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Neurotechnology in the classroom: Current research and future potential

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ERIH+

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CONTENTS

Comunicar, 76, XXXI (2023-3)

Neurotechnology in the classroom: Current research and future potential

Neurotecnología en el aula: Investigación actual y futuro potencial

DOSSIER

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'Comunicar', Media Education Research Journal is published by Grupo Comunicar Ediciones (VAT: G21116603). This established non-profit professional group, founded in 1988 in Spain, specialises in the field of media education. The journal has been in print continuously since 1994, published every three months.

Contents are peer reviewed, in accordance with publication standards established in the APA 7 (American Psychological Association) manual. Compliance with these requirements facilitates indexation in the main databases of international journals in this field, which increases the dissemination of published papers and therefore raises the profile of the authors and their centres.

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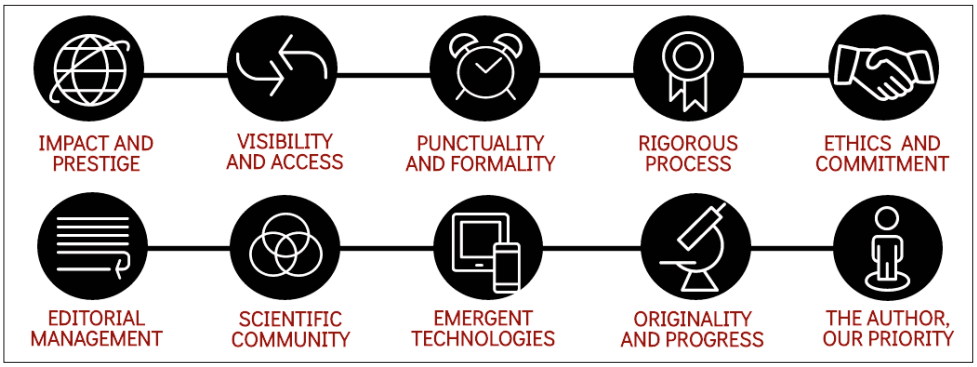

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• Received manuscripts internationalisation: 39 countries.
• Numbers of Reviews: 260 (72 internationals and 188 nationals) (update: www.comunicarjournal.com).
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Neurotechnology in the classroom: Current research and future potential

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Towards learner performance evaluation in iVR learning environments using eye-tracking and machine-learning

Hacia una metodología de evaluación del rendimiento del alumno en entornos de aprendizaje iVR utilizando eye-tracking y aprendizaje automático

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ABSTRACT

At present, the use of eye-tracking data in immersive Virtual Reality (iVR) learning environments is set to become a powerful tool for maximizing learning outcomes, due to the low-intrusiveness of eye-tracking technology and its integration in commercial iVR Head Mounted Displays. However, the most suitable technologies for data processing should first be identified before their use in learning environments can be generalized. In this research, the use of machine-learning techniques is proposed for that purpose, evaluating their capabilities to classify the quality of the learning environment and to predict user learning performance. To do so, an iVR learning experience simulating the operation of a bridge crane was developed. Through this experience, the performance of 63 students was evaluated, both under optimum learning conditions and under stressful conditions. The final dataset included 25 features, mostly temporal series, with a dataset size of up to 50M data points. The results showed that different classifiers (KNN, SVM and Random Forest) provided the highest accuracy when predicting learning performance variations, while the accuracy of user learning performance was still far from optimized, opening a new line of future research. This study has the objective of serving as a baseline for future improvements to model accuracy using complex machine-learning techniques.

RESUMEN

Actualmente, el uso de los datos del seguimiento de la mirada en entornos de aprendizaje de Realidad Virtual inmersiva (iVR) está destinado a ser una herramienta fundamental para maximizar los resultados de aprendizaje, dada la naturaleza poco intrusiva del eye-tracking y su integración en las gafas comerciales de Realidad Virtual. Pero, antes de que se pueda generalizar el uso del eye-tracking en entornos de aprendizaje, se deben identificar las tecnologías más adecuadas para el procesamiento de datos. Esta investigación propone el uso de técnicas de aprendizaje automático para este fin, evaluando sus capacidades para clasificar la calidad del entorno de aprendizaje y predecir el rendimiento de aprendizaje del usuario. Para ello, se ha desarrollado una experiencia docente en iVR para aprender el manejo de un puente-grúa. Con esta experiencia se ha evaluado el rendimiento de 63 estudiantes, tanto en condiciones óptimas de aprendizaje como en condiciones con factores estresores. El conjunto de datos final incluye 25 características, siendo la mayoría series temporales con un tamaño de conjunto de datos superior a 50 millones de puntos. Los resultados muestran que la aplicación de diferentes clasificadores como KNN, SVM o Random Forest tienen una alta precisión a la hora de predecir alteraciones en el aprendizaje, mientras que la predicción del rendimiento del aprendizaje del usuario aún está lejos de ser óptima, lo que abre una nueva línea de investigación futura. Este estudio tiene como objetivo servir como línea de base para futuras mejoras en la precisión de los modelos mediante el uso de técnicas de aprendizaje automático más complejas.

KEYWORDS | PALABRAS CLAVE

Virtual environment, game-based learning, machinelearning, eye-tracking, feature extraction, neuroeducation.
Entorno virtual, aprendizaje basado en juegos, aprendizaje automático, registro de mirada, extracción de características, neuroeducación.

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1. Introduction and state of the art

Over the past decade, lower neuro sensor costs and simpler dataacquisition and analysis techniques within different sectors have widened the scope of many final applications. Eye-tracking systems, for example, incorporate many of those techniques. The expensive customized solutions of advanced medical and even advertising research (Duchowski, 2002) have evolved into reliable commercial solutions such as high-end laptops and reasonably priced Virtual Reality Head Mounted Displays (Shadiev & Li, 2022). Compared with other neuro sensors, eye-tracking provides stable signals that describe gaze behavior, one of the main doors to the analysis of human behavior in both education and psychology (Rodero & Larrea, 2022), to name a few. Besides, eye-tracking has a powerful advantage in terms of final user acceptance: its low intrusiveness. For instance, the user can freely perform varied tasks wearing only a lightweight pair of glasses fitted with eye-tracking technology. This neurosensory device also has a drawback: it only records data on eye fixation pupil dilation and constriction. In other words, no cerebral responses to external visual objects that might cause the eye to react in one way or another are monitored.

Two promising fields of application for eye-tracking are education (García Carrasco et al., 2015) and training (Gardony et al., 2020). Eye-tracking can help to answer many questions: How do we look at learning materials depending on their multimedia presentation? How easily are we distracted? Which activities focus our attention more than others? For how long we can concentrate on a certain issue? etc. (Farran et al., 2016; Glennon et al., 2020). The answers to these questions can help teachers and trainers to better understand how we learn and how to optimize learning and training experience, to maximize learning and training outcomes. Eye-tracking can help to solve these questions in both 2D environments, i.e., screens (Añaños-Carrasco, 2015), and in 3D environments, i.e., real world and immersive Virtual Reality (iVR).

IVR environments present some challenging advantages for learning and training (Checa & Bustillo, 2020). Firstly, they offer hands-on learning: learner-centered rather than teacher-led interactive experiences. Secondly, the students learn in autonomous ways at their own pace, unlike standardized learning experiences that, in many cases, reduce learning outcomes. Thirdly, real-life difficulties may be simulated for both students and workers: from reorienting attention and dwell time in city environments (Lapborisuth et al., 2021) to awareness, prevention and detection of anxiety or depression in students (Martinez et al., 2021).

Finally, users of iVR environments have no feeling of being under observation: as the immersiveness of the experience increases within the iVR environment after a couple of minutes, the feeling of being observed decreases, prompting natural behavior. As the iVR experience can be recorded and closely monitored, user performance is more closely evaluated than it is, for example, in exam-based learning experiences. The analysis of behavior metrics can also be used for learner assessment in iVR. This VR simulation (Wismer et al., 2022) used for the assessment of compliance and physical laboratory skills accurately predicted (77%) both the expert and the novice status of the user. Collecting relevant behavioral data in VR, e.g., head and eye movement tracking, and behavior metrics data will yield more accurate results. Eye-tracking and iVR environments are, therefore, new technologies for learning and training with a challenging future, available to the general public and to specialists alike. The new Head Mounted Displays (HMDs) for immersive experiences within high-quality iVR environments record eye-tracking data in a non-intrusive way.

Up until now, eye-tracking has been used for basic actions: movements within iVR environments when physical room is limited (Sun et al., 2018), hands-free interaction within the iVR environment, such as text typing (Ma et al., 2018) and moving virtual objects (Tanaka et al., 2021). Some examples of complex tasks are prioritizing a scene according to user gaze (Patney et al., 2016) and measuring cognitive workload by means of eye-tracking, which was first investigated for a very specific task: training surgeons during analogous vesicourethral anastomosis tasks (Cowan et al., 2021). Leveraging eye-tracking technology within VR presents a novel approach to studying learner attention and motivation, while potentially improving teaching effectiveness and serving as a valuable assessment tool (Rappa et al., 2022). However, some major problems must be overcome before it can be fully implemented in learning environments that apply eye-tracking.

Firstly, efficient processing of massive iVR datasets of eye-tracked learning experiences must be demonstrated. Secondly, assuming that useful information could be identified in those datasets: could we identify the best way of learning depending on the available iVR contents? Thirdly, the most accurate techniques for extracting this hidden information should be established, considering that learning is a changing and customized process for each human being. All these questions should be answered for 3D eye-tracking, a more complex task than traditional screen-based 2D eye-tracking (Gardony et al., 2020). Eye-tracking technology has the potential to complement other data collection tools and provide distinct data sets that can enhance learning in virtual reality environments. For this purpose, machine-learning techniques might be one of the most promising solutions for all these tasks and questions (Gardony et al., 2020).

Machine-learning implies data-driven techniques used to learn from big datasets that describe complex tasks. The application of machine-learning techniques to eye-tracking datasets recorded in iVR learning environments can be for different tasks (Gardony et al., 2020). Firstly, machine-learning can perform a task commonly known as feature extraction, which is used to identify the main features of those datasets where key information is concentrated. For instance, hierarchical discriminant component analysis, a machine-learning technique, has been successfully used for eye-tracking and EEG-dataset feature extraction for gaze and attention reorientation across different gaze events (Lapborisuth et al., 2021).

Secondly, machine-learning can classify a user attention exercise and the quality of a learning environment; furthermore, on the same basis, it can predict user learning performance by comparison with previous patterns. Asish et al. (2022) roposed the use of deep learning (Convolutional Neural Networks) to classify attention in 3 exercises during an iVR learning experience based on a labelled eye-gaze dataset. Thirdly, ML may be used in a more complex architecture to adapt the learning iVR environment to the specific needs and pace of each individual user.

On the basis of the three tasks mentioned above, machine-learning can help the design of eye-tracked iVR experiences. In this research, the second task is addressed. Different machine-learning techniques were used to classify learning-environment quality and to attempt to predict user learning performance. These two objectives were then tested on a huge dataset (>50M data points) of real experiences within a realistic learning scenario where 63 students repeated a defined task and improved their performance.

Compared to a previous huge dataset (Asish et al., 2022), a labelled eye-gaze dataset with 3.4M data points, the one in this study is 15 times the size and has greater dataset diversity (different expertise levels and environmental conditions), increasing the complexity of the proposed task: from user identification to learning quality classification and the prediction of user-learning performance. Finally, the question to be answered in this research is whether eye-tracking-based datasets from iVR learning environments are suitable for the evaluation of learning conditions and learner performance by means of machine-learning. It should be outlined that this research does not aim to find a reliable and robust solution for these tasks, but a first approach that will provide a baseline for future improvements in this research strategy.

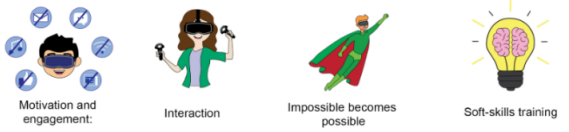
2. Material: An iVR learning environment

It is advisable to follow three steps (Figure 1) in the development of an effective iVR educational experience: pre-design, design, and evaluation (Checa & Bustillo, 2020). The first step, pre-design, establishes a scenario in which learning is enhanced through the introduction of iVR technologies. In this research, an iVR environment for learning how to operate a bridge crane has been created. The bridge crane is used in many industrial and transport-related processes. Remote-control operation means that iVR simulators can closely mirror industrial tasks. An iVR training experience acquires user performance data during exercises to test expertise and is designed to be short, easy to learn, and repeatable.

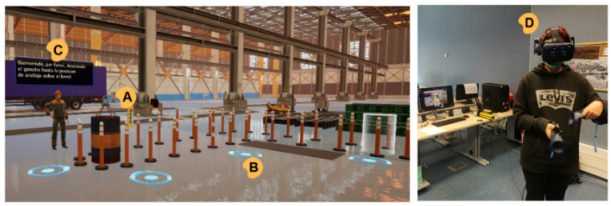
Once the learning objectives are fixed, it is necessary to apply a pedagogical approach and to take learning theories into account during the design phase. Learning theories provide guidelines on student motivations, learning processes, and outcomes (Pritchard, 2017). This experience seeks to promote learning by linking iVR to a fusion of principles from multiple pedagogical perspectives. There are many learning theories developed for use in iVR experiences or that can be easily accommodated for use in these new technologies. Four learning theories were considered for this research.

Figure 1. Stages followed for developing the iVR learning experience

(I) Pre-design: Establishing a scenario in which learning is enhanced by the introduction of iVR technologies. Advantages of virtual reality versus traditional learning (Checa & Bustillo 2022a):



(II) Design: The experience is designed to achieve the highest degree of user immersion. (A) Photorealistic environment to interact with the overhead crane controller. (B) Teleport point for fixation movement. (C) Virtual actor guiding the user. (D) User performing the experience with an HMD.



(III) Evaluation: (A) Analyze the handling skills of an overhead crane in novice users under ideal conditions. (B) Clocked environment (visual and auditory). (C) Environment with dim lighting (visual). (D) Environment with high operator traffic (visual and auditory).

Firstly, the theory of situated learning (Huang et al., 2010) that employs a constructivist approach, in so far as students learn professional skills by actively participating in an iVR experience. Secondly, the technological perspective of the 3D Virtual Learning Environments (Dalgarno & Lee, 2010), according to which students learn through autonomous interaction, hands-on learning, and problem solving.

Thirdly, the embodied cognition framework (Wilson, 2002) where there is a connection between our motor and visual senses; therefore, the more explicit the connection, as within iVR experiences, the easier the learning becomes. Finally, the theoretical underpinning of Dale's cone of experience (Dale, 1946) holds that students learn best when they go through a real experience, or the experience is realistically simulated. The proposed iVR learning environment offers a realistic experience in which to practice these principles and a safe environment where some mistakes can be corrected.

The second step of this methodology is the design phase. The experience is designed to achieve the highest degree of user immersion. Immersion is the subjective impression of participating in a realistic experience and involves the willing suspension of disbelief. The design of immersive learning experiences that induce this disbelief draws on 1) sensory, 2) action-oriented, and 3) symbolic factors (Dede, 2009). Related to sensorial factors, the goal is to replace real-world sensory information with synthetic stimuli, such as 3D visual imagery, spatialized sound, and force, or tactile responses (Bowman & McMahan, 2007). Related to action-oriented factors, action immersion is a way of empowering the participant in an experience where actions can be initiated that replicate those of the real world. The experience is designed to allow intuitive and natural actions. These interactions were developed with the support of a previously created framework (Checa et al., 2020). The framework simplifies the development

process with functions and services that are pre-programmed for their effective reuse. Remote control of an overhead crane is the primary means of interaction between the user and the application. The user can grab the controller with either hand and press the buttons that control the movement of the bridge crane with the other hand as shown in the video presentation of the simulator (Checa & Bustillo, 2022). Furthermore, the user is able to move within the available space of its current reality, approximately 3x3 meters. However, it was found that the user required additional space to complete the proposed exercise, so a movement system based on fixations was created. Four teleportation points were arranged as shown in Figure 1 (II-B).

Finally, considering the symbolic factors, the activation of semantic and psychological associations is essential for symbolic immersion of the participant in the content of the experience. A real situation that is recreated in a digital version deepens the immersive experience. In this case, in order to encourage these associations, the scenario, shown in Figure 1(II), was designed to be photorealistic. Unreal Engine, a graphics game engine compatible with the selected HMD, was used for the creation of this educational iVR experience.

The evaluation is the last phase of the development of this educational iVR experience. In this research, the skills of novice users when operating a bridge crane under ideal conditions and with external aspects that affect visual or auditory performance were analyzed. To do so, different environments were created in which the task to be performed was always the same, changing only certain external aspects that affected performance. The proposed task consisted of moving a bridge crane hook towards a barrel at a starting position, hooking up the barrel, and completing the proposed course within the shortest possible time, while trying not to knock down any cones. Figure 1 (III) shows the different factory premises where the task was performed. Figure 1(III-A) corresponds to ideal conditions, Figure 1(III-B) to the clocked environment (visual and auditory), Figure 1(III-C) to an environment with dim lighting (visual), and Figure 1(III-D) to an environment with high operator traffic (visual and auditory). It must be mentioned that a short experience with simple objectives was designed where different unforeseen factors could easily be introduced as disturbances. With this strategy, users can test the experience more than once within a short time, recording different levels of expertise as they quickly learn, by repetition and under different learning conditions, as the number of disturbances increased. Different data types, presented in Section 3.2. were automatically collected for this evaluation.

