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Potentialities and limitations of the use of EEG devices in educational contexts

Potencialidades y limitaciones de la usabilidad de dispositivos EEG en contextos educativos

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ABSTRACT
Wireless electroencephalography (EEG) devices allow for recordings in contexts outside the laboratory. However, many details must be considered for their use. In this research, using a case study with a group of third-grade primary school students, we aim to show some of the potentialities and limitations of research with these devices in educational settings. Several balances are apparent in the development of these experiences: between the interests and possibilities of the research teams and the educational communities; between the distortion of life in the classrooms and the opportunities for collaboration between academia and practice; and between the budget and the ease of preparing the equipment and the usefulness of the collected data. Among their potentialities is the knowledge that they allow access to different cognitive and emotional processes, and the learning opportunity represented by the links between researchers and educational communities. Life in the classrooms is interrupted by these types of experiences, but this can be a cost that facilitates more integrated future developments that benefit teaching and learning processes.

RESUMEN
Los nuevos dispositivos de electroencefalografía (EEG) inalámbricos permiten realizar registros en contextos fuera del laboratorio. Sin embargo, para su utilización hay que tener en cuenta muchos detalles. En este trabajo, a partir de un estudio de caso instrumental con un grupo de escolares de tercer curso de Educación Primaria, se pretende mostrar algunas potencialidades y limitaciones de la investigación con estos dispositivos en contextos educativos. Se aprecian varios equilibrios en el desarrollo de estas experiencias: entre los intereses y posibilidades de los equipos de investigación y las comunidades educativas; entre la distorsión de la vida en las aulas y las oportunidades de la colaboración entre la academia y la práctica; y entre el presupuesto y la facilidad de preparación de los equipos y la utilidad de los datos recogidos. Entre sus potencialidades encontramos el conocimiento al que permiten acceder sobre diferentes procesos cognitivos y emocionales, y la oportunidad de aprendizaje que suponen los nexos entre investigadores y comunidades educativas. La vida en las aulas se ve interrumpida por este tipo de experiencias, pero ello puede suponer un coste que facilite desarrollos futuros más integrados que beneficien los procesos de enseñanza y aprendizaje.

KEYWORDS | PALABRAS CLAVE
Neuroeducation, electroencephalography, neurophysiological measurements, primary education, educational contex, case study.
Neuroeducación, electroencefalografía, mediciones neurofisiológicas, educación primaria, contexto educativo, estudio de caso.

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1. Introduction

The development of new portable devices for recording electroencephalographic signals (EEG) has opened the possibility of transferring studies on brain activity from laboratory conditions to real contexts. Considering the situated and culturally constructed nature of learning (Brown et al., 1989), the interest in studying brain functioning in everyday educational contexts is understandable. Studying the complexity of cognitive processes requires environments in which the maximum number of variables can be isolated. However, laboratory recordings limit the extrapolation of results concerning more natural conditions (Shamay-Tsoory & Mendelsohn, 2019).

The potential of these devices, the incipient studies in educational, commercial, or artistic settings, or the publicity of the companies that commercialize them have generated many expectations in researchers and educators, but, as Xu et al. (2022) point out, the feasibility of using these methods with schoolchildren, including the technical and pragmatic challenges associated with data quality, have not been sufficiently addressed. The need to deploy "real-world neuroscience" (Matusz et al., 2019; Shamay-Tsoory & Mendelsohn, 2019) clashes with limitations when developing studies in educational settings (Janssen et al., 2021). To analyze the potentialities and limitations of using this technology in school contexts, we propose this instrumental case study whose results may be helpful to researchers or educators who have considered the use of EEG in their investigations or as support for their educational interventions.

1.1. Key concepts

We will briefly review some concepts about EEG. There are different types of sensors used to pick up polarity changes (Hajare & Kadam, 2021). Not all of them are equally accurate. Basically, we find wet electrodes that need some electrolytic substance to facilitate conductivity (gel or saline solution), those whose sensors pick up the signal without preparation (dry electrodes), and dry electrodes whose reception is facilitated by a solution (semi-dry). Wet electrodes have better signal quality (Lau-Zhu et al., 2019), but if the collection time is prolonged, they can be affected by sensor dehydration. In general, dry electrodes reduce device placement times, but artifacts may affect their signal more (Shad et al., 2020).

