses the method of collecting various samples and the treatment provided to the bottlenose dolphins by the research team. The responsible use of patient data was guaranteed and communicated, and consent was obtained for the use of the data obtained in the experiments. Before taking the samples and connecting the devices, the procedure was explained to the patients; those who did not agree could withdraw their participation immediately. Participants who accepted the methodology and materials for sample collection signed a written informed consent form (from November 14 to 17, 2023). Participants were also informed about the tests they would undergo, although some did not fully understand them before entering the tank with the cetaceans.

B. Electroencephalographic Device: Current Design

Even if it is not a more advanced technology, the current design of this EEG signal capture and recording device must be non-invasive, waterproof, easy to wear, portable; These features were selected based on the habitat of DAT since EEG signal capture and recording in presence of saline and aquatic environment. As such, when the device is attached to the patient's head and does some interaction with salt water, there should be no risk concerning short circuit.

TGAM1 sensor is an electroencephalographic device; this is a single-electrode brain-computer interface. The three electrodes: 1) EEG, 2) Reference and 3) Ground present allow raw brain-wave data collection by amplifying the signal, processing it into a readable version that can be digitized. This sensor was used for measuring EEG signals at the f_{p1} position in the prefrontal region of the brain. Moreover, it can also detect voluntary and involuntary eye blink movements of the user [29].

This reveals one of the limitations of the study, as it makes qEEG extraction unfeasible [30]. This limitation is expected because the children undergo Dolphin-Assisted Therapy and always, or almost always, have wet hair, which complicates the use of other electrodes, leaving only f_{p2} as a possibility, but the same limitation would apply since it is close to f_{p1}.

Now, the TGAM1 sensor was integrated into a sports visor (Fig. 5), which can be modified to patients with any disability or neurological problem. These TGAM1 sensors are contained in a hermetically sealed resin 3D printed box to ensure that the circuit does not move, also protecting it from salt water exposure. On the left side of the device are two holes for the cables that connect with dry electrodes and project into the visor, which serve to connect circuits implanted in a patient's skull and culminate inside his or her head, see Fig. 6.

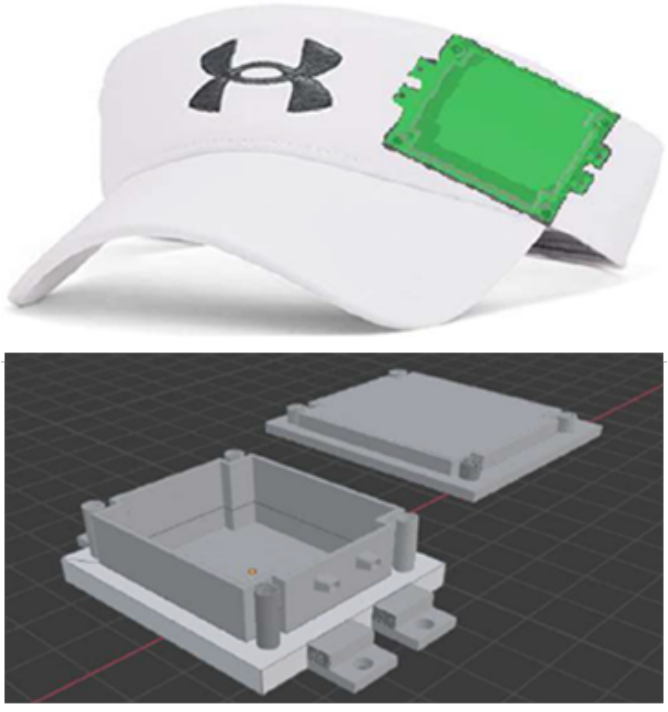

Fig. 5. Design of the electroencephalographic device.

Fig. 7 shows the connections between the TGAM1 EEG

Fig. 6. Electroencephalographic device of current use in DAT (AI-generated illustration based on the original scene; no real person's likeness is shown).