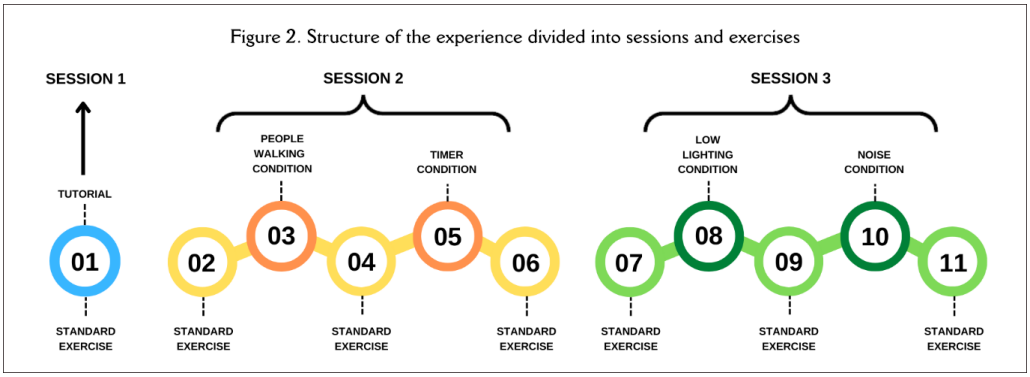
3. Learning experiences and dataset as the method

In this section, the participants and their learning experiences, as well as the data on the learning experiences are described.

3.1. Learning experiences

The learning experiences were split into 3 sessions performed in consecutive weeks for data collection. The structure of the entire experience is shown in Figure 2.

Figure 2. Structure of the experience divided into sessions and exercises



In the first session (Session 1 in Figure 2), the participants performed an iVR tutorial to learn to use the basic controls of the bridge crane and to become familiar with the iVR environment. They then

completed the standard exercise of the educational iVR experience described in Section 2. In this exercise, participants had to operate the bridge-crane so that the barrel was hooked up and transported through a circuit between cones without the load falling and without knocking down any cones. The exercise ended when the user left the load at the end of the circuit. This standard exercise was repeated in the following exercises to improve the skills of the participants at controlling the bridge-crane.

A week later, the second session took place, which consisted of 5 exercises (Session 2 in Figure 2), the first, third, and fifth of which were standard exercises of an educational iVR experience. In the second one, the user controlling the bridge-crane had to follow safety procedures when operatives were walking through the factory. In the fourth exercise, the sound of a factory bell was included that might be stressful for operator performance.

Finally, the last 5 exercises (Session 3 in Figure 2) formed the third session. The standard routine was repeated in the first, third, and fifth exercises. In the second one, lighting conditions worsened, which meant operating the bridge crane was more difficult. Finally, potentially stressful background noises within the factory while operating the bridge crane were added that could affect performance in the fourth exercise. Furthermore, to finish the whole experience, all participants were invited to complete a satisfaction survey. The purpose of gathering this information was to study whether the above-mentioned factors influenced the results of the participants.

The sample consisted of 63 students (56% female) of third-year Audio-visual Communication Degree or first-year Communication and Multimedia Design Master's Degree. The mean age of the sample was 22.3 years old (SD=2.15), and all participants performed the three sessions under the same conditions.

The setup used for the three sessions consisted of three desktop computers equipped with Intel Core i7-10710U, 32GB RAM and NVIDIA GTX 2080 graphics cards connected to HTC Vive Pro Eye HMDs and their hand-controllers (see Figure 1D). These experiences were all performed while following Spanish regulations to prevent the transmission of COVID-19. The approved Burgos University Bioethics Committee protocol was followed for data collection in compliance with data protection (Reference Number: UBU 01/2022).

3.2. Dataset description

A dataset was created to collect data from the experience described in Section 2. It included two types of data: 1) global data from each exercise; and 2) user performance data. The dataset is summarized in Table 1 (https://bit.ly/3nOpd5G). For the global data, the selected attributes were: user identifier (ID); time (T) spent on task; collision faults (F); and number of times two buttons simultaneously pressed on crane control (Pb).

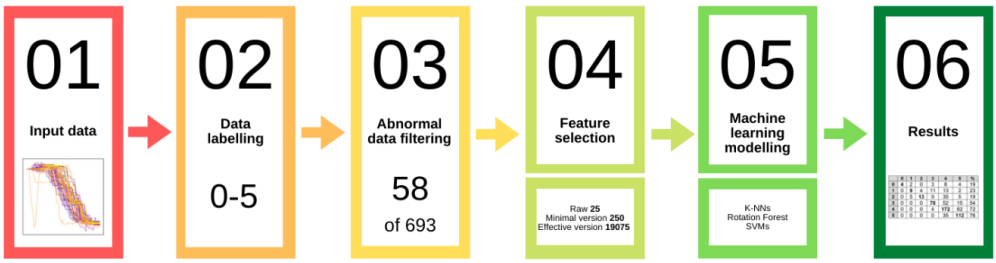
The user performance data consisted of 15 inputs or attributes within the iVR environment related to position and rotation of: the crane ($Cp_{x,y,z}$ and $Cr_{y,z}$), the load ($Lp_{x,y,z}$ and $Lr_{x,y,z}$), and the user's head ($Hp_{x,y,z}$ and Hr_x). Moreover, 10 inputs were extracted from the eye-tracking system: gaze focus position ($Fp_{x,y,z}$); distance between user and focal point (D); eye openness (EL_o and ER_o); and pupil position ($PLp_{x,y}$ and $PRp_{x,y}$). Those last 25 inputs were temporal series acquired at 120 Hz.

Figures in the left column of Table 1 show the temporal evolution of one input (Lp_x) for all users for the 2^{nd}, 8^{th}, and 11^{th} exercises, showing no possibility for traditional data analysis to extract immediate information from them. The Experience number (Xn) and the user Performance (P) results are also shown in bold in Table 1, variables that will be considered as outputs or classes for the prediction models, as will be explained in Section 4.1.

4. Analysis and findings

Having recorded the data from the learning experiences, totalling 693 exercises, the machine-learning modelling was performed in several stages. First, the data were labelled. Then, the data underwent pre-processing (data encoding, handling missing values and outliers and normalization), visualization, and feature selection, before input into the machine-learning algorithms. Finally, the application of classification techniques was tested. Figure 3 summarizes these stages.

Figure 3. Structure of data processing



4.1. Data labelling

In real-world environments, objective monitoring of learner performance to determine whether a learner is ready to perform a certain task or whether they need more preparation can be difficult. However, metrics such as completion time and accuracy can be objectively recorded in a virtual environment. These metrics have been used in this study as a learner performance measure.

The selected learner performance measure, labelled as an integer value between 0 and 5, was based on two parameters: 1) completion time; and 2) collision faults. The faults were calculated from the number of cones knocked over during the exercise and the number of times that several buttons of the controller were pressed at the same time. Both parameters were rated from 0 to 5, and the minimum of both was assigned as the final performance metric. As for the labels used for the learning context, they correspond to those used to identify each exercise and have been described in Figure 2.

Each exercise described in Section 3.1 for each user was considered a single sample, so a performance evaluation was assigned for each user and exercise performed. Each user performed 11 sessions and 63 users participated in the experiment, so the original dataset was composed of 693 samples. The distribution of each dataset label in the sample was as follows: label 0, 3%; label 1, 5%; label 2, 12%; label 3, 26%; label 4, 35%, and label 5, 19%. A clear unbalance, especially in classes 0 and 1, was observed- a natural result considering that users quickly learn the proposed task, improving their score after the first couple of sessions.

4.2. Data preparation and feature extraction

During the data-capture stage, errors may occur that are difficult to detect during the experience, and it is crucial to filter them out so that they do not introduce noise into the dataset. Software capture failures can occur due to buffer saturation, momentary sensor failure, and even circumstances such as reflections in the glasses or misalignment of the HMD. These are errors that can be detected by data visualization and then filtered.

Data pre-processing was therefore used to filter out abnormal data, prior to the machine-learning tasks. Several libraries that are widely used in the field of data science were selected for this task. On the one hand, for data visualization, the Pandas library (McKinney, 2011) and the tslearn package (Tavenard et al., 2020) were selected, due to their special design for time series analyses. As a result, 58 samples were removed from the original dataset of 693, because they showed very high abnormalities or unusual user behaviours. On the other hand, the samples were of different duration, as each learner completed the exercises within a different amount of time. Research on time series classification is usually focused on the case of uniform length series. As this work is intended to provide a baseline for future research, the time series were normalized, in this case to the maximum length (4326), making use of the Timeseries Resample function of the tslearn library which performs linear interpolation. The time series were then resampled to the longest duration (4326 datapoints), until they were all of the same length.

Secondly, feature selection of the raw data was performed. The objective of this task was to explore the amount of useful information hidden in each dataset. For this purpose, the FRESH algorithm (Christ et al., 2016) was used from the tsfresh package (Christ et al., 2018). Its library includes a wide variety of features that can be derived from raw time series data; in this case, 19075 features for each time series were

extracted. The set of features can include basic statistical attributes (peaks, highs, lows, etc.), correction measures, and evolution of a time series (white noise, trend, seasonality, autocorrelation, etc.). There are some library pre-defined dictionaries, two of which were used in this study. A lighter version, called "minimal", and a more complete one called "efficient". Feature extraction was carried out in both modes, thus obtaining two new datasets: one with the minimal version and the other with all the features, called the efficient version.

4.3. Learner performance and modelling process

The machine-learning algorithms were then used to predict learner performance and learning environment quality. The three different datasets proposed in Section 4.2 were tested: 1) the original raw data, 2) the minimal version of feature extraction and 3) the complete version (efficient version).

Three machine-learning techniques, each of a very different nature, were tested for this task: 1) k-nearest neighbours, a simple yet efficient clustering algorithm that uses proximity to make classifications or predictions about the grouping of an individual data point. The value of k defines how many neighbours will be checked (in this case k was set to 1). 2) Support Vector Machines (SVM), a complex well-established algorithm that defines a hyperplane in an N-dimensional space, with N as the number of features that distinctly classify the given data points. And 3) Random Forest (RF) an optimal diversity algorithm, which builds decision trees on different samples and uses majority voting for classification and averages for regression. The aim is to evaluate which one best predicts performance and the most suitable dataset for that classification task. The three algorithms were evaluated using the WEKA library (Hall et al., 2008).

A cross-validation scheme was selected, due to its statistical invariance for the selection of those subsets, to split the dataset into training instances and validation instances. A 10-fold cross-validation was selected due to the dataset size. The selected quality indicator was accuracy, representing the proportion of correctly classified observations over the number of total instances that were evaluated.

4.4. Results

Table 2 shows the results obtained for each of the mentioned experiments. The best results are highlighted in bold. The minimal version dataset obtained better results than the other two datasets, showing the necessity of feature selection in datasets of this sort. As for the algorithms, Random Forest was the one that clearly performed the best in both tasks.

Table 2. Environmental quality and learner performance classification results

	Exercises (Accuracy (%))			Learner Performance (Accuracy %)		
Algorithm / Dataset	RF	1-NN	SVM	RF	1-NN	SVM
Raw data	**43.56**	26.17	35.41	**42.38**	35.24	40.74
Minimal version	**44.29**	31.12	42.34	**59.31**	48.20	51.98
Efficient version	**40.11**	25.84	40.72	**59.12**	48.05	51.72

Some issues should be outlined. First, the poor performance of kNN showed that the algorithms that were used to search for previous experiences with a strong similarity to the one to be predicted were unsuitable for these sorts of tasks. So, this result outlines that different levels of expertise and learning conditions increase the complexity of predicting learner performance. It is a fascinating challenge where machine-learning techniques that are especially designed for complex data structures will play a central role. Second, all the feature-extraction techniques and machine-learning algorithms that were tested provided medium-to-low prediction performance, which was hardly highly accurate, revealing a future research line for improvement. Finally, average performance values are shown in Table 2, while the performance of all classes (performance levels or exercises) was not shown. The confusion matrix for the best method, Random Forest, and both classification tasks are shown in Table 3 to analyze this issue in detail, including the percentage of correctly predicted instances on the right of each confusion matrix. The confusion matrix for the classification of the experiences (on the left of Table 3) showed that the experiences with some kind of learning limitation (noise, time pressure…) achieved high levels of accuracy (78% on average compared

with the 26% for the standard exercises); those were exercises 3, 5, 8, and 10, marked with an asterisk in Table 3. Regarding learner performance, although the model failed to give the right classification, it tended to predict classes that were close to the right ones; therefore, the system was able to classify novice students and expert students correctly. The classifications of the models were significantly better for classes 3, 4, and 5 (medium-high good performance) than for classes 0, 1, and 2 (low performance). A result that was also foreseeable, given the imbalance of the classes outlined in Section 4.1.

Table 3. Confusion Matrix for classification of experiences (left) and performance (right) - RF model

	1	2	3*	4	5*	6	7	8*	9	10*	11	%
1	**21**	11	0	3	0	0	4	0	0	0	0	54
2	12	**26**	5	2	4	3	7	0	0	0	0	44
3*	6	9	**39**	0	5	3	4	0	5	0	0	55
4	3	11	9	**10**	3	7	5	0	9	0	13	14
5*	0	0	9	0	**43**	0	0	0	0	0	0	83
6	3	7	2	15	10	**4**	3	0	7	0	17	6
7	5	8	7	5	3	2	**15**	0	10	0	5	25
8*	0	0	0	0	0	0	0	**65**	0	0	0	100
9	0	2	0	9	2	9	8	0	**7**	0	21	12
10*	0	0	4	0	5	2	3	0	2	**46**	0	74
11	0	2	0	7	2	9	11	0	7	0	**15**	28

	0	1	2	3	4	5	%
0	**4**	2	0	3	8	4	19
1	0	**9**	4	11	13	2	23
2	0	5	**13**	9	35	5	19
3	0	0	0	**78**	52	15	54
4	0	0	0	4	**172**	62	72
5	0	0	0	0	35	**112**	76

5. Discussion and conclusions

Current iVR systems generally use standardized learning methods that do not adapt to the individual characteristics of each learner. This leads to high levels of demotivation, passive attitudes, boredom, low engagement, and frustration among trainees. Eye-tracking data can play an important role in monitoring these environments and as a complement to other data collection tools, e.g., behavior metrics. The use of AI techniques on datasets extracted from iVR training environments can be the desired solution, to adapt learning iVR environments to the different backgrounds and characteristics of each learner. In this study, the way in which basic machine-learning techniques can be applied to achieve that goal has been examined, specifically to evaluate learning conditions and learner performance, within areas where the existing bibliography is specially limited. To do so, an iVR environment and a testing experience have been designed, in such a way that the students were expected to repeat a simple short task while exposed to different disturbances, learning quickly and generating a dataset with a high diversity of exercises for the expertise of each user and under different environmental conditions. Different machine-learning techniques were then tested for two tasks: 1) quality classification of the learning environment; and 2) prediction of learner performance. Well-established data-science methods were followed to test the following techniques: data labelling, data filtering, feature extraction, and machine-learning modelling under a cross-validation scheme. Among the algorithms that were tested, Random Forest showed the best accuracy for both tasks. While high accuracy was achieved for classifying abnormal learning conditions (78%), the results were not so good for prediction of learner performance (59%). It should be outlined that the aim of this research is not to find a reliable and robust solution for these tasks, but it is a first approach that will provide a baseline for future improvements for the use of machine-learning in iVR learning environments.

Compared with the existing bibliography, similar accuracy levels were achieved for quality evaluation of the environment. While in this study the expert or novice status of the user could be predicted to an accuracy of 77% in an iVR simulation (Wismer et al., 2022) for the measurement of laboratory skills and learner assessment and compliance using behavior metrics, accuracy levels of 78% were achieved while rating the quality of the learning environment. Compared to the evaluation of attention or distraction (Asish et al., 2022), model accuracy was lower; a difference that arises from the definition of classes in both works: while up to 6 levels were used in this research, Asish et al. (2022) used a binary classification, that usually yields higher levels of accuracy. Finally, compared with the classification of driving (Deng et al., 2020), some common conclusions have been achieved in this work: the stability and high accuracy of

ensemble techniques, like Random Forest, over other classical algorithms, like kNN, or SVMs. Again, the high accuracy achieved in this work (up to 89%) might come from the selection of only 3 classes and the strong difference in behavior between drivers in each class. As was also outlined in those previous works, the extension of the datasets, in terms of learners and conditions, is required to achieve higher accuracy. Nevertheless, the suitability of machine-learning for the performance of such tasks has been confirmed in this research, in so far as one of the largest datasets more than 50M data points was processed far more efficiently than conventional human-based data-processing techniques.

Future studies could be focused on improving the accuracy of prediction models for learning evaluation in iVR environments. An aim that could be achieved by expanding the dataset to include experiences from new users, improving the labelling methodologies, and utilizing balancing techniques for highly unbalanced classes (such as the SMOTE algorithm). Additionally, alternative machine-learning techniques could be tested, such as Hidden Markov Models with proven results for time series, in order to capture the dynamic trends of learner performance. Furthermore, the results have motivated the need to add session-related information to the dataset, so that intra- and inter-session learner performance patterns could be extracted.

Authors' Contribution

Idea, C.P.A.; Literature review (state of the art), D.C.; Methodology, I.M.A., D.C.; Data analysis, A.S.M., C.P.A.; Results, A.S.M.; Discussion and conclusions, A.S.M., I.M.A.; Writing (original draft), C.P.A., I.M.A.; Final revisions, C.P.A., I.M.A.; Project design and sponsorship, D.C., A.S.M.

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Analysis of stress, attention, interest, and engagement in onsite and online higher education: A neurotechnological study

Análisis del estrés, atención, interés y conexión emocional en la enseñanza superior presencial y online: Un estudio neurotecnológico

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ABSTRACT

The aim of this work is to register and analyse, using neurotechnology, in onsite onsite and online university educational context, the effect on relevant variables in the learning process. This represents an innovation in the current academic literature in this field. In this study, neuroscience technology has been used to measure the cognitive processing of stimuli designed for an academic experience in a university master's degree class. The neurotechnologies employed were galvanic skin response (GSR), electroencephalography (EEG) and eye tracking. After the analysis of the brain recordings, based on attention, interest, stress and engagement in an onsite educational context and their comparative analysis with the online monitoring, the results indicated that the levels of emotional intensity of the students who followed the class in person were higher than those who attended online. At the same time, the values of positive brain activity (attention, interest and engagement) were higher in the onsite group, and the negative variable stress was also higher, which could be explained by the fact that the online students did not activate the camera. The brain recordings of students who were distance learning show less interest and attention, as well as less emotional intensity, demonstrating that distance (online) learning is less effective than classroom learning, in terms of brain signals, for a theoretical university master's degree class.