The aim of the positioning of each electrode is to collect information on activity in the area of location, so the more electrodes placed on the scalp, the more detailed information can be obtained from a greater number of areas. The quality of the collected signal also depends on the sampling rate of the device (number of samples collected from a continuous signal in one second). A low sampling rate will retain many fragments of the emitted signal and make it easier to study.

The information provided by the EEG signal can be studied in different ways. Time-domain studies can be performed under laboratory conditions with the control of the stimuli presented. In situations where a prolonged measurement is made, a quantitative analysis of some wave characteristics would be appropriate. One form of quantification comes from studying spectral power characteristics in different frequency bands with functional significance (Basar et al., 1999). Changes in the power spectrum of these bands (delta, theta, alpha, beta, and gamma) would serve as neuromarkers of specific brain activities. These correlations between certain characteristics of the frequency spectra and different cognitive or emotional processes and states would guide the analysis of the data obtained in real educational contexts. Some examples are presented in Table 1.

Table 1. Neural correlates of some mental processes

State	Neuromarkers	Example of studies
Attention	Increased beta and gamma frequencies; decreased alpha frequencies	Grammer et al. (2021)
Approach or rejection	Frontal alpha asymmetry	Coan & Allen (2004)
Emotional activation	(BetaF3+BetaF4)/(AlfaF3/AlfaF4)	McMahan et al. (2015)
Cognitive load	Theta/alfa ratio	Antonenko et al. (2010)
Engagement	Beta/theta+alpha ratio	Pope et al. (1995)

It is essential to understand that these markers indicate correlation, not causation. They are not precise markers that identify underlying brain processes. Each neuromarker has been obtained with a particular population, a particular type of recording, or specific processing and feature extraction. Varying any parameter (e.g., equipment with which EEGs are collected, type of experimental situation or context, ages of participants, type of pre-processing...) may affect the meanings of these markers.

1.2. EEG in educational contexts

The accessibility of low-cost EEG devices has meant that some studies have appeared in the last decade investigating their application in different educational contexts. Compared to fields such as marketing or video games, research is still limited (Xu & Zhong, 2018). Table 2 presents an overview of recent studies.

Table 2. EEG studies in school contexts

Authors	Topic	Sample	Device	Signal processing
Dikker et al. (2017)	Teacher-student and student-student brain synchrony	12 students (age: 16-18) Simultaneous record. Naturalistic situation.	EEG 14 channels (128Hz)	Continuous signal segmentation. Calculation of spectral coherence between channels (minimum of 30 segments) and between participants (in 6 channels).
Bevilacqua et al. (2019)	Teacher-student and student-student brain synchrony	12 students (age: 16-18) Simultaneous record. Naturalistic situation.	EEG 14 channels (128Hz)	Continuous signal segmentation. Calculation of spectral coherence between channels (minimum of 30 segments) and between participants (in 6 channels).
Khedher et al. (2019)	Assessment of engagement and cognitive load.	15 university students Individual record. Semi-naturalistic situation.	EEG 14 channels (128Hz)	Continuous signal segmentation. Power spectral density (PSD) calculation. Application of the ratio beta/theta+alfa.
Dikker et al. (2020)	Variations in alpha power and peak alpha throughout the school day.	22 students (age: 17-18) Simultaneous record. Naturalistic situation.	EEG 14 channels (128Hz)	Segmentation of continuous data (occipital channels). Alpha power spectra and individual alpha frequency peaks.
Grammer et al. (2021)	Variations in different frequencies according to attention states before different instructional activities (lecture, videos, discussion...)	23 university students Individual record. Semi-naturalistic situation.	EEG 24 channels (250Hz)	Power of different frequencies of a segmented continuous signal.
Vekety et al. (2022)	Improvement of mindfulness and executive functions through a neurofeedback program.	31 shoolchildren (age:8-12) Individual record. Semi-naturalistic situation.	EEG 4 channels (250Hz)	Using EEG with a feedback app for relaxation.
Xu et al. (2022)	Attention analysis	46 shoolchildren (age:6-7) Records in trios. Semi-naturalistic situation.	EEG 24 channels (250Hz)	Analysis of alpha frequency spectral density.