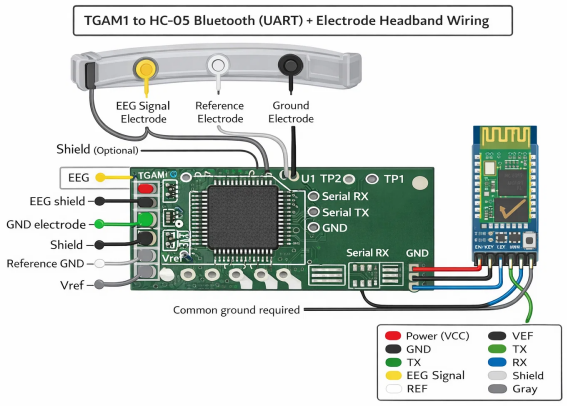

Fig. 7. TGAM1 EEG sensor connected to an HC-05 Bluetooth module via UART.

Fig. 8. Elements comprising the electroencephalographic device.

sensor module and the HC-05 Bluetooth module The TGAM1 communicates with the HC-05 over a simple UART serial connection that allows for bidirectional communication, as shown in the attached diagram. In particular, the TGAM1 serial transmitter (TX) pin connects directly to the HC-05 module serial receiver (RX) pin, and the TGAM1 serial receiver (RX) connects to HC-05 serial transmitter (TX), forming a full duplex asynchronous serial link. Note that both modules have a common ground connection; this is needed to ensure signal integrity and avoid voltage level mismatches. Power supply: There are two communication modules connected by a common VCC.

However, the electrode headband interface (top section of the wiring diagram) uses the three-electrode configuration needed for accurate EEG capture by the TGAM1. Signal electrode: Actual neural activity of the patient's prefrontal cortex at the position f_{p1} is measured using an EEG signal electrode, which is connected to the EEG input pin of the TGAM1 module. To complete the differential measurement, the reference electrode is connected to the pin V_{ref} and the ground electrode provides the common reference potential that connects to the pin of the GND module.

Ensure that once the dry electrodes capture the raw EEG signals, TGAM1 conditions them and transmits them through HC-05; this complete wiring arrangement makes it possible to collect data wirelessly during therapy sessions.

C. Proposed Redesign of electroencephalographic Device

1) Stage 1: This step was to create the parts of the electroencephalographic system using CAD software, a 1:1 scale representation for later design and adjustment. More specifically, SolidWorks design software is used in this research. The elements required for device operation can be found in Fig. 8; it is mainly composed of the TGAM1 sensor, two AAA batteries and other components that will make this equipment operable.

2) Stage 2: Cranial diameters are measured in a sample of 6 patients undergoing DAT. These cranial diameters and patient size are summarized, based on the types of conditions presenting in an infant, as shown in Table I. The new version of the device should adapt to both the smallest (50 cm) and largest (62 cm) cranial diameter measures.

TABLE I. DATA FROM PATIENTS UNDER STUDY

Patient	Condition	Cranial Diameter (cm)	Size	Age	Gender
1	Cerebral Palsy	53	S	12	M
2	Cerebral Palsy	50	XS	10	F
3	Autism	55.5	M	12	M
4	Down Syndrome	54	S	29	M
5	Down Syndrome	51	XS	12	M
6	Autism	62	XL	22	M

One of the challenges of the current electroencephalographic device is that the weight distribution was incorrect, making the box that houses the TGAM1 sensor tilt to the left. That is both inconvenient as it interrupts sampling of the EEG signal during DAT and uncomfortable for the infants being studied. Thus, the new device should fulfill metrics such as overall system comfort (to include electrode comfort), perception of system weight and stability perception [15]. Additionally, since the current device is made of rigid resin and includes screws that secure the enclosure containing the sensor, repeated opening and closing have led to the appearance of structural fractures (Fig. 9).