RESUMEN

Este trabajo tiene como objetivo registrar y analizar, mediante el uso de neurotecnología, en un contexto formativo universitario presencial y online, el efecto que tiene en variables relevantes en el proceso de aprendizaje, lo cual supone una innovación en la literatura. En este estudio se ha empleado tecnología de neurociencia para medir el procesamiento cognitivo de los estímulos diseñados para una experiencia académica de una clase de máster universitario. Las neurotecnologías empleadas han sido la respuesta galvánica de la piel (GSR), la electroencefalografía (EEG) y el seguimiento ocular. Tras el análisis de los registros cerebrales, basados en la atención, interés, estrés y conexión emocional (engagement), en un contexto educativo presencial y su análisis comparativo con el seguimiento online, los resultados indicaron que los niveles de intensidad emocional de los alumnos que siguieron la clase de forma presencial son más elevados que aquellos que asistieron de forma online. A su vez, los valores de actividad cerebral positiva (atención, interés y engagement) son superiores en el grupo de asistencia presencial, siendo la variable negativa estrés también superior, pudiendo justificarse debido a que los alumnos conectados online no activaban la cámara. Los registros cerebrales de los alumnos que asisten a distancia muestran menor interés y atención, así como una menor intensidad emocional, por lo que el aprendizaje a distancia (online) es menos efectivo, a efectos de señales cerebrales, que la enseñanza en el aula, para una clase teórica de máster universitario.

KEYWORDS | PALABRAS CLAVE

Learning, classroom teaching, online teaching, university, educational innovation, neuroeducation.
Aprendizaje, enseñanza presencial, enseñanza online, universidad, innovación educativa, neuroeducación.

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1. Introduction

Innovating in education means making changes in the learning process with the aim of improving the results obtained (Horn et al., 2009). Digital technologies, as part of the innovation process, are being increasingly integrated into education, often used as mediators in the teaching and learning process (da-Silva et al., 2023). There is a trend towards online teaching, which represents the basis for the construction of learning for society in the 21st century, with the COVID-19 pandemic marking the turning point at which the use of online methodologies to achieve online teaching became incredibly widespread (Sanchez-Mendiola et al., 2020). The analysis should not focus on the location of the teacher and the student, but on the interactions between them, both in terms of quantity and quality. Understanding the principles of how the brain functions in learning contributes to the advancement of educational innovation, and thus neuroeducation facilitates the development of educational systems (Hillman, 2011). The purpose of this research is to determine, through neuroscience technologies, the difference in brain activation levels between a group of students with classroom teaching compared with another group of students who follow the class remotely, synchronously (online), in a theoretical class session on consumer behavior, which is part of a master's degree course. In this case, biometrics were used to monitor the intensity or emotional arousal experienced (GSR - galvanic skin response) and brain activity (EEG - electroencephalography), shown through variables of attention, interest, stress and engagement. This study aims to respond, empirically, to aspects related to the difference in efficiency of classroom teaching compared to online teaching. The specific objectives of the research are as follows:

- Analyze the levels of emotional arousal registered depending on the format (classroom teaching or online).
- Analyze the levels of attention, interest, stress and engagement of the participants, depending on the format of the class.
- Determine which monitoring modality is most effective, according to data provided by the biometric measurements carried out.

2. Theoretical framework

Innovation can be defined as the sequence of stages to conceive new products or services which can be adopted or redesigned for their applications and transformation (Rikkerink et al., 2016), even in an open manner (Ramírez-Montoya & Lugo-Ocando, 2020). Thus, innovation is the result of applying new processes (strategy, methodology, organization, procedure, training, technical development), new services (provision, care, function, benefit, action, dependence, assistance), new products (material, prototype, manufacture, object, technology, application, result), or new knowledge (knowledge, evolution, cognition, talent, model, impact, transformation, patent, system).

The application of innovation to education is called educational research, the objective of which is the systematic inquiry of a research question of interest (Horn et al., 2009). What generally differentiates such research from other traditional types of research is typically the problem on which the work is focused. Innovation in services, products, processes and knowledge generates change in education, where innovation often helps to address problems and situations arising from teaching practices and presentation. In relation to this, innovating in education consists of generating changes that improve learning results, through improvements in training (Clark et al., 2016). To achieve this, educational innovation must be embraced in an inclusive and holistic manner, and so students, educational providers, communities, companies, and political organizations need to integrate the key aspects of innovation throughout their hierarchy of levels.

Similarly, it is important to understand the proposal of research applications stated by academics (Ramírez-Montoya & Lugo-Ocando, 2020). It is a comprehensive classification based on educational management (planning, organization, administration, management and evaluation of resources), psych pedagogy (teaching and learning), technology applied to education (use and development, both onsite and remote) and sociocultural management.

There is great interest within education in using digital technologies as mediators of the teaching and learning process (da-Silva et al., 2023). In the field of education, there is a growing interest in technologies

that support teaching and learning activities. When modern technology is systematically applied to an organized educational process, it can be used in three domains: tutoring, teaching tool and learning tool. Today, educators are increasingly familiar with tools that can be used in distance learning, educational games, and simulations; many researchers also pay more attention to the effects that technology can generate (Waxman et al., 2013). Many studies suggest that the use of technology could inspire positive effects among students, such as improving academic performance, increasing students' competitive abilities, and raising learning motivation (Clark et al., 2016; Lai & Bower, 2019). The growth and trends in the field of educational technology deserve attention.

Furthermore, the definition of technology may have numerous ramifications. In some recent studies, educational technology is defined as "tools that help students acquire cognitive knowledge, improve communication skills, and develop problem-solving skills" (Lee et al., 2019). Based on this definition, the emphasis would fall on those related to information technology (Doyle et al., 2019), since not only learning instruments are being revolutionized by technological advances, but also the pedagogies and mentalities of educators.

There is a trend towards distance learning, which represents the foundation for the construction of learning for society in the 21st century, with the COVID-19 pandemic being the turning point. This was a time when onsite education for high school and university students was interrupted in more than one hundred countries (Sánchez-Mendiola et al., 2020). This affected traditional programmed teaching and encouraged the use of online methodologies to be able to continue an education that suddenly had to be at a distance. There are comparative studies between virtual and classroom teaching scenarios, such as the didactic content preferences of university professors in different teaching environments (Sevimli, 2022), the lower grades in virtual environments (Morgan, 2015), the improvement of students' self-learning (Huamán-Romaní et al., 2021), the lack of motivation, contact with classmates or the absence of classroom practices and other aspects that cause disinterest and increase the dropout rate of subjects (Chávez-Miyauchi et al., 2021; Serrano-Díaz et al., 2022).

The key and innovative role of ICT and communication is to encourage interaction between the students themselves and reduce the teacher-student distance. This makes it necessary for the teacher, before starting the course, to correctly organize the work, achieving the same knowledge and skills, regardless of the format of attendance by the students. The lack of personalized contact with the student is one of the main disadvantages of distance learning. Videoconference, for example, is an adequate system to listen to and see the student, and there must always be a commitment from the teacher to respond within a good amount of time. Social interactions are key in the construction of knowledge (Van-Ameringen et al., 2003), however, those students with social anxiety may choose the distance approach as a solution to their mental disorder.

Linking learning and the brain, it is necessary to carry out a restructuring of pedagogical practices so that they can be linked to the contributions of neurosciences. Neuroscience allows us to rethink education and what data this field provides so that pedagogy can continue optimizing the explanations of the teaching and learning processes (Bueno-i-Torrens & Forés-Miravalles, 2021). Learning and memory are closely related in terms of mental processes, and these give rise to adaptive changes in behavior (Morgado-Bernal, 2005). Active learning makes the student go beyond simple memorization and make an effort to understand the concepts and information with which they answer the teacher's questions. This type of learning, based on relating and contrasting a range of information, helps make mental processes more robust and improves memory (Bernal, 2022). In this sense, neuroeducation is emerging as a new science whose main objective is the synergy of pedagogy, cognitive psychology and neuroscience, and with this, to be able to bring the necessary resources to the different educational agents in terms of the binomial brain-learning. Neurosciences are developing research focused on the neural bases of learning, memory, emotions and different functions of the brain, the results of which have high applicability in the field of learning (Bowers, 2016; Howard-Jones, 2014). The development of neuroeducation contributes to the advancement of educational innovation, as well as to the development of educational systems.

Over the past two decades, research in cognitive neuroscience has provided significant insights into how the brain functions and into the neural mechanisms of learning. It is important to know how the brain

is formed and learns (Bueno-Torrens & Forés-Miravalles, 2018), since one of the keys is the amygdaloid body, traditionally associated with the emotional system of the brain and is involved in emotional learning (Torras et al., 2001). Educational neuroscience is an interdisciplinary field of research that seeks to translate research findings on the neural mechanisms of learning into educational practice and policy. This field is also a basic science that studies how education changes the brain and the mechanisms that lead to behavioral changes (or lack thereof) through education. The relevance of neurobiology in relation to education was recognized throughout the 20th century, but it was not until the 1990s and the "Decade of the Brain" that technological advances in live imaging of brain function led to the theoretical advances that made educational neuroscience viable as a field (Varma et al., 2008).

Despite ongoing criticism and debate about the merits of applying knowledge from neuroscientific research to educational problems (Bowers, 2016), potential connections between neuroscience and education are being actively explored around the world. Different labels have been used to describe such efforts. These include neuroeducation, educational neuroscience, and mind, brain, and education. However, translating neuroscience research into education is difficult. This process is extensive and starts with a basic science foundation. The complexity of learning in the brain and the state of current scientific knowledge means that there is a risk of premature translation before the foundation is established. This risk is compounded by the legitimate desire of policymakers to use scientific evidence to inform their educational policies (Bittencourt & Willetts, 2018) and the enthusiasm that educators have to inform their teaching with insights into how the brain works. Furthermore, the interplay of the disciplines of neuroscience, psychology and education has sometimes been characterized by competition rather than collaboration, and educational researchers remain wary of the hype surrounding education.

Neuroeducation is a new discipline that is under development, thanks to the contributions of neuroscience, cognitive psychology, and educational sciences, to generate a better understanding of how to learn and how this information can be used to create teaching methods, curricula and educational policies (Carew & Magsamen, 2010). Despite the fact that neuroeducation is just beginning in the field of research, it is giving rise to new critical dialogue between teachers, those responsible for educational administrations, families and the scientific field.

Entering into the conceptual delimitation of the term, neuroeducation is classified as applied cognitive neuroscience, especially if there are no substantial differences in the philosophical orientations and methodologies found between education and cognitive neuroscience (Campbell, 2011). It is an area of educational research that is based on the mechanisms of information processes, theories and methods of applied cognitive neuroscience, but unlike these, it is not limited to these elements, since neuroeducation has the person as its principal object, and not only the physiological and biological mechanisms on which neurosciences are based. Considering the transdisciplinary approach of neurosciences, neuroeducation can contribute to the construction of new educational frameworks and new research methodologies that serve as a reference framework in the learning-brain binomial, including the learning of social values in favor of prosocial behavior that move towards an inclusive and sustainable society (Villardón-Gallego et al., 2018).

Regarding the centers of interest of the neurosciences with respect to neuroeducation, neuroscientific research addresses the pathologies of learning difficulties (Ferrari, 2011); consequently, the objective from educational research should be to understand the broader context of learning and personal development that complements the contributions of neuroscience and avoids the labelling of atypical students which often leads to possible stigmatization. It is this juncture of increased interdisciplinary collaboration between neurosciences and education that has made possible the emergence of this new disciplinary field, known as neuroeducation, which will not only inform educational approaches, but also advance scientific understanding of the relationship of neural processes with complex behaviors observed in the classroom.

3. Methodology

In this study, neuroscience technology has been used to record brain activity, with the aim of recording cognitive processing in an academic experience of a master's degree class (Consumer Behavior subject - theoretical class), through stimuli designed so that the session is followed in person and online

synchronously (without connection of cameras by the students). It is experimental research, and the results are limited to the conditions of the registered experience, not assuming a generalization of results for any experiment.

The use of neuroscience technology makes it possible to analyze the effectiveness of the stimuli projected onto users and the psychology of consumer behavior (Plassmann et al., 2012), providing more information than other conventional research methods, where the behavior or perceptions of participants may limit the study.

Eye tracking, galvanic skin response (GSR) and electroencephalography (EEG) are the three specific neuroscience techniques used in this work. The visual attention of the students is captured from the ocular movement (Duchowski, 2007). Electrodermal activity (EDA) is recorded through GSR, reflecting changes in emotional arousal due to projected stimuli. Finally, brain activity (brain waves format) is recorded by EEG (Yadava et al., 2017). The attention of the students is recorded by the eye tracker, starting the affective and cognitive process (partially recorded by GSR and EEG). When subjects focus their attention on a stimulus, it is recorded by the eye tracking system and initiates cognitive and affective processing (recorded by GSR and EEG) (Ramele et al., 2012). The variables measured with these biometrics focus on stress, attention, interest, and engagement (Juarez et al., 2020). Stress measures how comfortable an individual is with a task. Elevated stress can result from the inability to complete a difficult task or fearing negative consequences for not meeting the task's requirements. In general, a low to moderate level of stress can improve productivity, while a higher level tends to be destructive and can have long-term consequences for health and well-being. Attention is a measure of concentration on a specific task. This variable records the depth of attention, as well as the frequency with which attention switches between tasks. A high level of task switching is an indication of inattention and distraction. Interest measures the degree of attraction towards the stimuli, the environment or the current activity. Low interest scores indicate a strong dislike of the task, high interest indicates a strong affinity for the task, while mid-range scores indicate that individuals neither like nor dislike the activity. Finally, emotional connection is experienced as alertness and the conscious direction of attention toward task-relevant stimuli. It measures the level of immersion in the moment and is a mixture of attention and concentration, and contrasts with boredom.

The first task is to find out how the neural bases of the brain predispose us to act in one way or another in relation to autonomy and happiness, establishing a series of conclusions about how the neural bases of the brain influence and how they contribute to learning. In this context, neuroeducation is a new-born discipline which facilitates the study of users, their perceptions, and the global experience (Bercík et al., 2016). Neuroeducation, therefore, makes it possible to register the existence of a possible positive emotional connection between students and the classes that are taken, allowing us to determine in a scientific way the levels of attention and emotion that are generated by paying attention to the classes taught, making a clear distinction between online and onsite.

There are studies on the use of portable EEG technology (PEEGT) in educational research (Xu & Zhong, 2018). These tools have been used mainly to assess the attention and meditation of the participants. PEGT has been used primarily in seven research topics: reading context, patterns of presentation of learning materials, interactive behavior, edutainment, e-learning, motor skill acquisition, and promoting learning performance with PEEGT.

Although brain wave analysis is now quite advanced in a variety of academic and professional contexts, such as healthcare, few studies have put brainwave analysis in the classroom setting. In the past, brainwave experiments required a lot of preparation, and also required the use of gel to affix electrodes to the experimental subject's head. For these reasons, it was challenging to administer brainwave experiments in the classroom. However, with advances in technology, EEG equipment is becoming more and more portable, so it is now possible to obtain accurate brainwave data with just a simple miniature setup.

Regarding portable EEG technology (PEEGT), most offer a painless, low-cost, ergonomic, wireless EEG monitoring solution for researchers and everyday users who are interested in monitoring neural correlations associated with various behaviors and mental processes. Nowadays, there are indications that more and more researchers like to use PEEGT as a research tool in their educational research, which suggests that PEEGT is becoming an increasingly relevant tool in educational research. However, this

statement needs to be further supported through the application of experiments and, above all, through empirical evidence.

Wang & Hsu (Wang & Hsu, 2014) used the PEEGT Neurosky equipment Mindset to measure students' attention levels during computer-based instructional learning, in which participants completed three lessons of easy, medium, and hard levels. Ghergulescu and Hava-Muntean (2016) used the neuroheadset Emotiv EPOC to measure student engagement during game-based e-learning. Other work (Lin & Hsieh, 2016) also used the NeuroSky headset MindWave to recognize student attention levels during e-learning. Most of the published works used PEEGT to assess the attention (and meditation) of the participants, with a few studies using it to detect the motivation of the participants (and commitment) and emotions.

Most of the EEG experiments (Wang & Hsu, 2014) lasted less than 60 minutes. The sample sizes of the EEG experiments were small, the largest research group was university students, and the portable EEG devices used in the educational research were primarily developed by NeuroSky Inc. and Emotiv Inc.

It is important to understand the relationship between the EEG data and the different cognitive aspects, as well as the pedagogical implications highlighted in these cognitive aspects:

Attention and Meditation: Attention is the behavioral and cognitive process of selectively concentrating on a discrete aspect of information, whether considered subjective or objective, while ignoring other perceptible information (Talmi et al., 2008). Unlike mindfulness, meditation is an intentional, self-regulated focus of attention to relax and calm the mind (Anand et al., 2014). Meditation does not represent the physical state of an individual, but their mental state, and refers to a reduction of the brain's active mental processes. That is, higher relaxation values indicate that an individual is more relaxed and less stressed. PEGT detects human brainwaves according to selected α, β, δ and θ wave characteristics. The variation of the β wave in the EEG is strongly correlated with attention, and the α wave is strongly correlated with meditation. Higher levels of meditation can increase students' ability to pay attention and, as a result, can help them better absorb and retain information. If the levels of attention and meditation are high, the students will be in the optimal state to learn.