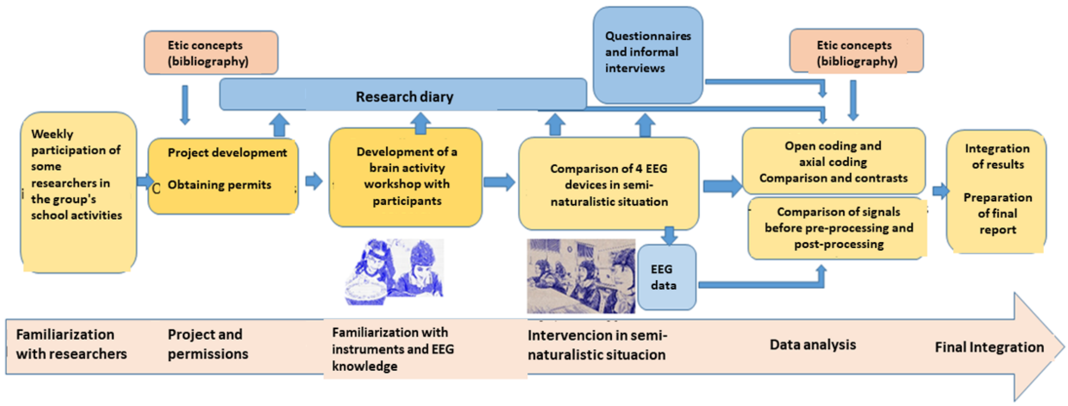
Matusz et al. (2019) suggest three categories to define research approaches concerning the degree of "naturalism": controlled laboratory, partially naturalistic laboratory, and naturalistic research. Accordingly, it is apparent from the review by Xu and Zhong (2018) that fully naturalistic works still need to be made available. Few studies integrate EEG technology into the regular classroom setting by simultaneously placing devices on all participants.

Studies with university students are dominant. The number of studies with schoolchildren is minimal. Sample sizes are small. Many studies use low-cost devices with less than five dry sensors, which limits the reliability of the data. The high cost of quality devices, their lengthy preparation, or the accessibility of samples with child populations could be some of the explanations for the limitations shown in this current picture. This case study explores these aspects, analyzing the potential and limitations of using EEG devices in school contexts.

2. Material and method

Since the purpose of this study is to analyze the potential and limitations of the use of this technology in school contexts, to inform researchers or educators who have considered the use of EEG in their studies, or as support for their educational interventions, an instrumental case study was chosen (Stake, 2010). From Stake's constructivist ontology, the methods are inductive and flexible, discovery and interpretation co-occur, the starting point is flexible initial conceptual frameworks, and the objective is understanding the phenomenon through interpretation and decreasing the distance between researchers and participants. The process followed is summarized in Figure 1.

Figure 1. Methodological process



The following issues (tensions) were taken as a starting point:

- Ease of use/quality of the recording.
- Potential of the data/possibilities and limitations of application in an educational context.

Based on these issues, the following guiding questions were posed:

- What pre-intervention aspects need to be considered?
- What are the advantages and disadvantages of each type of device?
- How do participants experience these interventions?
- What problems are posed by using these devices in educational contexts?
- What are the ethical implications of these investigations?

2.1. Context and participants

The study was conducted with a group of 17 third-grade primary school children aged between 8 and 9 years (10 girls and 7 boys) in a regular school with which the researchers collaborate. The schoolchildren knew part of the research team since they participated in weekly activities with them.

The design of the school tasks on which the recordings were made was agreed upon with the group's teachers, considering their concerns. To reduce the impact on the students when introducing these devices in the classroom and to take the opportunity for the students to understand better neuronal functioning, a week before the start of the study, a workshop was held in which the group was introduced to different aspects of brain activity, using playful neurofeedback devices. The study was carried out with the school permission, the informed consent of the families, and the approval of the University Ethics Committee.