3) Stage 3: The heads of the patients studied vary in size and shape. Conventional EEG caps are the only option for electroencephalographic devices flexible enough to account for

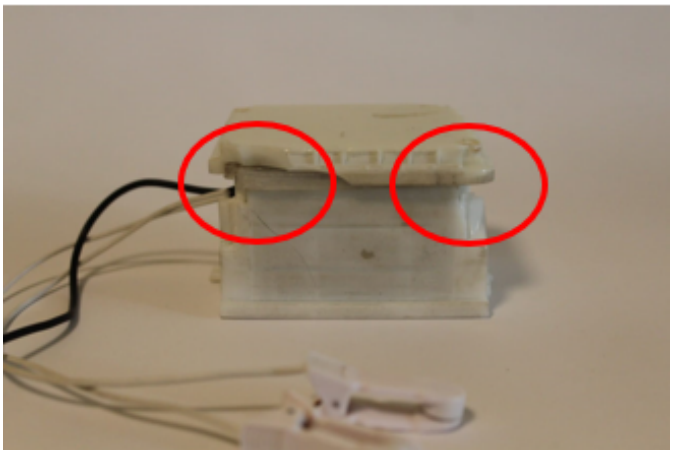

Fig. 9. Fractures appeared on the first electroencephalographic device.

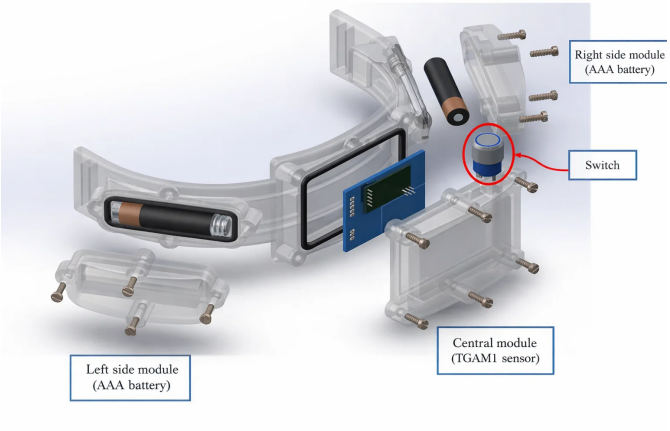

Fig. 11. Redesign of the electroencephalographic device.

this variability. Therefore, the device measurements are based on a conventional cap standard. Construction dimensions in cm for this device development are displayed in Fig. 10. The angle at which the TGAM1 sensor is placed falls within f_{p1} location parameters of the 10/20 international system [5].

Components of the device were rearranged to offer better comfort for users. The electroencephalographic device contains 3 sections (Fig. 10), which absorb the TGAM1 sensor (middle) and AAA batteries (sides). We modified the integration of dry electrodes to the patient, changing from a single connection point at one ear to connections at either ear, with goals related to meeting Stage 2 metrics: overall system and electrode comfort, perception of system weight, and stability. A fastening technique adapted from standard caps was proposed, relying on an elastic band that enable the adjustment of the device to the size of patient's head.

These modules were built under the IP68 standard (IEC, 2013), so that if the device falls into water. Fig. 10: Switch were installed to facilitate the ON/OFF state of sensor; Fig. 11: Reduce tension stress that would cause fracture to some material, (plastic inserts) or improve fastening.

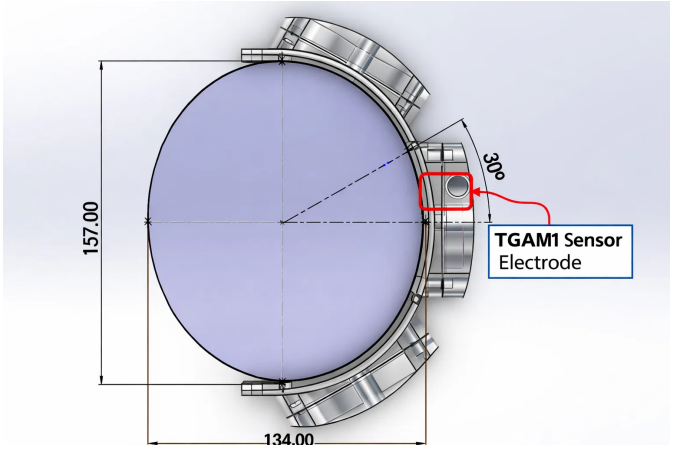

Fig. 10. Dimensions of the electroencephalographic device.