Motivation and commitment: Student motivation is one of the main aspects that must be addressed for a successful learning process. Consequently, the assessment and measurement of learner motivation have attracted a great deal of research interest in the area of e-learning in general and in game-based learning in particular. There are studies that show that commitment is a main indicator of motivation (Saeed & Zyngier, 2012), and other studies have confirmed that the $\beta/(\alpha+\theta)$ index obtained from EEG data better reflects commitment (Prinzel et al., 2009).

Emotion (frustration and excitement): According to the broaden-and-build theory, positive emotions broaden the span of attention, cognition, and action, and these then broaden the range of perceptions, thoughts, and actions existing in the mind at that moment. Isen and Reeve (2005) found evidence that students with more positive emotions had better memory recall and were therefore able to remember things more easily. Furthermore, it has been recognized that learning with positive emotions improves learning motivation, problem-solving ability, and cognitive behavioral ability more than when learning with negative emotions.

At present, only the neuroheadset Emotiv EPOC provides a standard development kit (SDK) that can extract frustration and emotion intensities from brain signals in real time. The emotional state is represented by the frustration and arousal values obtained from the SDK.

3.1. Sample

The sample selected in the study is made up of master's degree students between the ages of 22 and 25, interested in the subject taught (Consumer Behavior), who volunteered to participate and signed a consent agreement. A total of 20 students (50% men, 50% women) were monitored (with more non-monitored classmates), making the sample size adequate for a neuroeducation study (Cuesta-Cambra et al., 2017). The field work was carried out between March and April 2022 and the location of the study was in the city of Valencia (Spain).

3.2. Data collection and analysis

The research phase, with the stimuli exposed, was performed using eye tracking models «Pupil Core» (from Pupil Labs manufacturer, with a sampling frequency of 200 Hz) for classroom learning, and «Gazepoint» (from the manufacturer Gazepoint, with a sampling frequency of 60 Hz) for online learning. For data collection and analysis, the Pupil Capture software, v.1.23 (classroom learning) and the Gazepoint software Analysis UX Edition v.5.3.0 (online learning) were used. To record the electrodermal activity, the Shimmer3 GSR+ model was used in both follow-up models, using the ConsensysPRO software, v.1.6, for data collection. The data gathered showed the emotional arousal that the participants felt throughout the class.

Finally, to record brain activity, the portable EPOC+ electroencephalography equipment was used, with 14 channels and saline-based electrodes from the manufacturer Emotiv. For data collection, the EmotivPRO v.2.0 software was used. This technology is used to interpret the most relevant emotions felt, derived from the information collected from brain activity. The brain activations that were analyzed were attention, interest, stress, and engagement, with engagement being the ability of a brand, product, service, or stimulus to create a lasting bond between both parties (Van-Doorn et al., 2010).

The statistical analysis of the data was performed with the R software, v.3.6.3. Common elements (stimuli) were defined for all consumers (volunteers). The independent variables were the age and gender of the participants, with a similar sociocultural profile and determined by the main profile of the master's degree program. The dependent variables were the level of emotional intensity and the levels of attention, interest, stress, and engagement, in response to the observed stimuli.

To carry out this study, an experiment was carried out with a biometric approach. The objective is to know the subconscious perceptions of the students when observing the classes, both in their classroom format and online. There were 20 students per session, but only the volunteers were monitored (a total of 4 per session). The study was carried out over 5 days with 4 different participants, repeating the same session on Friday afternoon at 4:00 p.m., which was the first hour of class that day. The students could participate in a set of closed concepts. The technology was installed and calibrated by experts in neuroscience, obtaining values within tolerance. A total of 50% of them followed the class in person and the other 50% at a distance, synchronously. The total duration of the class was 45 minutes, during which the brain activity of the students was recorded with the Eye Tracking, GSR and EEG technologies. During the calibration process and because they are wireless technologies and almost imperceptible, students and teachers do not perceive them.

4. Analysis and results

In order to record and analyze the emotional arousal of the students throughout the 45 minutes, the data was divided into three parts:

- First part: 0-15 minutes.
- Second part: 15-30 minutes.
- Third part: 30-45 minutes.

Table 1 shows a summary of the average data collected for the 2 groups (classroom and online). The recorded values are shown in parts per unit, with 0 a null value and 1 the maximum achievable value for each measured variable. The overall average of the experiment refers to the average of each of the average values of the three-time ranges (the 3 parts).

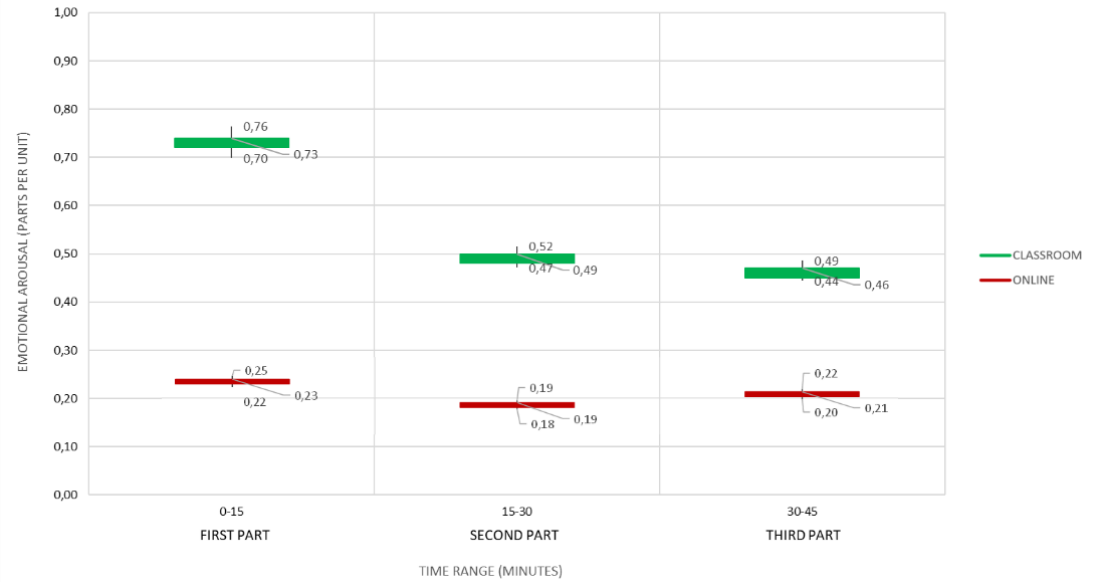
Table 1. Average brain activity data for the classroom group and the online group

	Classroom				Distance/Online			
Part of the class (minutes)	**0-15**	**15-30**	**30-45**		**0-15**	**15-30**	**30-45**	
Registered emotion (average – percent)				**Average experience**				**Average experience**
Average Emotional Intensity	0.73	0.49	0.46	0.56	0.23	0.19	0.21	0.21
Average Attention	0.41	0.44	0.46	0.44	0.42	0.42	0.46	0.43
Average Interest	0.74	0.59	0.63	0.65	0.56	0.62	0.66	0.61
Average Stress	0.45	0.50	0.52	0.49	0.36	0.43	0.47	0.42
Average Engagement	0.74	0.59	0.63	0.65	0.56	0.62	0.66	0.61

4.1. Emotional arousal analysis – GSR

The following figure (Figure 1) shows the average emotional level in each part, for classroom and online formats, measured through the galvanic skin response (GSR).

Figure 1. Results of the GSR analysis



The levels of emotional arousal (intensity) of the students who followed the class in person are higher than those who attended online/at a distance. The level of emotional arousal of the classroom group reached the following values:

- First part (minutes 0-15): 0.73 (73%).
- Second part (minutes 15-30): 0.49 (49%).
- Third part (minutes 30-45): 0.46 (46%).

On average, in the entire class, the classroom students showed a 56% level of emotional intensity. On the other hand, the online students reached the following levels of emotional arousal throughout the 3 parts of the class:

- First part: 0.23 (23%).
- Second part: 0.19 (19%).
- Third part: 0.21 (21%).

On average, in the entire class, online students showed a 21% level of emotional intensity. It should be noted that the emotional intensity values are higher in the classroom group during the first third of the class, decreasing as the class progresses. However, in the online group the values are lower and more stable.

4.2. Analysis of brain activity - EEG (electroencephalography)

We analyzed and compared the levels of attention, interest, stress and engagement (emotional connection), accompanied by the level of emotional arousal (intensity), differentiating between the group that followed the classes in the classroom and distance/online formats.

Figure 2 shows the average level of emotional arousal and the average level of attention, for classroom and distance/online formats, for each part measured through portable electroencephalography (PEEGT).

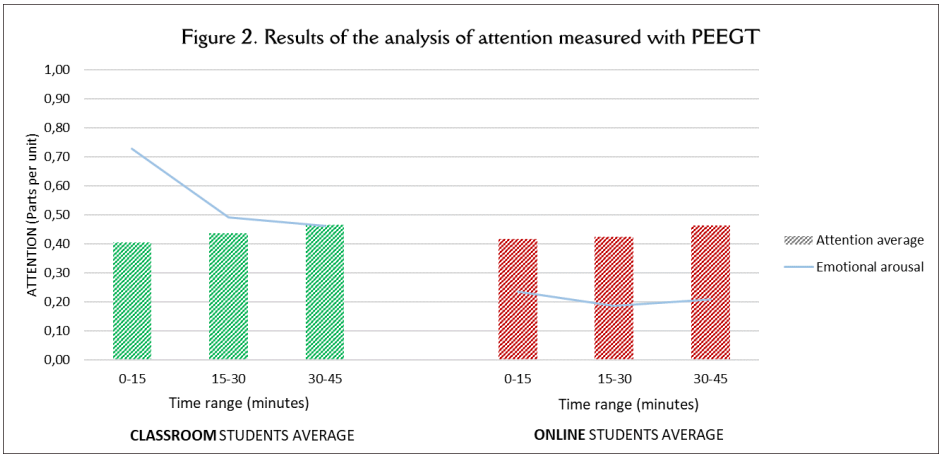
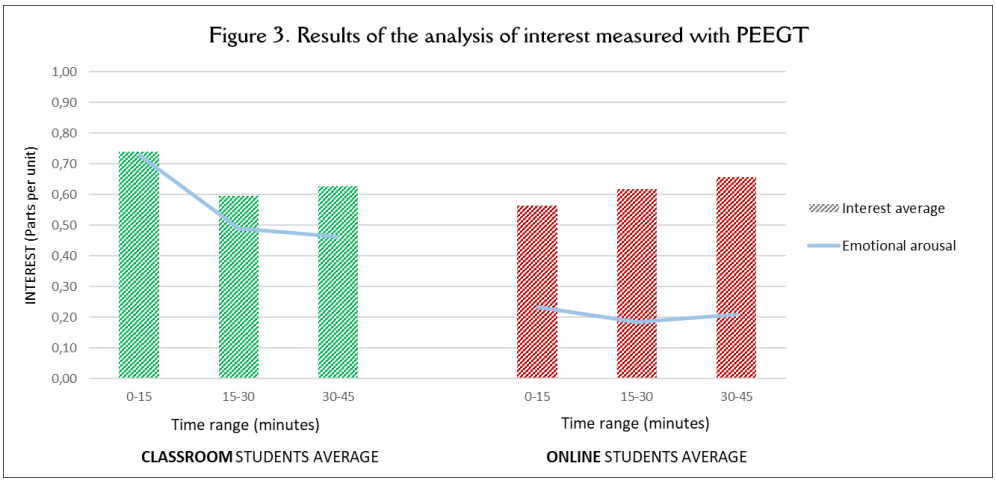


Figure 2 shows that the levels of attention are similar, although slightly higher for students who attend class online in the first part (minutes 0-15). Later, the levels of attention increase for the classroom students, and it is maintained in the online group (part 3), ending with an equal level in part 3 of the class. In the experiment, the classroom students reached an average level of attention equal to 44%, while the online attendees reached 43% (the figure shows the results in parts per unit). There is a minimum difference of 1% in level of attention in the percentage scale in which the values are recorded.

The level of attention of the online students is more constant than that of the classroom group, while the classroom students start the first part with a lower level of attention but end with a higher level in the third part.

Figure 3 shows, for each part, the level of average emotional intensity and the average level of interest, for classroom and distance/online formats, measured through portable electroencephalography (PEEGT).

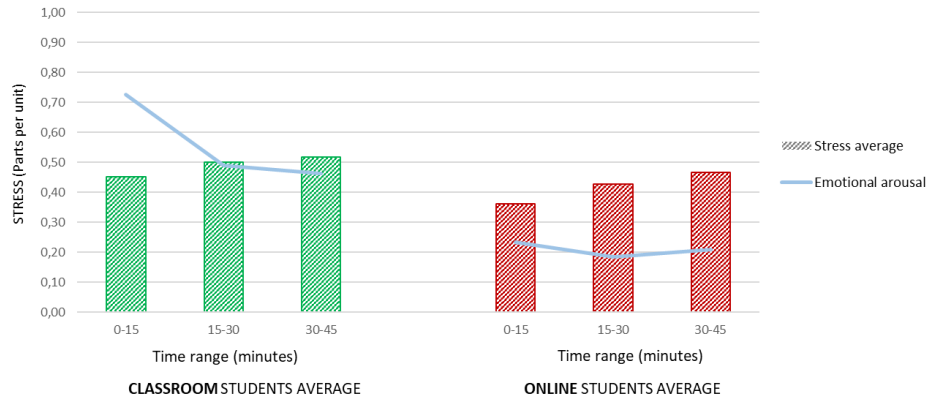


The levels of interest are higher, in general terms, for the classroom group, with average values of 65%, compared to 61% for the distance group. In the first part (first 15 minutes of class), interest levels are higher for students who attend in person. Afterwards, the level of interest for the classroom group decreases and increases for the online group, ending with an increase in interest for the online group, above the classroom group (part 3).

The online students are more constant in their level of attention, and this grows as the class progresses, while the classroom students begin with a higher level of interest in the first part of the class and decrease as the class develops, slightly changing the trend in the third part.

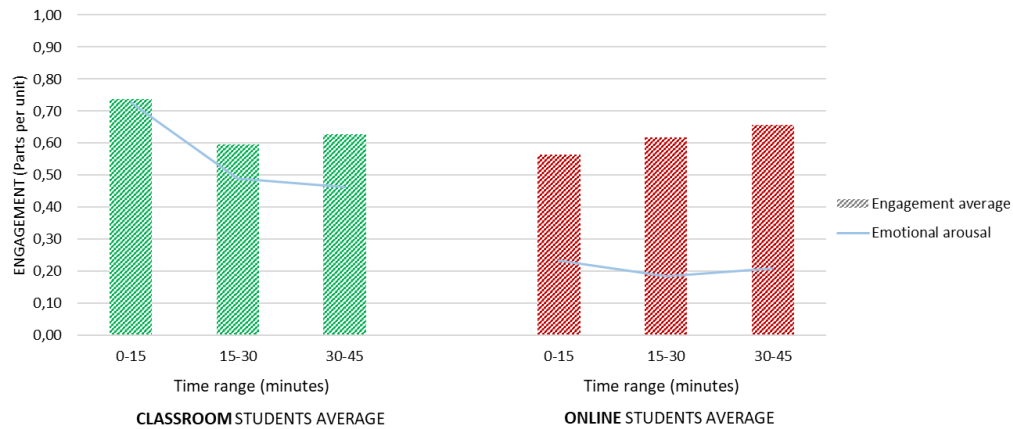
Figure 4 shows, for each part, the level of average emotional intensity and the average level of stress, for classroom and distance/online formats, measured through portable electroencephalography (PEEGT).

Figure 4. Results of the stress analysis measured with PEEGT



Stress levels are higher, in general terms, for the classroom group, with average values of 49%, compared to 42% for the remote group. In the 3 parts of the class, stress levels are higher for students who attend in person. In both groups the level of stress grows as the class progresses, always with lower values for the online students (note that they do not connect the camera). Figure 5 shows, for each part, the level of average emotional intensity and the average level of engagement, for classroom and distance/online formats, measured through portable electroencephalography (PEEGT).

Figure 5. Results of the analysis of engagement measured with PEEGT



Engagement levels are higher, in general terms, for the classroom assistance group, with average values of 65%, compared to 61% for the remote group. The first part of the class generates a higher level of engagement for the classroom students, falling in the second part and slightly changing the trend in the third part. However, the level of engagement has a growing trend for distance/online students, finishing a third of the class ahead of face-to-face students.

5. Discussion and conclusions

The current globalization is forcing educational centers to adapt, in a constantly evolving teaching context, where new forms of learning must be continually designed. Online learning facilitates accessibility, regardless of the location of the student and the teacher. However, the quality and quantity of interactions between teacher and student is the key, leaving the location of both in a secondary level (Hillman, 2011). The final result (knowledge and skills) should be the same, both for onsite students and for online students. Educational innovation is favored with the integration of digital technologies, where designs converge when working with mixed methods, in a holistic way and improving the focus of

researchers (Klingner & Boardman, 2011). In a study conducted with classroom and online students (Price et al., 2007), the experiences of those taking the same course through distance learning were compared, when tutorial support was delivered conventionally (using limited classroom sessions with some contact by phone and email) or online (using a combination of computer-mediated conferencing and email). Students who received online teaching reported worse experiences than those who received classroom teaching. For online students, tutoring was seen not only as an academic activity but also as a highly valued pastoral activity. For online teaching to be successful, both tutors and students need training on how to communicate online in the absence of paralinguistic signals. The examples used in the teaching-learning process have a crucial role in fostering conceptual understanding, and some variables may affect instructors' use of graded examples (Sevimli, 2022).