2.2. Procedure

Given the limited number of devices (three of each type) and to avoid disrupting the normal development of the classes, a semi-naturalistic intervention was chosen (Matusz et al., 2019). A classroom adjacent to the group's regular classroom was used to develop the study. The students were summoned to the room in trios or pairs. While the different devices were placed, the students were reminded of some details about brain activity collection through EEG, as explained in a previous workshop.

After placing the devices and confirming the correct reception of the signals, two baseline recordings were made (2' with eyes closed and 2' with eyes open looking at a point in the central part of a blank sheet of paper). From the baseline recording the electroencephalographic activity of the students listening to different explanations about mathematical applications and performing some arithmetic tasks was collected. After using each device, the students were asked to answer questions about the comfort of the device, discomfort in its preparation, and interference in attending to or performingthe proposed tasks. The devices were placed randomly with each group of participants to avoid possible fatigue accumulation effects. The average recording duration with each group was 48'.

2.3. Instruments

Four EEG devices (three units of each) were used to compare their possibilities and limitations in a school context:

- Brainlink Pro: headband with two dry electrode contact sensors in the frontal area. The sampling rate is 512 Hz. Bluetooth sends the signal to the computer, which is collected thanks to Lucid Scribe software, which can be exported as a CSV file for pre-processing in EEGLab (Delorme & Makeig, 2004) or Medusa (Santamaría-Vázquez et al. ,2023).
- Emotiv Epoc: 14-channel EEG device with sensors requiring a saline solution to facilitate conduction and with a sampling rate of 128 Hz. The sensors are mounted in fixed positions on a plastic structure. The signal is sent wirelessly to the computer, which is collected by TestBench software, which can be exported as an EDF file for further pre-processing and analysis. It has been used in numerous investigations (Williams et al., 2020a).
- Epoc Flex: 32 channels with passive Ag/AgCI sensors (EasyCap) mounted on a neoprene cap allowing a choice of mounting positions. A gel provides conductivity. The sampling rate is 128 Hz. The amplifier placed in the cap wirelessly sends the signal to the computer. It is collected through an online application (Emotiv Pro) from which the data can then be downloaded in CSV or EDF formats. Their validation is reported in the study by Williams et al. (2020b).
- The Muse (InteraXon) device has 4 channels of dry contact electrodes that collect data with a sampling rate of 250Hz from the frontal and temporoparietal areas. The signals, sent via Bluetooth, can be collected on a tablet using the Mind Monitor application, which can be exported as a CSV file for further processing. This procedure has been validated by different research articles. Some research has validated it (Krigolson et al., 2017).

The assessments of the participating schoolchildren were collected through a questionnaire and informal interviews. Following previous work (Zerafa et al., 2018), the questionnaire asked them about their sensations during the device placement (Preparation: "very long", "long", "good", "very good"); the comfort of the device (Comfort: "very uncomfortable", "somewhat uncomfortable", "comfortable", "very comfortable") and the possible interference of the device in the tasks performed (Distraction: "very distracting", "somewhat distracting", "I have not noticed").

The responses to the questionnaire could be nuanced and expanded upon through interviews. A research diary was also used to record aspects of the project design, tasks and procedures, agreements with the school's teaching staff, interviews, informal exchanges with teachers and students, and critical incidents, difficulties, and details in the development of the experience.

2.4. Data analysis

EEG signals were compared before and after pre-processing with EEGLab. High-pass (0.5Hz) and low-pass (45 Hz) IIR Butterworth filters were applied in the pre-processing. For the data obtained from the Muse device, a 50Hz notch filter was also applied (Emotiv devices integrate this filter for electrical signal interference in the electroencephalographic signal).

The data were cleaned of artifacts with a first visual inspection, after which an algorithm for artifact subspace reconstruction was applied to discard channels muted for more than 5 seconds or with high-frequency noise of more than 4 deviations. Next, the data were re-referenced by computing the average reference (CAR). Finally, independent component analysis (ICA) was applied, and components dominated by non-neural sources (artifacts) were discarded.

For the analysis of the qualitative sources, open coding (Glaser & Strauss, 2006) was carried out in Atlas.ti, guided by the orienting questions and seeking the multi-referentiality of the data (among three researchers).