4) Stages 4, 5, and 6: Stage 4: The prototype from stage 3 was printed in a 3D impression (Fig. 12). The resin prints of the device, first hard resin. However, when performing the functionality tests corresponding to Stage 5, it was found that this kind of material cannot mold properly into the human head shape. Thus, one of the errors during stage 6 was switching up to semi-flexible resin material type. It was found that this material conformed tighter with human skull shape after a novel 3D printing process (Fig. 13) compared to the standard BA in Fig. 14.

Likewise, it was observed that, due to variability in patients' cranial dimensions, it was necessary to develop different device prototypes until identifying the one that provided the best fit for most users. Fig. 15 shows the different versions developed, which followed a continuous improvement process until reaching the design that best adapts to the patients.

Fig. 12. Electroencephalographic device 3D design: printed with hard resin.

V. Discussion

Patients were asked to evaluate various aspects relevant to the use of the headbands, which are presented in Table II [15]. Based on the results obtained, the corresponding graphs

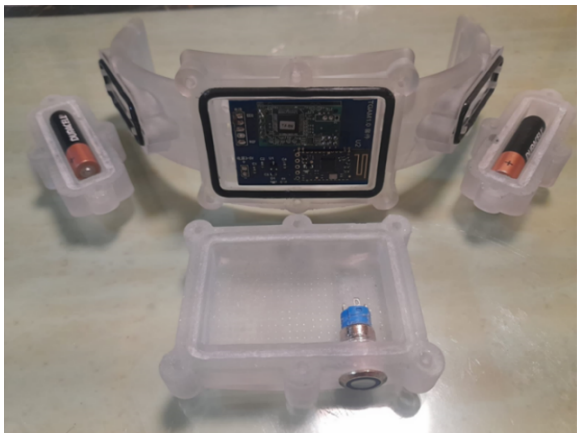

Fig. 13. Electroencephalographic device 3D design: printed with semi-flexible resin.

Fig. 14. Use of the electroencephalographic device (AI-generated illustration based on the original scene; no real minor's likeness is shown).

Fig. 15. EEG device prototype evolution.

were generated (Fig. 16). Regarding overall system comfort, a significant improvement can be observed compared to the previous version. Most patients rated the device as very comfortable (Fig. 16A). This is mainly attributed to the fact that, in the previous version, the concentration of the sensor on one side caused discomfort. Additionally, the redesign of the adjustment mechanism made the device easier to place and more comfortable during use.

TABLE II. FACTORS FOR EVALUATING COMFORT AND PERCEPTION

Evaluated Variable	Description	Scale
Global system comfort	Overall comfort level of the device considering the electrodes, headband, and amplifier.	1 = Not comfortable at all … 7 = Very comfortable
EEG electrode comfort	Perceived comfort of the electrodes and their contact with the forehead skin.	1 = Not comfortable at all … 7 = Very comfortable
System weight perception	Sensation of the device's weight during use.	1 = I do not feel the weight; 2 = Noticeable but not bothersome; 3 = Noticeable and slightly bothersome; 4 = Very noticeable and bothersome
System stability perception	Perceived stability of the device when placed on the user's head.	1 = I feel it stable; 2 = I feel it a bit unstable; 3 = I feel it unstable