Educational neuroscience seeks to translate research findings on the neural mechanisms of learning into educational practice and policy and to understand the effects of education on the brain (Thomas et al., 2019). Neuroscience and education can interact with each other directly, by virtue of considering the brain as a biological organ that needs to be in optimal conditions to learn (' brain health '); or indirectly, as neuroscience shapes psychological theory and psychology influences education.

The main objective of this work has been to demonstrate that online learning is less effective, in terms of brain signals, than classroom teaching for a theoretical class intended for master's level university students. The results of this experiment indicate that the levels of emotional intensity of the students who followed the class in person are higher than those who attended online/at a distance and can be justified by the presence of the teacher, colleagues and participation. However, the level of emotional intensity experienced by the group that followed the class remotely is more stable, the justification of which may be due to the lack of visual control, both by the teacher and by the classmates, by not connecting the camera.

Regarding the recording of brain activity by the students, recorded by portable electroencephalography (PEEG) biometry, the values are higher in the classroom attendance group, in general terms. Three of the four registered variables are positive, having higher values in classroom training (attention, interest and engagement). This may be due to a different and more motivational attitude from being in the classroom. However, the fourth variable, stress, is also higher in the classroom group, which can be justified because the students connected online did not activate the camera. The sensations perceived by the students suggest that the classes are more productive in person. The sensations and emotions provoked in the students who attend at a distance show that they have less interest and pay less attention, as well as showing lower emotional intensity.

Finally, regarding future lines of research using neurotechnologies in the classroom, it is very interesting to analyze how the different didactic methodologies (group dynamics, reverse teaching, etc.) bring the levels of brain arousal closer or further apart between classroom and online groups, allowing a basis for the proposal of actions to enhance and improve the results of the groups that follow distance teaching. Similarly, we aim to complement the techniques used with the use of quantitative surveys focused on recording perceptions and possible improvements for each proposed methodology.

Authors' Contribution

Idea, D.J.V., I.B.G; Literature review (state of the art), D.J.V., I.B.G., B.B.G; Methodology, D.J.V., B.B.G; Data analysis, D.J.V., I.B.G., B.B.G; Results, D.J.V., I.B.G., B.B.G; Discussion and conclusions, D.J.V; Writing (original draft), D.J.V., I.B.G; Final reviews, D.J.V., B.B.G; Project design and sponsorships, D.J.V., B.B.G.

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Application and challenges of eye tracking technology in Higher Education

Aplicación y retos de la tecnología de movimiento ocular en Educación Superior

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ABSTRACT

Advances in neuro-technology provide new insights into how individual students learn in educational contexts. However, applying it poses challenges for teachers in natural settings. This paper presents an example of the use and applicability of eye-tracking technology in Higher Education. We worked with a sample of 20 students from three universities (Burgos and Valladolid in Spain and Miño in Portugal). The objectives were: (1) to determine whether there were significant differences in indicators of cognitive effort (FC, FD, SC, PD, VC) found with eye-tracking technology between students with and without prior knowledge; (2) to determine whether there were clusters of learning behavior patterns among students; and (3) to analyze differences in the visualization of behavior patterns. A quasi-experimental design without a control group and a descriptive design were used. The results indicated significant differences in learning outcomes between students with and without prior knowledge. In addition, two clusters were found in indicators of cognitive effort. Finally, a comparative analysis of learning behavior patterns between students in cluster 1 vs. cluster 2 was performed. Eye-tracking technology makes it possible to record large data about the learning process. However, using it in natural educational settings currently requires teachers to have technological and data mining skills.

RESUMEN

Los avances neurotecnológicos están posibilitando en los contextos educativos nuevos conocimientos sobre la forma de aprender de cada estudiante. No obstante, su aplicación plantea retos para la docencia en contextos naturales. En este trabajo se presenta un ejemplo de uso y aplicabilidad de la tecnología de seguimiento ocular en el ámbito de la Educación Superior. Se trabajó con una muestra de 20 estudiantes de tres universidades (Burgos y Valladolid en España y Miño en Portugal). Los objetivos fueron: 1) comprobar si existían diferencias significativas en indicadores de esfuerzo cognitivo (FC, FD, SC, PD, VC) hallados con la tecnología de seguimiento ocular entre estudiantes con y sin conocimientos previos; 2) comprobar si existían clústeres de patrones de conductas de aprendizaje entre los estudiantes; 3) analizar diferencias en la visualización de los patrones de conducta. Se utilizó un diseño cuasiexperimental sin grupo control y un diseño descriptivo. Los resultados indicaron diferencias significativas entre los estudiantes con y sin conocimientos previos respecto de los resultados de aprendizaje. También, se hallaron dos tipos de clústeres en los indicadores de esfuerzo cognitivo. Finalmente, se efectuó un análisis comparativo sobre los patrones de conducta de aprendizaje en estudiantes del clúster 1 vs. clúster 2. El uso de la tecnología de seguimiento ocular posibilita el registro de un gran volumen de datos respecto del proceso de aprendizaje. No obstante, en la actualidad su uso en contextos educativos naturales exige al profesorado conocimientos tecnológicos y de minería de datos.

KEYWORDS | PALABRAS CLAVE

Neuro-education, learning patterns, eye tracking, personalized learning, cluster analysis, educational technology.
Neuroeducación, patrones de aprendizaje, seguimiento ocular, aprendizaje personalizado, análisis de clúster, tecnología educativa.

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1. Introduction and state of the art

This study examines the functionality of using eye-tracking technology in the teaching-learning context in a university setting. It is important to first address what eye-tracking technology is. It was first used in 1800 and one of the most notable figures in its development was Louis Émile Javal, who used eye tracking in optical physiology to study strabismus. Eye-tracking technology is based on recording the visual sweeps a person makes when they interact with objects, images, videos, documents, spaces, etc.

The metrics this technology collects can be classified as static or dynamic. Static metrics include fixations (these refer to the frequency of positioning the gaze on a stimulus) (Joe-Louis-Paul et al., 2019), saccades (these refer to the movement from one stimulus to another) (Elliott et al., 2020), pupil diameter (this refers to the dilation of the pupil for different stimuli) (Sáiz-Manzanares et al., 2021a), and chain length (referring to the length of the scan path or gaze point for each participant in the eye tracking route implemented) (Kao et al., 2019; Seifert et al., 2017). The dynamic metrics record the time of gaze fixation within an area defined by cartesian coordinates (Sáiz-Manzanares et al., 2020). That area can be split up by the experimenter into relevant areas, non-relevant areas, or partially relevant areas (Joe-Louis-Paul et al., 2019). In other words, eye-tracking technology records each person's exploration path in a given time interval (Sáiz-Manzanares et al., 2021a). Table 1 gives information about some of the static metrics and their potential interpretation in the teaching-learning process. These interpretations are included in the user manuals for eye-tracking technology.

Table 1. Eye-tracking metrics and their meaning in the learning process

Metric	Meaning	Meaning in the learning process
Fixation Count (FC)	An overall measure of searching. More fixations on a stimulus may indicate novelty for the learner or that they find it difficult to discriminate the information in it.	It may serve to distinguish new from experienced students and between students with and without attentional problems (Rodziewicz-Cybulska et al., 2022).
Fixation Duration (FD)	An indicator of students' levels of interest and response times. Fixation duration provides information about the search process and concentration. Longer durations may indicate deeper information processing.	It may help to determine each student's levels of reflection during a task (e.g., differentiating between domain-dependent students and non-domain dependent) (Sáiz-Manzanares et al.,2020, 2021a, 2021b)
Saccade Count (SC)	The number of saccades used in each stimulus. A smaller number may indicate lower cognitive effort.	For example, more saccades may mean the student is using more orientation strategies to do a task. It may also indicate a lower level of prior knowledge. Kulomäki et al. (2022) reported more gaze changes in complex tasks than in simple ones.
Pupil Diameter (PD)	Eye-tracking technology collects the mean pupil diameter in all fixations within an Area of Interest (AOI) during a given time.	Indicates students' levels of attention or interest in a stimulus and may be an indicator of the difference between new and experienced users (Asadi et al., 2022; Rodziewicz-Cybulska et al., 2022).
Visit Count (VC)	The number of visits to an AOI during a set time.	Maybe an indicator of students' attention or interest in part of the information. It may also indicate a user's difficulty with this information (Sáiz-Manzanares et al.,2020, 2021a, 2021b).

Note. The meanings for the metrics are from the Tobii Pro Lab User Manual v 1.194. The relationship between the metrics and the learning process is expanded on in studies by Sáiz-Manzanares et al. (2020; 2021a; 2021b).

1.1. What does eye-tracking technology offer the teacher?

Eye-tracking technology is used as a tool supporting the study of human behavior and can be applied in various fields, including education (Tsai et al., 2022). More specifically, it can be used in the education field to study attention levels and their relationship with learners' cognitive processes (Taub & Azevedo, 2019) while doing a task (Ollesch et al., 2021). As noted above, the technology provides static and dynamic metrics. The static metrics cover a range of different parameters (duration, frequency, speed, and number of fixations and saccades, along with pupil diameter, etc.) (Merchie et al., 2022). The ultimate aim of analyzing these metrics is to detect patterns of behavior with the stimulus, and, based on the learning results, determine which is more effective (Chango et al., 2022). The specific benefits of these static metrics in education are related to the information they give to teachers about students' levels of attention and cognitive effort when doing various types of tasks (Prokop et al., 2020; Shojaeizadeh et al., 2019; Yang & Wang, 2023). This data allows teachers to tailor the content or structure of learning tasks to the needs of each student, driving the personalization of learning (Chemerys & Ponomarenko, 2022; Ollesch et al., 2021).

Eye-tracking technology also records dynamic metrics about the path and time of a student's gaze while they complete a task (Diwanji, 2022; van-Marlen et al., 2018). Within each stimulus (elements making up a learning task), teachers can differentiate relevant Areas of Interest (AOI) (the information the teacher considers to be most important) and non-relevant areas (those they think are less important). Once that differentiation of AOIs is made, teachers can find patterns of student behavior within the applied learning stimulus (Coskun & Cagiltay, 2022; Merchie et al., 2022; Tsai et al., 2022). The relationship between those patterns and learning outcomes can then be analyzed (McLeod et al., 2022; Ollesch et al., 2021) to identify the most effective (Feng & Law, 2021; McLeod et al., 2022; Merchie et al., 2022; Tsai et al., 2022; Yang & Wang, 2023). In summary, the data offered by eye-tracking allows teachers to provide specific pedagogical guidance aimed particularly at students with less satisfactory results (Molina et al., 2017; Sáiz-Manzanares et al., 2021b).

1.2. What are the problems and limitations of using eye-tracking technology in a natural learning context?

Eye-tracking technology has become much more user-friendly over the last ten years and modern eye-tracking equipment can be applied more easily in natural settings (Schweizer et al., 2022). The technology can also be incorporated into augmented reality devices (Thees et al., 2022), virtual reality devices (Chango et al., 2022; Mills et al., 2016; Rother & Spiliopoulou, 2022; Yang & Wang, 2023), or mobile devices (Kuhnel et al., 2018). All this functionality will make it easier to apply the technology in day-to-day teaching. However, using eye tracking presents significant challenges for teachers.

Firstly, although the devices have become smaller and can be used outside the laboratory, they still need skilled users to deal with them. The process in an educational setting would involve 1) designing the learning task; 2) integrating the task and the eye-tracking device; 3) calibrating the students' gaze for the screen; 4) once the learning activity is completed, the recorded data must be extracted, refined, treated, and interpreted. Currently, eye-tracking technology offers a simple automatic interpretation of data. However, that does not include all of the data treatment and analysis possibilities. The challenge in this regard is the large volume of data that these devices collect (Sáiz-Manzanares et al., 2020). This is a very important functionality but requires the application of Educational Data Mining (EDM) techniques in order to properly analyze and interpret the results (Chango et al., 2022; Feng & Law, 2021). These techniques involve using Machine Learning algorithms to analyze educational data (Bogarín et al., 2018). In short, eye-tracking technology in educational contexts is promising, but to use it well requires teachers to be trained in the aspects indicated above.

1.3. What are the possibilities of using other neurological evaluation resources with eye-tracking technology?

Other recording devices can be included with eye-tracking technology, such as devices to measure galvanic skin response (GSR) (He et al., 2022), electroencephalography (EEG), (Luo & Zhou, 2020; Scharinger et al., 2020), and recording the learner's face for subsequent analysis of emotions during a task. The technology, depending on the sophistication of the equipment, can also facilitate incorporating these metrics in multiple records. That would give greater confidence in the interpretations of students' learning processes (Alemdag & Cagiltay, 2018), although they would need to be applied in laboratory settings. It is also important to bear in mind that they would provide information about students' information processing during different types of tasks (Giannakos et al., 2019).

As already noted, task design is fundamental in this context. This is because, depending on each learner's learning style, one presentation or another of the same task could be more—or less—effective for the learning process. Along these lines, studies using multi-channel analysis (Azevedo & Gaševi , 2019; Taub et al., 2017) have concluded that tasks that are offered through dual channels (audio and video) increase the cognitive load in information processing (Souchet et al., 2022).

In addition, tasks that are presented through video and which require the application of procedural knowledge have a higher cognitive load for the student (Pi & Hong, 2016). In contrast, it seems that including graphics or diagrams in tasks reduces cognitive load and eases understanding (Fiorella, 2022).

Nonetheless, interpreting these results requires the application of EDM techniques, the most notable of which are described below.

1.4. What does using EDM techniques offer for the interpretation of eye-tracking results from the teaching-learning process?

EDM techniques can be defined as the application of Data Mining (DM) techniques in an educational setting (Chango et al., 2022). More specifically, DM techniques use some Automated Learning techniques. These may be supervised, which include prediction (Seinen et al., 2022) and classification techniques (Díez-Pastor et al., 2014); or unsupervised, which include clustering (Sáiz-Manzanares et al., 2021a). Table 2 gives an overview of the most important EDM techniques in the education field.

Table 2. EDM techniques and their application to educational practice

Supervised EDM techniques	Definition	Applicability to teaching practice
Prediction		
Linear Regression	A model used to approximate the relationship between continuous variables and one or more dependent variables.	It can help predict the effect of one or more variables on student learning outcomes.
Classification		
Decision Tree	An algorithm that detects the influence of a series of variables (independent) on other variables (dependent) in a hierarchical order. Decision trees are quick to construct and interpret and are sensitive to small changes (Sáiz-Manzanares et al., 2019)	They can help detect the most effective methodology for each student.
Unsupervised EDM techniques	**Definition**	**Applicability to teaching practice**
Clustering		
k-means	Allows an element to be assigned to a group without applying a prior grouping variable. Assignation is done by detecting the shortest distance to the center of the cluster (Sáiz-Manzanares et al., 2020).	The results allow groups of students with similar characteristics to be found without prior application of a grouping variable. This will make it easier for teachers to adapt methodologies to each group's characteristics.
Educational Process Mining (EPM)	Apply specific algorithms to discover patterns and possible hidden relationships. Each element belongs to a single instance of the process (Bogarín et al., 2018).	Understanding each student's patterns of execution will give the teacher information about the most effective or least effective learning behaviors regarding a task. This will strengthen the personalization of learning.

1.5. Does the use of eye-tracking technology present new ethical challenges in the teaching-learning process?

Clearly, making records that include student activity during tasks brings with it ethical challenges. These center on the necessary authorization from the student to participate in this type of teaching. Students might have misgivings about granting this authorization as it means recording a task and might include images of them. This means that a procedure of this kind might introduce biases due to authorization from some students and not others because the students who do participate will get feedback to improve their learning processes while others will not. That will clearly lead to a situation with an equality gap in the pedagogical intervention which may cause increased differences in academic performance between students who do and do not participate. In summary, eye-tracking technology is promising in the field of education as it allows teachers to produce data about how their students process information. By analyzing that data, teachers can also identify the patterns of behavior during learning. All this information will presumably help teachers to personalize the design of learning tasks, which will facilitate education tailored to the needs of each student. This will enhance attention to diversity and foreseeably promote better academic inclusion. Based on all of the above, the research questions (RQ) for the present study were:

- RQ1: Will there be significant differences between students with and without prior knowledge in the parameters of cognitive load (FC, FD, SC, PD, VC) and in the learning outcomes (LO)?
- RQ2: Will there be clusters of patterns in learning behaviors that are different between students?
- RQ3: Will the study find patterns of learning behaviors that are more effective and less effective?

2. Materials and methods

2.1. Participants

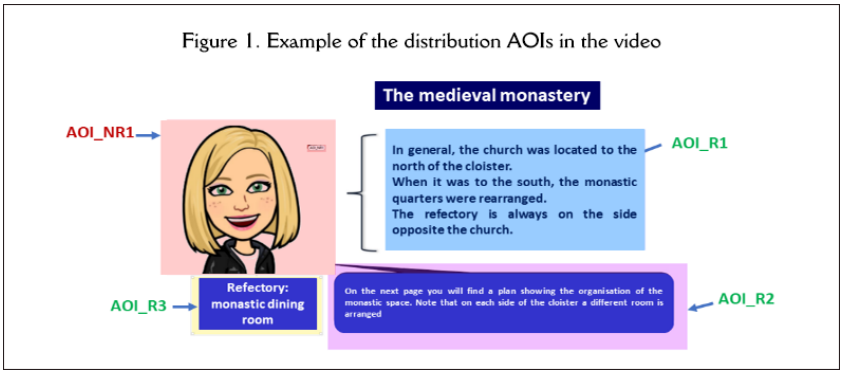
The study used a non-probabilistic convenience sample (based on agreeing to participate in the study) of 20 university students from three universities: 7 from the University of Burgos (UBU) (3 women M_{age}=22 years, SD_{age}=2.00; 4 men M_{age}=21 years, SD_{age}=1.41) 11 from the University of Valladolid (UVA) (8 women M_{age}=22.38 years, SD_{age}=2.77; 3 men M_{age}=24 years, SD_{age}=1.00), and 2 from the University of Miño in Portugal (UMINHO) (2 women M_{age}=21.50 years, SD_{age}=0.70). The students were identified as with or without prior knowledge based on the knowledge branch of the course they were studying. Those studying Art History (n=7) were considered to have prior knowledge, whereas those studying Psychology (n=5) and Education (n=8) were considered not to have prior knowledge.