A first-order theoretical analysis was then carried out, constructing interpretations and translating descriptive codes into theoretical categories (Shkedi, 2004), supported by contrasting the concepts with other authors (Shkedi, 2004). Through comparison and contrast among codes and with theoretical categories from the literature, the data were integrated into axial coding (Glaser & Strauss, 2006) from which the following categories and topics emerged:

- Organizational aspects: previous contacts, impact reduction, familiarity with participants, researcher-teacher collaboration, expectations and reluctance, project, permissions, disruption of school life, space and time, and human resources.
- Equipment possibilities and limitations: adaptation to different sizes, preparation time, signal quality, and the limited number of channels.
- Participants' perspective: students' expectations, feelings about the preparation, comfort, distractions from the task due to the device, and teachers' expectations.
- Ethical implications: disruption/integration into school life, learning opportunity, data sensitivity, benefits.

3. Analysis and results

3.1. Organizational aspects

Since there is a change in the routine of the school with new people and equipment, maintaining prior contact is recommended. In the case studied, as commented by the teachers involved, the history of collaboration between the researchers and the school facilitated the latter's openness to new proposals. A proposal such as this one for using EEG in the classroom can generate curiosity and reticence. It generates a favorable disposition in most of the teaching staff, in most families, and in the student body. However, placing devices associated with electricity, pathology, or "access to the mind" creates misgivings among some teachers and families. For this reason, the project needs to be explained in detail. The teachers recognized that the trust generated in previous collaborations facilitated openness to this explanation.

Obtaining permission from the school and families takes time and requires, as mentioned, a detailed and pedagogical explanation of the project. In this case, some families did not give their permission. This would be a problem in the case of fully naturalistic projects implementing this technology in conventional classrooms.

This type of experience involves harmonizing schedules and spaces. School agendas are usually tight, and it is difficult to find time when some students can leave the regular classroom for another activity. In addition, only sometimes is there a free space available in the schools during data collection. In this case, the experience was postponed for almost two months until a suitable week was found.

For ethical and practical reasons, it is necessary to agree with the teachers in the design of the experience, considering their concerns and the educational program. This way, the proposal will be better adjusted to the students and the teacher's programming. The arrival of between 4 and 8 researchers at the school also impacts school life. The experience generates many expectations in the students. In the weekly meetings during the previous months, the students, who were enthusiastic, constantly asked us about the moment of "putting on the caps" and "reading their thoughts". Some asked with amusement if they were going to get electricity. We interpret that familiarity with the students allows them to open up and share their concerns. This familiarity of the students with some of the researchers also had repercussions on the state of the children when they took the tests. Schoolchildren say that trust makes them feel more at ease during the installation of the equipment or the development of the tests. This is important when, for example, we want to analyze anxiety states when faced with the proposed school tasks. The tension generated by the discomfort of the experimental situation could distort the data obtained. The students recognized that the previous workshop with playful activities on brain activity helped to generate a favorable disposition towards the devices, to have interest in the topic, to reassure them about the "experiments", and to get to know and approach the research team (9 researchers who would later participate in the data collection all took part in the workshop). The students said the workshop allowed them to understand details about topics they had studied (functioning of the nervous system and neuronal activity).

The use of several EEG devices simultaneously involves a lot of human resources. At least one person for each device to install it, synchronize it with the computer receiving the signal, ensure a good connection throughout the test, and record and save the different parts of the experiment (the preparation of a device with more channels is facilitated by the intervention of two people). In addition, it is interesting to have another person responsible for the questionnaires and the development of the different tests proposed to the students and one responsible for taking note of possible incidents and recording the experience.

The schedules for the research are adapted to the availability of the students; therefore, the collection of information is not continuous, and the members of the research team must spend hours at the school organizing the information, cleaning the devices, or preparing the new data collection. In any case, combining the team's availability with the school's timetable is another limiting aspect.