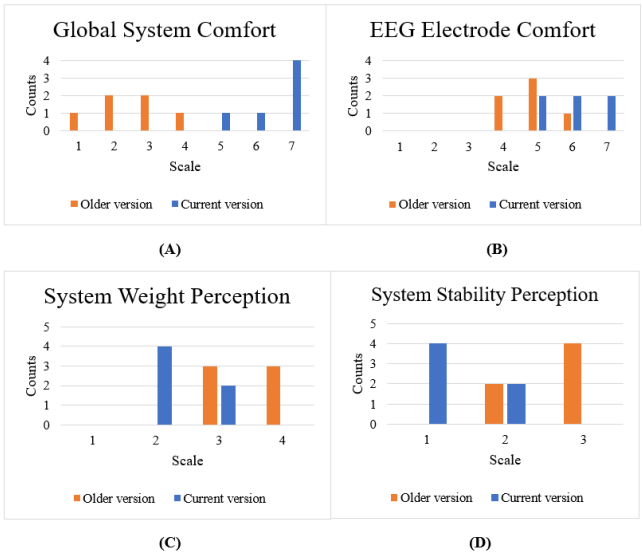

Fig. 16. Comfort metrics.

With respect to the comfort of the EEG electrodes (Fig. 16B), a notable improvement was also identified. While in the previous version comfort was predominantly rated at level 5, in the new design the evaluations were concentrated at levels 6 and 7. This change is due to the redesign ensuring better contact between the electrode and the forehead, thereby increasing perceived comfort. Regarding the perception of the system's weight (Fig. 16C), the previous version was mostly rated as *very noticeable and bothersome*. In contrast, in the new version this perception shifted to *noticeable but less bothersome*, indicating an improvement. This result can be explained by the redistribution of the system's weight, particularly by placing the batteries on both sides of the device instead of concentrating them on a single side.

In this way, in terms of the perception of system stability (Fig. 16D), a similar improvement can be observed. The evaluation shifted from *unstable* in the previous version to *stable* in most cases. This improvement is mainly due to the redistribution of components in the new design, which enhances balance and fit during use.

On the one hand, the TGAM1 EEG sensor features an advanced quality assessment mechanic via its Poor Signal flag system [31], which constantly checks the integrity of neural signal acquisition. The NeuroSky guide has defined the poor signal parameter between 0 and 200, where 0 is the ideal signal and 200 denotes absolute garbage. This flag system works by simultaneously monitoring several attributes of the incoming brainwave data, including signal flatness, excessiveness, power ratio, and off-head. Each of the above mentioned attributes maps to certain flag values, including 25 for flatness in signal range (not enough EEG signal, usually associated with large movements or peak saturation), 26 for convexity in signal range (too much noise from muscle movement or headset motion), 27 for power ratio information (periodic environmental interference), and 29 for off-head detection of device placement. One thing in particular here is right: multiple flags can be enabled at once but their values add to a unique identifier, so 51 would mean that both the flatness (25) and excess (26) tests failed; this is an important part of the system. In other words, to preserve the behavioral logic of the system, *eSense* Attention and Meditation signals are updated only if Poor Signal equals zero; whenever it is non-zero, these constructs freeze in their last known values. In addition, if Poor Signal is higher than 51 during seven seconds, then the *eSense* values reset to zero, and it takes four seconds of perfect signal quality for the system to be reinitialized. In settings like Dolphin-Assisted Therapy, where patient movement and water conditions can have a detrimental effect on the fidelity of captures, this intelligent framework for quality assessment is highly relevant.

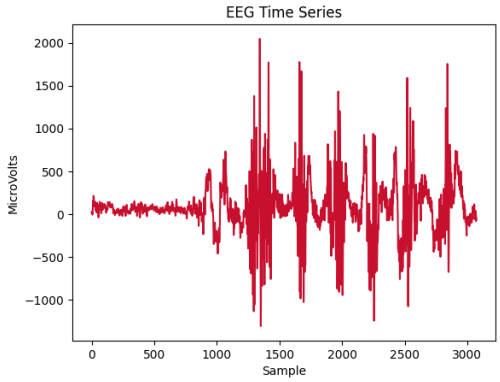

Fig. 17. EEG signal acquired using the original device version during a DAT session.