2.2. Instruments

a) Tobii Pro Lab version 1.194.41215 and a 15.6-inch monitor with a resolution of 1920 X 1080, at 64 Hz. Static metrics in this study were analyzed using SPSS software v. 28 (IBM, 2022). Dynamic metrics were recorded via the gaze point offered by Tobbi and Orange 3.33.0 was used to produce the heat maps.

b) The stimulus for the eye-tracking technology was a self-regulated video about the development of monasteries in Europe. A recorded voice read out information, putting stress on the most important data. The video also included diagrams and pictures summarizing the most important content. The information for the video was taken from the "SmartArt Toolkit for Knowledge Transfer" which can be found at https://bit.ly/3CPkEwq. The SmartArt project was co-financed by the European Union (information about the project can be found at http://bit.ly/3kLeF5J). The video used in the study is available at http://bit.ly/3VzdMd9. The video contains 1 non-relevant AOI—AO1_NR1— (an image of an avatar) and 3 relevant AOIs: Relevant AOI 1 (AOI R1; an outline of important concepts); Relevant AOI 2 (AOI R2; summary of the most important spoken content); and Relevant AOI 3 (AOI R3; key concepts from the spoken information). An example showing the distribution of the AOIs is given in Figure 1.

Figure 1. Example of the distribution AOIs in the video



c) Knowledge test about the concepts seen in the video. This test consists of 9 questions about the most important concepts in the video. The questions were taken from the "SmartArt Toolkit for Knowledge Transfer" and were the first 9 questions from "Self-assessment questionnaire 1. Basic level" (p. 63-64), which can be found at https://bit.ly/3CPkEwq.

2.3. Procedure

Before carrying out the study, approval was obtained from the UBU Bioethics Committee (IR 27/2019). Following that, students at UBU, UVA, and UMINHO were offered the chance to participate in the study. Students who agreed signed their informed consent to participate voluntarily and without remuneration. The experimental phase was carried out with each student individually in two classrooms (one in UBU, the other in UVA) with controlled lighting conditions and without distracting stimuli. The experiment was performed in all cases by the same researcher who was an expert in the use of this technology.

2.4. Research design

This study was exploratory. To test RQ1, given the characteristics of the sample, we applied a quasi-experimental design without a control group where the independent variable was "prior knowledge of art history" and the dependent variables were the parameters of cognitive load and the learning outcome. To test RQ2 and RQ3 we applied a descriptive design (Campbell & Stanley, 2005).

2.5. Data analysis

Because non-probabilistic convenience sampling was used, and because the sample was smaller than 30 participants, we used non-parametric statistics to test the RQs. For RQ1, we used the Mann-Whitney U test and calculated the non-parametric effect size r, with the cutoff points: (a) up to 0.30, small; (b) from 0.30 to 0.50, moderate; (c) over 0.50, high. This analysis was done using SPSS v. 28 (IBM Corp, 2022). For RQ2 we used k-means clustering using SPSS v. 28 (IBM Corp, 2022) along with visualization using heat maps and clustering using Machine Learning and data visualization from the Orange toolbox 3.33.0 (Demšar et al., 2013). Finally, for RQ3, we used the visualization of gaze point patterns offered by Tobii Pro Lab version 1.194.41215.

3. Analysis and results

There were no statistically significant differences between students with or without prior knowledge in terms of the cognitive load parameters (FC, FD, SC, PD, VC). However, there was a slight difference (p=0.06) in SC_AOI_R2 (this parameter refers to the saccade transition in the summary of the most important spoken content). There were also significant differences between the two groups in learning outcomes [U=20, p=0.03] with a moderate effect size, r=0.49. The students with prior knowledge had higher scores (Median (Mdn)=5) than students without (Mdn=2). See Table 3.

Table 3. Mann-Whitney U

Variables	Group 1 (n=8) Mean range	Group 2 (n=12) Mean range	U	z	p	r
FC_AOI_NR1	9.69	11.04	41.50	-0.50	0.62	0.11
FC_AOI_R1	9.38	11.25	39.00	-0.70	0.52	0.16
FC_AOI_R2	9.88	10.92	43.00	-0.39	0.73	0.09
FC_AOI_R3	13.63	8.42	23.00	-1.95	0.06	0.44
FD_AOI_NR1	10.13	10.75	45.00	-0.23	0.85	0.05
FD_AOI_R1	8.38	11.92	31.00	-1.31	0.21	0.29
FD_AOI_R2	10.38	10.58	47.00	-0.08	0.97	0.02
FD_AOI_R3	12.75	9.00	30.00	-1.39	0.18	0.31
SC_AOI_NR1	8.88	11.58	35.00	-1.00	0.34	0.22
SC_AOI_R1	8.81	11.63	34.50	-1.04	0.31	0.23
SC_AOI_R2	7.38	12.58	23.00	-1.94	0.06	0.43
SC_AOI_R3	11.75	9.67	38.00	-0.80	0.47	0.18
PD_AOI_NR1	9.88	10.92	43.00	-0.39	0.73	0.09
PD_AOI_R1	10.50	10.50	48.00	0.00	1.00	0.00
PD_AOI_R2	10.25	10.67	46.00	-0.15	0.91	0.03
PD_AOI_R3	9.13	11.42	37.00	-0.85	0.43	0.19
VC_AOI_NR1	12.38	9.00	33.00	-1.17	0.27	0.26
VC_AOI_R1	9.31	11.29	38.50	-0.74	0.47	0.17
VC_AOI_R2	11.13	10.08	43.00	-0.39	0.73	0.09
VC_AOI_R3	12.63	9.08	31.00	-1.34	0.21	0.30
LO	14.00	8.17	20.00	-2.18	0.03*	0.49

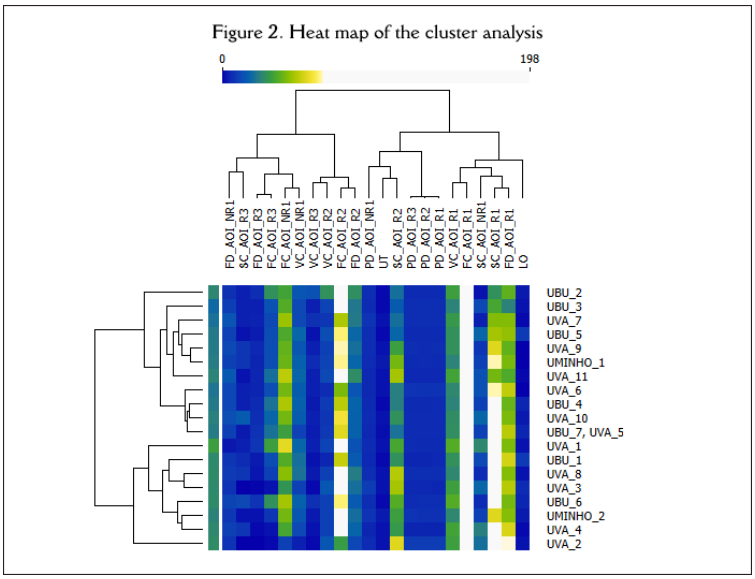
Note. *p≤0,05. Group 1=students with prior knowledge; Group 2=students without prior knowledge; U=Mann-Whitney U; FC_AOI_NR1=Fixation count in Non-relevant AOI; FC_AOI_R1=Fixation count in Relevant AOI 1; FC_AOI_R2=Fixation count in Relevant AOI 2; FC_AOI_R3=Fixation count Relevant AOI 3; FD_AOI_NR1=Fixation duration in Non-relevant AOI; FD_AOI_R1=Fixation duration in Relevant AOI 1; FD_AOI_R2=Fixation duration in Relevant AOI 2; FD_AOI_R3=Fixation duration in Relevant AOI 3; VC_AOI_NR1=Visit count in Non-relevant AOI; VC_AOI_R1=Visit count in Relevant AOI 1; VC_AOI_R2=Visit count in Relevant AOI 2; VC_AOI_R3=Visit count in Relevant AOI 3; PD_AOI_NR1=Pupil diameter in Non-Relevant AOI; PD_AOI_R1=Pupil diameter in Relevant AOI 1; PD_AOI_R2=Pupil diameter in Relevant AOI 2; PD_AOI_R3=Pupil diameter in Relevant AOI 3; SC_AOI_NR1=Saccade count in Non-relevant AOI; SC_AOI_R1=Saccade count in Relevant AOI 1; SC_AOI_R2=Saccade count in Relevant AOI 2; SC_AOI_R3=Saccade count in Relevant AOI 3; LO=Learning Outcomes; $r=|Z|/\sqrt{N}$.

To test RQ2, we performed a cluster analysis using the k-means algorithm. Beforehand, we used the elbow method to estimate the number of clusters (the results are available at https://bit.ly/3W0Qe0Q). Two clusters were found regarding the variables considered in Table 3.

Figure 2 shows a visualization of the distribution of students in each cluster. The k-means unsupervised machine learning technique provides a visualization of each student's position in each cluster without the prior application of a grouping variable. This allows grouping variables to be detected that have not been established previously. The cluster analysis is available in Table 4 on the Figshare platform (http://bit.ly/3JiNrNf). An ANOVA test between the clusters found significant differences in:

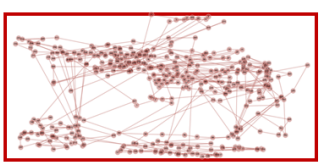
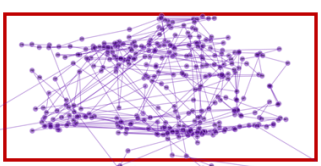
FC_AOI_R1 (F=12.98, p=0.00), with the higher scores in cluster 2—indicating that the students in this cluster may have had difficulty in discriminating between relevant and non-relevant information in the task; FD_AOI_NR1 (F=9.79, p=0.01), with higher scores again in cluster 2—indicating that the students in this cluster paid more attention to the information in the non-relevant AOI; FD_AOI_R1 (F=10.13, p=0.01), with higher scores in cluster 1—which may be an indicator that these students paid more attention to this stimulus; VC_AOI_R1 (F=5.74, p=0.03), with higher scores from students in cluster 1—which may indicate greater interest from these students in Relevant AOI 1; SC_AOI_NR1 R1 (F=14.55, p=0.00), with more saccades from students in cluster 1—this may be explained from greater use of guidance responses in these students which may be related to greater cognitive effort discriminating between relevant and non-relevant information; and SC_AOI_R1 (F=22.43, p=0.00), there were more saccades from students in cluster 1—which may be related to greater cognitive effort in these students in relation to the information in Relevant AOI 1. Lastly, it is worth highlighting that there was a tendency towards difference in FD_AOI_R2 (p=0.05) and FD_AOI_R3 (p=0.05). FD was longer in students in cluster 2, which may be an indicator of greater cognitive effort in relation to the information in Relevant AOIs 2 and 3.

Figure 2. Heat map of the cluster analysis



In response to RQ3, we performed a visualization analysis of students' learning behavior patterns considering the results of the cluster analysis (Figure 2).

Figure 3. Example comparison of eye-tracking patterns between students from the two clusters

Cluster 1 Student	Student learning behavior patterns, Cluster 1	Student learning behavior patterns, Cluster 2:	Cluster 2 Student
UBU_2			UBU_1

As an example, we present a comparison of the gaze point. Between a student in cluster 1 and a student in cluster 2 (Figure 3). In the comparison, the path followed by the cluster 1 student deviates slightly from

the way the cluster 2 student tracks the information presented in the video. The cluster 2 student's path is more spread out (the gaze path strays outside the frame where the information is presented).

4. Discussion and conclusions

Neurotechnological resources such as eye-tracking technology offer teachers a range of promising opportunities in the 21st century. These include recording learning behaviors in various types of tasks. Eye-tracking technology in particular offers information about students' attention and cognitive effort (Asadi et al., 2022; Kulomäki et al., 2022; Rodziewicz-Cybulska et al., 2022; Taub & Azevedo, 2019) during tasks (Ollesch et al., 2021). It can also record students' learning behaviors regarding relevant and non-relevant information in AOIs that the teacher defines beforehand, along with information about each student's patterns of task resolution (Coskun & Cagiltay, 2022; Merchie et al., 2022; Tsai et al., 2022). Teachers can then determine the most and least effective patterns for each task (Feng & Law, 2021; McLeod et al., 2022; Ollesch et al., 2021; Tsai et al., 2022; Yang & Wang, 2023). Effectiveness will be determined based on each student's learning outcomes, and such a comparison could serve as a reference for teachers to create personalized learning (Sáiz-Manzanares et al., 2021b). This is a notable step forward as it mitigates the subjectivity that might be associated with observing learning processes in natural contexts without using such technology and measuring resources. However idyllic this achievement may seem; it is not without its handicaps. Although the technology of eye-tracking has advanced in terms of functionality, it still needs EDM techniques to be used for the interpretation of the records (Chango et al., 2022; Feng & Law, 2021). This is a challenge for teachers or for institutions that wish to use it.

This study demonstrated an example of how eye-tracking technology works in analyzing university students' learning processes from watching a video and how it relates to learning results. In summary, the results indicate that prior knowledge did not seem to be important in a self-regulated video task in terms of cognitive load parameters but were important in terms of learning outcomes. This finding is in line with the studies by Fiorella (2022). Nonetheless, we did find that other variables that had not been previously defined did seem to influence the indicators of cognitive effort (FC, FD, SC, PD, VC). Students in one of the clusters seemed to use more techniques of reflection and focused their attention on the more relevant information, inhibiting the less relevant information, unlike the other group, who seemed to have more problems focusing attention on the relevant information. More specifically, these differences appeared in the AOI defined as non-relevant and one relevant AOI related to the outline information. These results are important for the teacher, as they can offer guidance about how to produce teaching materials that are better tailored to the learning characteristics identified in each of the clusters.

Future studies should analyze the characteristics of the students assigned to each cluster in order to detect the variables that can explain the clustering. In addition, this study has demonstrated an example of the detection of learning behavior patterns in different types of students that had previously been grouped together. This is significant functionality for teachers, as studying each pattern will help us understand where each student's difficulties with learning lie, and based on that, the teacher will be able to offer individual guidance to each one (Chango et al., 2022; Molina et al., 2017; Sáiz-Manzanares et al., 2021b). Nonetheless, the results of this study must be taken with caution, as it used a small convenience sample, meaning that generalization of the results is limited, although the ultimate aim of this study was to demonstrate possible applications and challenges of using eye-tracking technology in a university education setting. In summary, analyzing the data collected by eye-tracking technology offers great potential for precision teaching, but there is still a long way to go before it can be implemented smoothly in natural settings.

Authors' Contribution

Idea, M.C.S.M.; Literature review (state of the art), M.C.S.M., R.M.S.; Methodology, M.C.S.M., L.J.M.A., R.M.S., L.A., M.A.C.M.; Data analysis, M.C.S.M.; Results, M.C.S.M., L.J.M.A., R.M.S.; Discussion and conclusions, M.C.S.M., L.J.M.A., R.M.S.; Drafting (original draft), O.L., J.G.M.; Final revisions, M.C.S.M., L.J.M.A., R.M.S., L.A., M.A.C.M.; Project design and sponsors, M.C.S.M., L.J.M.A., R.M.S., L.A., M.A.C.M.

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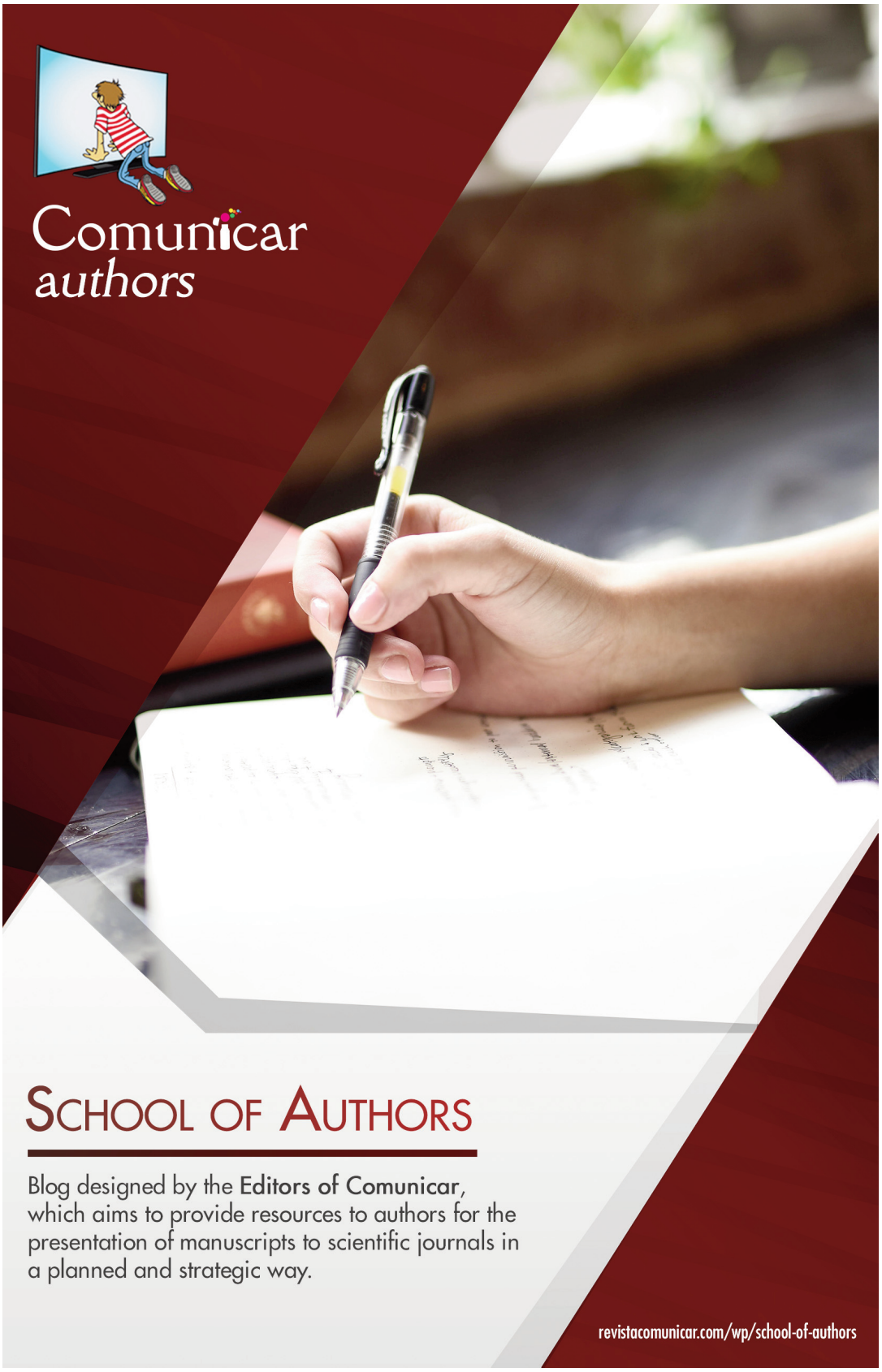

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Potentialities and limitations of the use of EEG devices in educational contexts

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.