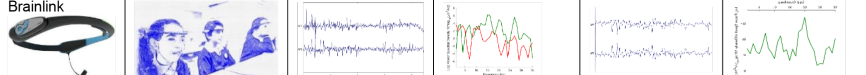
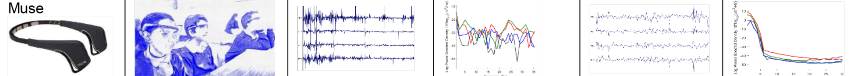
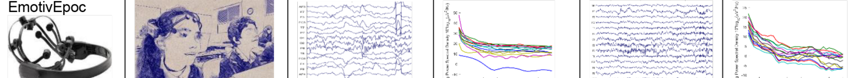
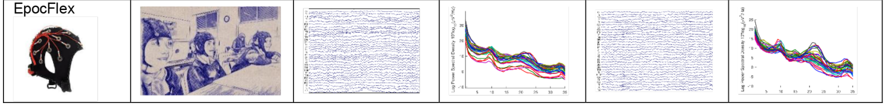
3.2. Device possibilities and limitations

The devices used have a wide range of adaptability to varying head sizes and shapes. Brainlink has a mobile strap system with easily adjustable Velcro. Hard plastic straps attach the Emotiv Epoc electrodes to the device's body. These straps adapt to different head shapes, although it must be verified that the sensors contact the same areas on all participants. With the Epoc Flex, caps of two sizes (size 50 and 54) were used according to head size. The flexibility of the neoprene makes it fit perfectly. Muse has an adjustable plastic headband that adapts to various head sizes.

The setup time varies mainly depending on the speed or problems with the connection between the EEG device and the device receiving the signal. BrainLink setup time averaged 2'21" and the most extended delays were due to pairing via Bluetooth with the computers receiving the signal. The average installation time of the Emotiv Epoc was 7'02", and the main problems derived from contact with the scalp of the sensors in those participants with curly or very thick hair. Problems were also caused by the sponges that facilitate contact falling off or the sensor terminals unscrewing from their holders. Epoc Flex, with 32 channels with gel, had an average preparation time of 10'15", but the longest delays were not due to the application of the gel (M=6'56"), but to problems with the wireless connection or opening the online application for data collection. Finally, Muse had an average preparation time of 2'45", especially due to finding good contact on the sensors behind the ears.

Because the devices are wireless, care must be taken to establish the connection between the EEG and the receiver by separating one device from the other so that recognition errors do not occur. The quality of the recorded signal varies among the different devices. Table 3 shows a visual example of the signals before and after pre-processing.

Table 3. Comparison of device signals

Device	Example of devices in context	Example of raw signal	Example of frequency spectrum without pre-processing	Example of pre-processed signal	Example of frecuency spectrum after pre-processing
Brainlink 					
Muse 					
EmotivEpoc 					
EpocFlex 					

The signals that record the highest number of artifacts (distortion of the signal by other sources such as movement, blinking, pulsation, or the field generated by the electric current) are those of Muse. The placement of its contact sensors on the forehead and behind the pinnae means they are greatly affected by blinking and jaw contractions. Table 3 shows that their frequency spectrum is somewhat unusual, with ups and downs in power and many differences among channels and high powers for high frequencies.

The case of Brainlink is similar. Its two front contact sensors are susceptible to blinking and facial movements. Similarly, the frequency spectrum does not resemble the usual one for EEG waves.

The poor fixation of the Emotiv Epoc's sensors means that it picks up several periods of contact loss and is very sensitive to head movements. Before pre-processing, the spectrum of its signal presents a picture closer to the usual spectrum of an EEG signal. The Epoc Flex gives the best signal quality (less affected by artifacts). Its better fixation to the head, and the better connectivity provided by the gel, resulting in fewer artifacts.

During pre-processing, the smallest number of signal segments that had to be deleted was in the Epoc Flex recordings. This is important to subsequently segment the signal and perform different analyses of cortical activity in the tasks proposed in the class. By applying an automatic artifact rejection method (Artifact subspace reconstruction, ASR), several BrainLink, Muse, and Emotiv Epoc device channels were automatically suppressed. Since these are devices with few channels, suppressing any of them cannot be compensated for by interpolating the measurements in nearby channels, and the loss of information will prevent measurements of different mental processes.