On the other hand, the improvements in ergonomic design of the electroencephalographic device for use during DAT include a significant improvement in signal acquisition reliability through rigorous testing compared to previous versions, considering the challenges identified by the Poor Signal monitoring system. Through quantitative analysis given the sampling rate of 512 samples per second (sps), the original device configuration caused an average loss of 608 samples per minute or 1.98% of all neural data obtained during therapy sessions. This translates to about 1.188 seconds of lost or corrupted EEG data per minute of patient-dolphin interaction, which is a significant loss in neurally monitored continuity. In the redesigned device, this reduction is dramatic, with only 298 samples lost per minute on average (0.97% of all samples), which translates into approximately only 0.582 seconds without signal in each therapy minute. This translates into an approximately 51% improvement in signal retention, meaning that for each hour of Dolphin-Assisted Therapy, the ergonomic redesign device reinstates almost 36 seconds of additional high-quality neural data that would have been lost due to Poor Signal conditions.

This redesign of the device showed a lower signal artifacts rate in comparison to the previous version, and better signal-to-noise ratios with error rates equal to those obtained from the original design thanks to its ability to be more adapted to cranial shapes and then making involuntary relative movements between dry electrodes and scalp significantly reduced.

The upgraded ergonomics, the semi-flexible resin materials improving electrode contact area, weight balance when worn, and three-point stable ear references for fitting quality control collectively address the movement artifacts plus contact-loss types of flatness/oversaturation flags (which are both highlighted in the Poor Signal) during sessions. As a result, clinicians and researchers may be able to acquire more continuous and accurate EEG recordings during periods of dolphin interaction, thus improving the understanding of possible therapeutic outcomes and helping to develop better evidence-based protocols to use dolphin intervention in the neurorehabilitation field with children experiencing this range of disorders.

As can be observed in Fig. 17 (original device) and Fig. 18 (redesigned device), a qualitative comparison of the signals taken from both devices shows that the continuity of the signal is improved for the redesign version, as well as its noise.

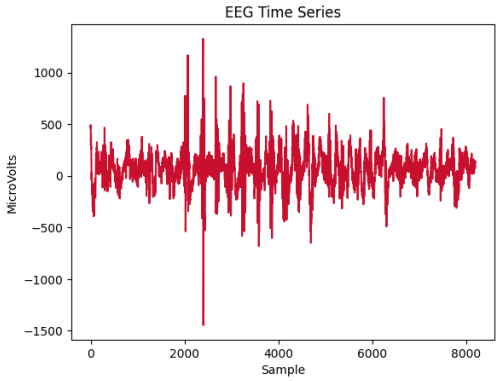

Fig. 18. EEG signal acquired using the redesigned device version during a DAT session.

The experiment was developed collecting data from six individuals, participants in dolphinarium facilities, where were part of a study examining the impact of dolphin-assisted therapy on people with neurodevelopmental disorders. One female and five males (aged 10 to 29 years) received diagnoses of Cerebral Palsy, Down Syndrome and Autism Spectrum Disorder (Grade II). A matlab console-level application was developed to collect DAT. of brain activity and interaction patterns during dolphin-assisted sessions, before DAT (one minute), five minutes during DAT and one minute after DAT.

Finally, there are still very few studies that keep ergonomic aspects in mind for the design of electroencephalographic de-

vices [14], [15]. Here, CAD became a fundamental component of this study by allowing us to develop a three-dimensional model representation of the EEG device. This enabled specific visualization of the prototype and adjustments to be made as required prior to 3D printing. For this study, since the size and shape of patients' heads were not uniform, it was decided to rely on typical measurements for traditional caps in order to define the dimensions of such a device. With the semi-flexible resin in 3D printing and the fastening style of a traditional cap, using an elastic band, enabled it to fit perfectly to the shape of the patients' heads. The redesigned version of the EEG device serves not only as a replacement for the TGAM1 sensor, but it also harnesses ergonomic principles in order to accommodate for DAT's corrosive and saline environment. The redistribution of components helps prevent tensile stresses that may cause fractures in the material, such as those that occurred in the previous device, and ensures the overall comfort of the system, including electrode comfort, weight perception, and stability, as evaluated by López et al. [15]. However, it is important to note that this questionnaire has a limitation, as it is a personalized instrument.