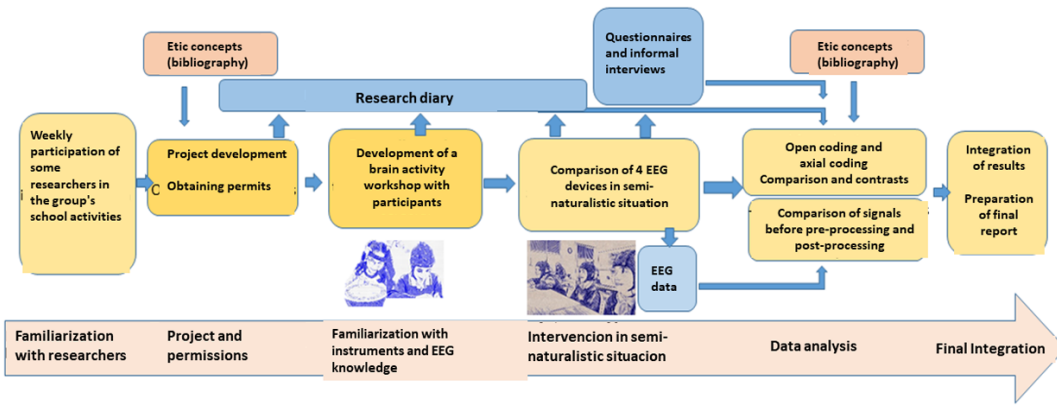
Studies with university students are dominant. The number of studies with schoolchildren is minimal. Sample sizes are small. Many studies use low-cost devices with less than five dry sensors, which limits the reliability of the data. The high cost of quality devices, their lengthy preparation, or the 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.

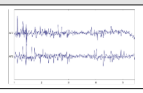
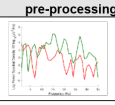
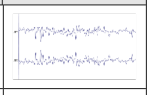
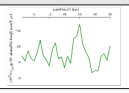
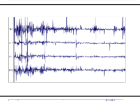
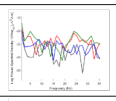
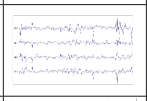
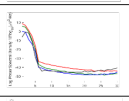
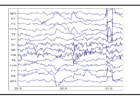
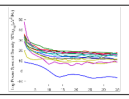
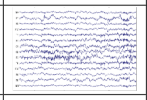
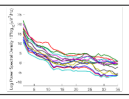
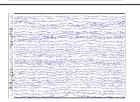
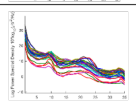
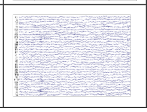
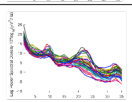
3.2. Device possibilities and limitations

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

BrainLink						
					Mean	**SD**
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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Application of neurotechnology in students with ADHD: An umbrella review

Aplicación de la neurotecnología en alumnado con TDA-H: Una revisión paraguas

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ABSTRACT

Currently, classrooms are experiencing an increase in the number of schoolchildren with a diagnosis of attention deficit hyperactivity disorder (ADHD). Numerous studies propose, as an alternative to medication, the implementation of different neurotechnology in the classroom to improve the symptomatology and enhance the cognitive abilities of children with this diagnosis. This umbrella review aims to compile the scientific evidence that exists on the application of these techniques, as well as their implementation, in schools. A systematic review was carried out, following accepted recommendations (PRISMA), which included systematic reviews in English or Spanish, published in scientific journals, which deal with ADHD, apply some neurotechnology used in this population such as neurofeedback, transcranial stimulation (tDCS) or hyper scanning, and which refer to education or school. Fourteen systematic reviews were retained, which show that neurofeedback is the most widely used neurotechnology, although its actual implementation in school has been scarcely treated or only aimed to evaluate its efficacy. In second place, tDCS appears with a more clinical approach, while hyper scanning does not appear. Despite the promising experimental results, ecological studies proposing the effective implementation of these techniques in educational centers are necessary; on the other hand, the commitment to neuroeducation would entail the emergence of new professional figures.

RESUMEN

En la actualidad, las aulas experimentan un incremento del número de menores escolarizados con un diagnóstico de trastorno por déficit de atención e hiperactividad (TDA-H). Numerosos estudios proponen, como alternativa a la medicación, la implementación de diferentes neurotecnologías en el aula para mejorar la sintomatología y favorecer las capacidades cognitivas de los escolares con dicho diagnóstico. La presente revisión sistemática persigue recopilar la evidencia científica que existe sobre la aplicación de estas técnicas, así como su implementación en el aula. Se realizó una revisión sistemática, siguiendo los estándares de rigor aceptados (PRISMA), incluyendo las revisiones sistemáticas en inglés o español, publicadas en revistas científicas, que aborden el TDA-H, apliquen alguna neurotecnología utilizada en esta población (neurofeedback, estimulación transcraneal (tDCS) o hiperescaneo) y que hagan referencia a la educación o a las aulas. Se retuvieron 14 revisiones sistemáticas, poniendo de manifiesto que el neurofeedback es la neurotecnología más utilizada, aunque su implementación real en el aula ha sido escasamente tratada o sólo lo ha sido con fines de evaluación de eficacia. En segundo lugar, aparece la tDCS con un enfoque más clínico, mientras que el hiperescaneo no aparece. A pesar de encontrar resultados experimentales prometedores, son necesarios estudios ecológicos que propongan la implantación efectiva de estas técnicas en los centros educativos; por otra parte, la apuesta por la neuroeducación conllevaría la aparición de nuevas figuras profesionales.

KEYWORDS | PALABRAS CLAVE

Cognitive stimulation, hyper scanning, neuroeducation, neuroscience, neurofeedback, ADHD.
Estimulación cognitiva, hiperescaneo, neuroeducación, neurociencia, neurofeedback, TDA-H.

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1. Introduction and state of art

Advancements in neuroscience and neurotechnology appear to be reconfiguring the approach of traditional disciplines. In the field of education, neuroscience is providing a scientific basis for new pedagogical models that affect all dimensions of educational activities, from active methodologies to assessment systems, new teaching resources, and innovation models (Coch & Daniel, 2020). In this new scenario, the focus is not only on what the teacher should teach, but also on how they should teach it so that the student can learn. This shift is not accidental; it responds to the need to fulfil the 2030 Agenda, which includes the goal of quality education (SDG 4), which aims to reduce early school dropout to 9%. In Spain, over the past decade, there has been a downward trend in school dropout rates, nearly halving (49.3%) (INE). However, we are still far from achieving the desired goal: in 2021, the early school dropout rate was 13.3% (INE). The creation of inclusive schools that can attend to the diversity of the classroom at all levels, from social inequalities to students with special educational needs (Márquez & Indarramendi, 2022) remains a challenge. Developmental disorders constitute one of the first non-academic aspects of early school dropout (González-Rodríguez et al., 2019), so addressing ADHD through new strategies can help reduce the mentioned rate.

Currently, ADHD accounts for 50% of child psychiatry consultations and comorbidity with other disorders is present in 70% of cases (Rusca-Jordán & Cortez-Vergara, 2020). The worldwide prevalence of this disorder in young people is 5.9% (Francés et al., 2022), and evidence of probable ADHD symptoms has been shown in 5.4% of the Spanish child population aged 4 to 6 years old (Cerrillo-Urbina et al., 2018). Therefore, it is important to advance treatments that improve the quality of life of these children and enable them to better adapt to their environment, which implies the need to propose new approaches within school. ADHD is defined as a persistent pattern of inattention or hyperactivity-impulsivity that interferes with functioning or development for a period of more than six months and is characterized by three core symptoms: inattention, hyperactivity, and impulsivity. These symptoms should occur before the age of 12, manifest in two or more contexts, interfere with social, academic, or work functioning, or reduce quality of life, and cannot be explained by another disorder, such as oppositional defiant disorder (5th ed.; DSM-5; 2013). Individuals with ADHD have difficulty attending to certain stimuli, planning and organizing actions, reflecting on their possible consequences, or inhibiting the first automatic response to change it to a more appropriate one (Rusca-Jordán & Cortez-Vergara, 2020). In turn, motivation, introspection, and self-awareness are also affected, as well as the recognition and regulation of emotions, which are manifested in internalizing problems (Sjöwall et al., 2013), which can lead to social interaction avoidance. Although as a person develops, hyperactivity and impulsivity decrease (Rusca-Jordán & Cortez-Vergara, 2020), some symptoms persist into adulthood, including other psychological manifestations such as feelings of frustration and shame (Weinstein, 1994). This can be due to cognitive and emotional changes that occur after puberty, to the maturation and consolidation of the neural connections in the prefrontal cortex, an area of special importance for executive functions such as reasoning and impulse control (Nigg, 2017).

According to Quintero and Castaño-de-la-Mota (2014: 602), "ADHD is a disorder of heterogeneous, multifactorial, and complex etiopathogenesis, in which a series of biological vulnerabilities interact with each other and with environmental factors." The same authors argue that genetic factors play an important role in the onset of the disorder, with a heritability of around 75%. Recently, one of the theories that seeks to explain the etiology of ADHD states that the prefrontal cortex undergoes a developmental delay and, as a result, executive functions and inhibitory control are affected. However, new findings support the importance of the "Callous Unemotional" (CU) traits, which lead to lower levels of guilt and empathy (Graziano et al., 2017). This neuroanatomical origin shows the relevance of implementing neurotechnology, not only to improve a diagnosis, which is controversial, but also to alleviate some symptoms, improve certain cognitive abilities, or monitor the anatomical-functional substrate of certain social skills. To address the issue, we review the main options currently available: neurofeedback, transcranial stimulation, and hyperscanning. Each of them has both advantages and disadvantages when implemented in the real setting at school.

1.1. Neurofeedback

The technique that first began to be used, dating back to the 1970s (Arns et al., 2014) and which possibly motivated the further exploration of other neurotechnology with applications for ADHD, was neurofeedback. Essentially, neurofeedback, based mainly on electroencephalographic (EEG) recordings at different brain activity frequencies, is "a self-regulation technique that uses a brain-computer interface (BCI) to influence neural plasticity and efficiency. Neuro-regulation is carried out by providing the individual with information about brain electrical activity" (Cannon, 2015). The person, through training and by operant conditioning, learns to modify brain activity when the interface warns that brain activity is not appropriate. Without going into the criteria for rating brain activity as appropriate or not, this technique is promising for treating ADHD, is currently applied, and has received much attention from researchers.

In certain scientific studies, the academic success has been considered. In 2013, Meisel et al. (2014) conducted the first randomized trial with a six-month follow-up comparing the efficacy of neurofeedback versus usual pharmacological treatment and found a similar reduction with both procedures, based on functional symptoms reported by parents, but with greater efficacy in the neurofeedback group in terms of academic performance. On the other hand, Sudnawa et al. (2018), in a study conducted on forty children, concluded that it is a promising technique, although improvement was statistically significant only in the case of reports from teachers and not from parents. Kuznetsova et al. (2022) point out that, although the technique is effective in learning cases, it does not seem robust regarding efficacy in reducing symptoms specific to ADHD.

1.2. Transcranial electrical stimulation (tDCS)

Neural stimulation through electromagnetic current is one of the techniques that is also presented as a complementary or alternative therapy to drugs to alleviate cognitive difficulties or promote learning tasks in populations affected by neurological disorders (Camacho-Conde et al., 2022). There are various modalities that allow such stimulation in a more or less invasive way, and numerous research studies focus on the technical parameters of interventions to optimize results. Among others, its usefulness has been demonstrated in the case of ADHD to achieve a reduction in symptoms (Salehinejad et al., 2020) or to enhance the performance of young people in cognitive and behavioral aspects such as information processing or inhibitory control (Nejati et al., 2022), which are key aspects in the educational context to avoid school failure.

In the case of transcranial direct current stimulation (tDCS), its safety has been widely verified in healthy individuals, vulnerable populations, and also in ADHD (Salehinejad et al., 2020). There are promising results in tasks related to learning (Schlechter et al., 2023) which, together with the evidence of improvement in certain attentional abilities in ADHD, make the technique an interesting option when the goal is to improve the performance of certain intellectual or even physical tasks.

1.3. fNIRS Hyperscanning

On many occasions, learning and good dynamics in the classroom depend not only on the cognitive abilities of students, but also on the social interactions that occur among the agents participating in the process, in this case, the students and the teacher. Therefore, it seems reasonable, from the perspective of neurotechnology, to be interested in the possibilities that the tools of this technology offer when it comes to measuring, calibrating, or interpreting coherence between individuals in various dimensions, including their brain activity.

As one could colloquially say, it is about checking if people are "on the same wavelength" through neurophysiological recordings of several people simultaneously, which is known as hyperscanning and has been used in the study of different real social interactions, although the educational context has not received priority attention, according to the review conducted by Nam et al. (2020). The relevance of using neural synchrony between subjects as a predictor of successful learning outcomes for different types of tasks has been analyzed by Zhang et al. (2022), whose meta-analysis concludes that there is a positive relationship between such synchrony and good results, which therefore motivates its implementation in the academic field. Other interesting examples can be found both in the study by Lu et al. (2021), which

suggests that there is greater cerebral synchrony between subjects who exchange information and share ideas, which in turn would depend on the educational diversity context in which they are immersed, and in Liu et al. (2019), whose authors analyze the effectiveness of communication between teachers and students through hyperscanning and the technique under discussion in this section.

One of the recent techniques that is shedding light on inter-subject synchrony is functional near-infrared spectroscopy (fNIRS), which overcomes certain practical issues, such as robustness to motion artifacts or flexibility for the conception of experimental designs (Janssen et al., 2021), compared to the unquestionable legacy of EEG. fNIRS is being successfully applied in ADHD (Gossé et al., 2021) on fundamental aspects of basic psychology using classic tasks such as Go/no Go, Stroop, and Oddball, which allowed to corroborate an hypoactivation of the right prefrontal region in ADHD in elementary cognitive processes. In the specific case of hyperscanning, fNIRS has been studied in attention, which is so affected by ADHD, and in neurodiverse populations such as people with autism spectrum disorders (Kruppa et al., 2021).

2. Methodology

2.1. Research question and objectives

The present study poses the following research question: Is there scientific evidence of the effectiveness of neurotechnology as a complement to educational interventions for students with ADHD? Based on this question, the objectives of this review are:

- To compile all those reviews that incorporate the neurotechnology used to reduce the symptomatology of ADHD in the educational context.
- To verify the feasibility of the application of neurotechnology in the classroom for students with ADHD.
- To propose the need for training for educational actors on the practical implementation of neurotechnology in the classroom.

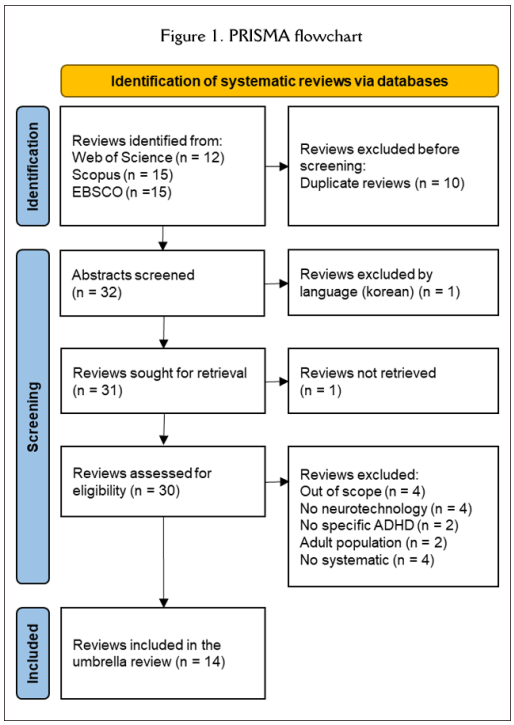
2.2. Search strategy

To carry out the present review, we followed the PRISMA (2020) recommendations for conducting systematic reviews (Page et al., 2021), as well as the method proposed by Smith et al. (2011) for the specific case of systematic reviews of existing systematic reviews, also known as umbrella reviews. The search strategy began by identifying keywords or descriptors related to the use of neurotechnology in ADHD at school, configuring the following search equation: (ADHD OR TDA-H OR attentional deficit hyperactivity) AND (neurofeedback OR hyperscanning OR tDCS) AND (school OR classroom OR education). This equation contains the relevant sections of our objective. The search was carried out independently by two researchers in the Web of Science, Scopus databases, as well as APA PsycArticles, APA PsycInfo, APA PsycTherapy, ERIC, MEDLINE, and the Spanish database PSICODOC, which were accessed through EBSCO (Figure 1). The databases used in our search provide the most significant results in the educational context (e.g., Hurtado-Parrado et al., 2022).