Using EEGLab's ICALabel tool (which shows the probability that a component captures brain activity or other artifacts), it was found that components of recordings with BrainLink, Muse, and Emotiv Epoc were strongly affected by muscle sources. An inverse relationship between preparation time and the number of electrodes was observed, but limiting the number of electrodes has consequences: fewer channels with fixed positions will not allow access to many neural correlates, and source recognition is less feasible or accurate.

3.3. Participants' perspective

As mentioned above, the students' expectations were very high, and after the experience, they all wanted to repeat it. This attitude is relevant to understanding that they likely tended to value the devices positively. Table 4 shows the results of their responses to the questionnaires on their feelings about the preparation, the comfort of the devices, and the possible distractions they generated during the tasks. The table shows the number of responses given and the average scores.

Table 4. Results of the questionnaire on sensations with the devices

					Mean	SD
BrainLink						
Preparation	Very long: 0	Long: 0	Good: 6	Very good: 11	3,647	0,477
Comfort	Very uncomfortable: 0	Somewhat uncomfortable: 5	Comfortable: 3	Very comfortable: 9	3,235	0,876
Distraction	Very distracting: 0	Somewhat distracting: 4	Not noticed: 12		2,75	0,433
Emotiv Epoc						
Preparation	Very long: 1	Long: 3	Good: 4	Very good: 9	3,235	0,94
Comfort	Very uncomfortable: 0	Somewhat uncomfortable:3	Comfortable: 7	Very comfortable: 7	3,235	0,729
Distraction	Very distracting: 0	Somewhat distracting: 5	Not noticed: 12		2,705	0,455
Epoc Flex						
Preparation	Very long: 2	Long: 3	Good: 1	Very good: 11	3,235	1,112
Comfort	Very uncomfortable: 0	Somewhat uncomfortable: 1	Comfortable: 2	Very comfortable: 14	3,764	0,545
Distraction	Very distracting:0	Somewhat distracting: 2	Not noticed: 15		2,882	0,322
Muse						
Preparation	Very long: 0	Long: 1	Good: 2	Very good: 14	3,764	0,545
Comfort	Very uncomfortable: 0	Somewhat uncomfortable: 2	Comfortable: 1	Very comfortable: 14	3,705	0,665
Distraction	Very distracting: 0	Somewhat distracting: 2	Not noticed: 15		2,882	0,322

The students, in this case, waited patiently for the preparations. In some cases, where the computer connections failed, or the online application failed to open, and the process took longer, they commented that they had become a little bored. With the Emotiv Epoc, the problems in the connection of some electrodes in girls with thicker hair and the repositioning of contact sponges or electrodes led four participants to evaluate the preparation of this device as long (3) or very long (1). In the case of the Epoc Flex, the problems of wireless recognition of the device, or errors in accessing the data recording platform, lengthened the process and led some schoolchildren to rate it as very long (2) or long (3).

Regarding comfort, in general, the sensations were good. The discomfort recorded came from the pressure on the forehead of the BrainLink sensors (5 cases); the pressure of some sensors in the temporal region of the Emotiv Epoc (3); some itching behind the ears of Muse (2); and a particular sensation of rubbing under the chin by the fixing tape of the Epoc Flex (1 case). To avoid discomfort from the gel residue used in the Epoc Flex, the hair was cleaned with alcohol and brushed afterward. Few participants felt distracted from tasks by the devices. In some cases, they commented that they were careful not to move the device (Muse and Emotiv Epoc) or not to move themselves to avoid introducing "noise" into the signal.

As for teachers' expectations about these experiences, they expected to learn details about their students' responses to different tasks and the neural processes underlying learning, as well as to corroborate their opinions about each student. In some cases, they had higher expectations of what can be researched in practice. Moreover, they saw that it involved too great a deployment of means and people to be integrated into the classroom. They had doubts about the feasibility of integrating these devices into conventional classrooms.

3.4. Ethical issues

The above findings carry several ethical implications. This type of experience disrupts school life. To reduce this possible disruptive effect, it is essential to integrate them into the program and plan them according to teaching criteria. The tests should be brief to avoid student fatigue and should not interfere with other school activities. For students, it is an opportunity to get in touch with devices, procedures, and knowledge that are difficult to access.