VI. Conclusion and Future Work

The necessity of creating a standard method during DAT development [9] showed that adjusting the electroencephalographic device to record EEG signals before, during and after DAT is not only interrupting the sequence of operations throughout the sessions but also uncomfortable for use. It was re-conceptualized for comfort, functionality, and aesthetic appeal to the patient through ergonomic concepts and methodologies such as Computer-Aided Design and 3D printing. User acceptance in terms of ergonomics and usability represents one of the main challenges for EEG systems to become widely adopted technologies within neurotechnology and non-invasive brain–computer interfaces [10].

In this research, through the redesign of the electroencephalographic device, significant improvements were achieved in key aspects such as overall system comfort, electrode comfort and their contact with the skin in the frontal area, perceived system weight, and perceived stability, compared to the evaluation of the previously used device in DAT.

As an additional advantage, not only were comfort conditions improved, but environmental considerations were also incorporated into the design, making the device more resistant to the environmental conditions to which it is exposed during use. Furthermore, the implementation of an EEG signal acquisition system based on the TGAM1 module, with wireless transmission capability, represents a significant improvement, as it facilitates its use under the dynamic conditions required by DAT and enables continuous monitoring of EEG signals throughout this study.

The ergonomic improvements were also reflected in concrete gains in signal quality. Due to the Poor Signal monitoring system designed within the TGAM1 sensor operating at a sampling frequency of 512 sps, with the loss of an average of 608 samples per minute (1.98% of neural data), approximately 1.188 seconds of corrupted signal would be produced each minute throughout therapy when using this original device configuration. This should be compared with 298 samples lost per minute (0.97%) for the redesign, meaning that only 0.582 seconds of signal was lost per average minute, therefore it had precisely 51% more signal retention. As a result, for example, nearly on the average 36 seconds of additional high-quality neural data can be recovered per hour of therapy due to this more continuous and accurate EEG recording throughout dolphin interactions.

Although the redesign of the device demonstrates significant improvements in signal acquisition achieving a 51% increase in signal retention there are still critical aspects that need to be addressed. These include the inherent limitation of using a single-channel EEG, which restricts the richness and resolution of neurophysiological data, the durability of the prototype under prolonged use conditions, the need to validate its performance across different therapeutic environments to ensure the generalizability of the results; and the challenges associated with scaling the manufacturing process through 3D printing, particularly in terms of costs, production time, and consistency in device quality.

As future work, a time analysis using the new multichannel electroencephalographic device is proposed, in order to perform multidimensional analysis along with qEEG preprocessing.

It is expected to reduce downtime caused by device adjustments, positively impacting the efficiency of both the trainer and the therapist, and enabling uninterrupted EEG signal acquisition before, during, and after DAT sessions.

Similarly, as future work, it is proposed to perform inferential statistical tests, such as the Wilcoxon signed-rank test or the paired t-test, to confirm that the differences observed in the redesigned device (general system comfort, perception of EEG electrodes, perceived weight, and perceived stability) are statistically significant. Furthermore, an evaluation using the System Usability Scale is planned to strengthen the assessment of ergonomic factors.

In subsequent work, considering that the evaluation conducted represents a preliminary validation, it is proposed to carry out a larger-scale study to establish the generalizability of the findings obtained.

Finally, it is proposed to continue refining the EEG device following the methodological cycle presented, with the aim of further improving the current design and enhancing the evaluated ergonomic aspects: overall system comfort, electrode comfort and skin contact, perceived weight, and system stability. This is intended to improve patient comfort during the study.

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