Data are sensitive, and ensuring their confidentiality and security is essential. We are dealing with children's biological signal data, and it is important to follow all the protocols for data protection. We understand that the child's benefit is the basic criterion to guide these experiences. If the research results can help teachers better orient their educational practice and the experience enriches the participants, the disadvantages will have been compensated for. Hence, the designs of these experiences allow access to relevant information for teachers and students.

4. Discussion and conclusions

This case study aimed to analyze the possibilities and limitations of using EEG devices in school contexts to inform researchers or educators who have considered using EEG in their studies or as support for their educational interventions. The development of these experiences involves the interests of teachers, schoolchildren, families, and researchers, which requires collaboration and advancing interdisciplinary research (Katzir & Paré-Blagoev, 2006). This connection between research and educational practice can help scholars better understand school reality by refining their research questions (Liu & Zhang, 2021). To the educational community, it can show the potential of brain research (Mason, 2009). This entails seeking partnership models based on analyzing teacher, student, and family demands (Howard-Jones et al., 2016; Liu & Zhang, 2021) that can better fit these experiences into educational programming. Likewise, it entails relationships of mutual trust (Liu & Zhang, 2021) forged over time. In any case, the costs of deploying material and human resources and adjusting schedules must be considered.

Regarding the devices, the results on the adaptability and comfort of the devices used align with previous studies with other age groups (Zerafa et al., 2018). Similarly, previous studies warn of the sensitivity to the movement of equipment such as the Emotiv Epoc, but not so for Muse's sensitivity to blinks or facial movements (Krigolson et al., 2017). The quality of the recordings with the Epoc Flex aligns with previous studies (Browarska et al., 2021). No references to delays caused by connectivity or access problems to the data collection platforms were found.

The limitation of the number of electrodes in some devices is a problem for accurate source modeling (Akalin-Acar & Makeig, 2013). It reduces the processes to be studied and the possible analyses (Lau-Zhu et al., 2019). Looking at Table 1 about some possible neural correlates, it will be understood that with 2 or 4 channels, it is difficult to analyze many cognitive processes. To generalize these correlates around an age group and to be able to simplify the number of electrodes, a process would be needed in which, after a recording with a large sample and a wide coverage of the scalp, signal classification could be performed (through machine or deep learning) that would allow the development of applications that classify new signals from data generated by devices with few sensors (Craik et al., 2019).

Beyond the organizational or technical aspects, we find the ethical implications. The potential of this work lies in benefitting educators with a better understanding of the processes underlying their proposals and the effects of their work, thus facilitating educational situations that are better adjusted to the characteristics and needs of the students. However, as Rose and Abi-Rached (2014) explain, we must not lose sight of the fact that emerging neurotechnologies increase the risk of using the brain as a "biopolitical resource", promoting processes of optimization and competitiveness. Williamson (2018) also warns of the dangers of "neurogovernance" that aspires to "scan" the brain to "sculpt" specific capabilities. The political dimension of education is well known, and its objectives and implications should be considered in this type of research.

The development of immersive experiences in education entails a series of tensions that must be carefully navigated. These tensions involve striking a balance between the interests and possibilities of research teams and educational communities, as well as between the potential distortion of classroom life and the opportunities for collaboration between academia and practice. In addition, there is a need to balance the budget and ease of preparation of research teams with the usefulness of the data collected.

Currently, the extension of these experiences to entirely naturalistic settings is limited by the costs of necessary devices and human resources. However, ongoing efforts to expand the scope of these experiences hold promise for generating a robust body of knowledge that can inform future applications. As sensors continue to improve and device costs potentially decrease, it may be possible to broaden the reach of these experiences for the benefit of education.

Authors' Contribution

Idea, A.G-M.; Literature review, A.G-M., H.R-N.; Methodology, A.G-M., H.R-N., J.M.M-P.; Data analysis, A.G-M., H.R-N., J.M.M-P.; Results, A.G-M., H.R-N., J.M.M-P.; Discussion and conclusions, A.G-M., H.R-N-N., J.M.M-P.; Editorial (original draft), A.G-M., H.R-N., J.M.M-P.; Final revisions, A.G-M.; Project design and sponsorships, A.G-M., H.R-N., J.M.M-P.

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