Next, we selected systematic reviews based on the following inclusion criteria: 1) qualification as articles or book chapters of systematic reviews by the database (excluding books, conference contributions, and reports), 2) English or Spanish language, 3) any range of publication dates, 4) study on children or adolescents with ADHD, 5) inclusion of the school context, 6) presentation of interventions based on neurotechnology. Regarding exclusion criteria, we considered: 1) narrative reviews, 2) that do not include at least one mention of any of the three mentioned neurotechnology techniques, 3) that are based exclusively on results on the adult population, 4) that are not specific to ADHD, although it is included as part of other learning disorders or presented with significant comorbidities of other disorders.

3. Results

Figure 1 shows the flowchart and number of reviews retained and withdrawn. A total of 14 systematic reviews have been selected.



Tables 1 and 2 compile the basic information of each neurofeedback (NF) and transcranial stimulation (tDCS) reviews respectively.

Table 1. Retained systematic reviews where Neurofeedback is listed

Selected from Web of Science, Scopus, PsyArticles, Psydoc, PsyInfo, ERIC, MEDLINE, PsyArticles, Psydoc.

Authors and year	Number of studies	Technique used	Teachers' report or academic measure	Classroom application	Main conclusion on: 1) school performance/behaviour or 2) symptoms or 3) other aspects.
Che et al. (2021)	83	NF (n=23)	Not included	Not mentioned	NF shows improvements in attention, but has less acceptability than other techniques such as meditation.
Evans et al. (2014)	21 (EBT criteria)	NF (n=1)	Symptoms SDQ, ODD, Aggression	Behavioral assessment only	NF training met the criteria for Level 3 (possibly effective).
Goode et al. (2018)	54	NF (n=3)	Symptoms (n=1)	Not mentioned	Inconclusive assessment of academic improvement with NF.
Guan-Lim et al. (2020)	15	NF (n=4)	Not included	Is mentioned	Need for more quality studies to conclude the long-term effects of NF.
Hodgson et al. (2014)	14	NF	CTRS (n=1)	Not mentioned	NF shows symptom improvement and can be considered an evidence-based intervention.
Moreno-García et al. (2022)	67 RCT	NF	CTRS symptoms	Evaluation Implementation	Benefits of NF and significant symptom improvement are reported for NF implemented in schools in one study.
Patil et al. (2022)	21 (14 in childhood ADHD)	NF (n=21)	Symptoms (n=1)	Behavioral assessment only	Improvement of symptoms according to teachers, higher correlation in attention. Small to medium effect on hyperactivity and impulsivity.
Razoki (2018)	8 RCT	NF (n=8)	Symptoms (n=5)	Behavioral assessment only	There are no differences in teacher reports, although there are differences in parental reports.
Sibley (2014)	17 CT	NF (n=1)	CRS symptoms (n=1)	Behavioral assessment only	No significant differences were found in the study using NF.
Van-Doren et al. (2019)	10 RCT	NF (n=10)	Symptoms	Behavioral assessment only	Moderate immediate and medium-term difference in Hyperactivity and Impulsivity and large difference in Inattention.
Willis et al. (2011)	14 (Exp and QExp)	NF (n=14)	Symptoms (n=4)	Behavioral assessment only	Best performance according to teachers in one of the 4 studies including their assessment.

Note. CRS: Conners Rating Scale; CT: Controlled Trial; CTRS: Conners Teacher Rating Scale; EBT: Evidence Based Treatments; Exp: Experimental Study; ODD: oppositional defiant disorder; QExp: Quasi-experimental Study; NF: Neurofeedback; RCT: Randomised Controlled Trial; SDQ: Strengths and Difficulties Questionnaire.

When possible, the number of studies in each review that address each aspect mentioned in the table is indicated in parentheses: studies that include reports from teachers or employ any neurotechnology. The conclusions presented prioritize those drawn from reports from teachers or academic performance questionnaires where they were used. If such measures were not included, whether there was improvement in symptoms or other aspects is indicated.

According to the retained studies, although the school setting seems like a good context to evaluate intervention efficacy, in no case is the technique implemented in school. Teachers' reports are not always available, and when they are, their criteria are not always the same as those of parents, with teacher reports being preferred because they are usually a blind evaluation (Razoki, 2018). In most cases, the behavior evaluation questionnaires used in the classroom are based on symptomatology measures (RS-IV, CRC), and cognitive measures rarely appear in that context.

Regarding the techniques, no systematic review has been found that addresses the hyperscanning procedure in this population, despite the fact that no specific type of technique was detailed, and different neurotechnology techniques are not usually compared, with a higher number of reviews that focus on NF and compare it with other pharmacological or non-pharmacological treatments. Sometimes, NF is considered within the category of cognitive stimulation (Sibley et al., 2014).

Table 2. Retained systematic reviews in which tDCS is listed

Selected from Web of Science, Scopus, PsyArticles, Psydoc, PsyInfo, ERIC, MEDLINE, PsyArticles, Psydoc.

Authors and year	Number of studies	Technique used	Teachers' report or academic measure	Classroom application	Main conclusion on: 1) school performance/behaviour or 2) symptoms or 3) other aspects
Brauer et al. (2021)	13 RCT	tDCS (n=13)	Not included	Not mentioned	Immediate effect of tDCS on Inattention and Impulsivity, and long-term effect on hyperactivity.
Cosmo et al. (2020)	11 (6 in childhood ADHD)	tDCS (n=11)	Not included	Not mentioned	Variable efficacy of tDCS depending on the protocol used and validation as a safe technique.
Rubio et al. (2016)	18 (8 in childhood ADHD)	tDCS tMS	Not included	Not mentioned	The efficacy of tDCS depends on the location and stimulation protocol, with improvement associated with other cognitive techniques. Repeated tMS reduces symptoms for weeks.

Note. RCT: randomised controlled trial; tDCS: transcranial electrical stimulation; tMS: transcranial magnetic stimulation.

4. Discussion

Based on empirical evidence extracted from retained reviews, neurofeedback is the technique that appears most frequently in systematic reviews of non-pharmacological treatments and alternative treatments to the psychosocial approach for ADHD when descriptors associated with school are included. However, its feasibility and effectiveness in educational contexts have been sparsely reported. An example where this is taken into account is the review conducted by Patil et al. (2022), which suggests certain aspects to consider for the practical implementation of neurofeedback for populations with ADHD, such as the cost of customizing devices. Previously, this issue was addressed by Krell et al. (2019), who highlighted important factors such as optimization of schedules and protocols, and the need for pre-intervention mediator factor analysis that compromises external validity on expected sustained attention benefits. In 2014, Steiner et al. analyzed the efficacy of a training program carried out in school. These authors proposed training interventions of 45 minutes three times a week for five months, which involved about 50 sessions, carried out by a research technician. As a result of these interventions, where tasks were performed to stimulate different cognitive processes, improvement in symptoms was reported by parents up to six months later.

Recently, technology offers us new options that facilitate the incorporation of neurofeedback into accessible and unobtrusive mobile devices (Antle et al., 2019), allowing its use in various situations and contexts through apps; a model that may resemble the increasingly established mHealth interventions. On the other hand, the ethics studies related to this technique have experience that shows its safety, since it is not about stimulating the brain but about real-time monitoring, which shows an advantage over the potential adverse effects that drugs can have.

To a significantly lesser extent, neurotechnology based on tDCS appears. According to the review, in general, studies on its efficacy show an improvement in ADHD symptoms (Cosmo et al., 2020), although its

reproducibility is compromised by inter-subject variability or it depends on specific application conditions, affecting inhibitory control, hyperactivity, or attention deficit differently. However, despite the close relationship between cognitive abilities and education, where a relevant field of application could be found, most studies have been carried out with clinical protocols or in controlled laboratory environments, with little evidence of viability in ecological academic environments or real school situations. In some cases, it is justified that the natural environment of a classroom would be too complex to draw reliable conclusions, as discussed in the study by Siciliano et al. (2016), focused on the particular case of foreign language learning, where it is suggested that the excess of distracting stimuli would decrease its efficiency. On the other hand, the customization required in the procedures, the intervention adjustments required in child and adolescent populations, as pointed out by Salehinejad et al. (2020), and the sensitivity of efficacy depending on the number of sessions (Cosmo et al., 2020) do not make it useful for the teacher or users to determine application conditions, which shows the need for qualified personnel for its use. In addition, the mention of invasive methods can make users reluctant to use it, especially in the case of ADHD, where there is still no consensus on possible over-diagnosis.

Currently there is a wide variety of devices for applying tDCS[1] that are relatively affordable, favoring easy portability, wireless connectivity, and ergonomic designs that allow freedom of movement that would not interfere with the tasks performed in a classroom. Thanks to recent studies on the efficacy of tDCS that take into consideration the heterogeneity of ADHD users (Lipka et al., 2021), their results are endowed with important external validity, a matter of particular relevance for potential real-world applications in classrooms, where the student profile is diverse and poses a threat to such validity. Threats to internal validity arising from the presence of parasite variables linked to contextual classroom characteristics remain to be addressed, as well as certain ethical concerns that even prevent experimentation in such a situation: " The need to protect vulnerable groups in general and children in particular in research can sometimes lead to a vicious circle: for many treatments, evidence does not exist to initially establish, for example, relevant safety thresholds" (Sierawska et al., 2019: 3).

Regarding hyper-scanning with fNIRS, after the umbrella review conducted, the combination of descriptors yielded no results, suggesting a rather unexplored research field. In any case, the transfer of studies on hyper-scanning in general (Dikker et al., 2017), or fNIRS in particular, to the real context of a classroom, has been proposed by some researchers. It is not easy to find articles where concrete proposals are made, as they usually focus primarily on disseminating the technique, or presenting the operational bases to educators, such as the work of Barreto and Soltanlou (2022). At this point, we can mention the work of Brockington et al. (2018), who carry out three experiments of high ecological validity compared to other laboratory studies, since they present situations similar to real settings, which also address key aspects related to ADHD, such as interaction with the teacher, group attention, and attention during reading.

In all cases, the successful implementation of hyper-scanning in real classroom situations would first require the programming of powerful algorithms that provide reliable parameters from the hemodynamic signals derived from neuronal activity, and in this sense, numerous contributions have been made. On the other hand, and no less important, it should be noted that currently, fNIRS equipment is not always comfortable and there is a considerable time restriction, which would not allow monitoring during long sessions, but rather during specific moments to obtain a diagnosis of a specific situation from a few samples. In the particular case of students affected by ADHD, the inherent characteristics of this population, which may make them prone to fatigue more quickly, and for whom the setup of the intervention could represent an additional distraction, would have to be added as a difficulty, in addition to defining who would be part of the groups participating in hyper-scanning.

5. Proposal for the transfer of the use of neurotechnology in ADHD to educational centers

In addition to the technical, economic, or functional aspects related to each of the presented techniques and the necessary equipment, there are issues related to human resources that are equally important to consider. Managing the attention to students with special needs is perhaps the greatest challenge teachers are currently facing. Articulating different learning speeds is an excellent example of the difficulties involved. Institutions establish ratios of students with special needs to ensure that classrooms do not suffer attention

imbalances. In the case of Spain, the model works with low ratios (2.9% for Primary Education and 3% for ESO, in 2019-2020), understanding that with the indications and support of the orientation department that teachers receive, it is sufficient to attend to this student body (Ministerio de Educación y Formación Profesional, 2021). However, these ratios are applied to autism spectrum disorders, but not to students with ADHD, which may imply a higher percentage of students with this diagnosis.

It is worth asking: how do teachers perceive students with ADHD? Are they aware of the disorder they suffer from? To answer positively, it will be essential for teachers to have information about ADHD. It is not about being an expert, but they should know what this disorder consists of. Soroa et al. (2016) conclude that teachers' level of knowledge about ADHD is low to moderate. Frequently, teachers identify students with ADHD as "restless" or even "conflictive." Does the teaching staff know that these students have certain anatomical-brain characteristics different from those of their peers? If these issues are unknown, it is difficult to find the necessary coherence to make both the relevant curricular adaptations and implement neurotechnology whose foundation lies in the findings of neuroscience. Therefore, neuroeducation is essential to advance knowledge of neurodiversity. This reality points to the need for further training for teachers in the neuropsychological bases of learning (Ministerio de Educación y Formación Profesional, 2023).

With this objective, our proposal is to create a pilot project with an interdisciplinary training figure, from the field of neuroscience, and with a deep knowledge of the educational reality and its actors: students, families, and teachers, as well as the times and educational dynamics of the schools: "class of professionals whose role would be to guide the introduction of cognitive neuroscience into educational practice in a sensible and ethical manner" (Leisman, 2023: 3).

This figure will cover two needs. First, to give training courses in educational centers on neuroeducation. This will not only cover the findings of neuroscience applied to new teaching-learning pedagogical forms through metacognition processes but also understand the reality of students with special needs and the possible pedagogical strategies that can be implemented (Gavin et al., 2023). On the other hand, the purpose of these workshops could be to combat such important aspects as neuromyths or stigmas of certain disorders, such as ADHD. Providing these training courses to teachers, families, and students is important, as it is the only way to articulate the intervention in a transversal way.

Secondly, this figure can be fundamental for implementing new neurotechnology in the classroom, as long as they respect the basic principles of neuroethics (Simoes & Nogaro, 2019). Their implementation requires a dual knowledge of neuroscientific techniques and their impact on the children to whom they are applied, as well as of the conditions of the educational environment as a whole. It is not just a matter of knowing how to apply a particular technique, but also of informing teachers, pupils, and families about the application, impact and benefits of this technique. Only in this way will we be able to successfully implement neurotechnology in the classroom. Without sharing this information, several problems could arise, such as the increased stigmatisation of these pupils, with the associated ethical issues that this entails, or the rejection of these techniques. As for the techniques that could currently be implemented in the classroom, the umbrella review provides relevant information. Among the three techniques, the only one that could be implemented at present is neurofeedback, as not only is it non-invasive, but it is the one that has been most developed in the clinical setting and, therefore, the most tested, with very favorable results for people with ADHD. In addition, the device is discreet, which avoids stigma and allows neurotechnology to be introduced in the school environment. Finally, it allows the student to be autonomous, with no direct implications for teachers.

The second technique which appears in the review has been transcranial electrical stimulation; however, this technique is not yet sufficiently developed to be implemented in the classroom. Several reasons support this: firstly, it is a technique that still has application variables (age, application time, etc.) that need to be clarified. Secondly, the equipment required for this technique, despite being highly simplified, may increase stigma among peers. Thirdly, it requires a level of monitoring that cannot be assumed by the teacher. Therefore, we consider that the application of this technique needs to be further developed in the clinical setting and simplified for use in the school environment, which should be more familiar with neurotechnology and ADHD before implementing this technique.

Finally, some limitations of the review should be noted. The databases used primarily collect significant results of interventions, and systematic reviews tend to overlook non-effective interventions. Additionally, journals may suffer from publication bias, which excludes the inclusion of new approaches or methods, e.g. functional near-infrared spectroscopy (fNIRS), which despite being a non-invasive technique with promising results, is not included in the review, indicating a lack of scientific evidence on this topic.

We consider that the implementation of neurotechnology in the school environment should be staggered into two phases. The first phase should involve the three actors in the educational setting (students, teachers, and families) in an information campaign. The second phase should involve the implementation of techniques, of which only neurofeedback currently seems suitable. The need to implement these types of proposals in the classroom becomes evident when compared to other sectors, such as advertising or audiovisual content creation, which rely on neuroscience findings to improve their effectiveness (Ferrés & Masanet, 2017).

Notes

[1] https://www.tdcs.com.

Authors' Contribution

Idea, A.R.H.M., C.T.U; Literature review (state of the art), A.R.H.M., D.A.V., A.G.P., C.T.U; Methodology, A.R.H.M., D.A.V; Data analysis, A.R.H.M., D.A.V., A.G.P; Results, A.R.H.M., C.T.U; Discussion and conclusions, A.R.H.M., C.T.U; Writing (original draft), A.R.H.M., D.A.V., A.G.P; Final revisions, A.R.H.M., C.T.U; Project design and sponsorships, A.R.H.M., C.T.U.

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Comunicar 76

Kaleidoscope

Researchs

Studies

Proposals

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The credibility of newscasts in public service media in Spain

La credibilidad de los informativos de la televisión pública en España

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ABSTRACT

The audiences of generalist television's newscasts reflect that the viewers' interests and loyalties are constantly changing. Research shows that several elements influence the success of programs and formats, but in this paper, we draw attention to the factors that determine the credibility of newscasts. We also want to know how pluralism is safeguarded in newscasts, as we consider that credibility and pluralism are two intertwined values that influence one another. As credibility is a subjective value, it is required to find new information criteria that is suitable and of the utmost rigor. The main aim is to delve into whether there is a consensus on the basic parameters for the definition, identification, and assessment of credibility of nationwide public service media in Spain. Moreover, we are also interested in whether audience figures can be used to determine the degree of trust of newscasts. The analysis brings forward the observations of researchers, scholars and media professionals that offer a vision on the different approaches that integrate the multiple aspects affecting news consumption and interpretation. We conclude that credibility is a concept composed of multidimensional components, resulting from a process where different filters condition fact perception. That is why a story can have different meanings, related to the different point of views of citizens.

RESUMEN

Las audiencias de los informativos de las televisiones generalistas reflejan que el interés y la fidelidad de los espectadores cambian constantemente. Numerosas investigaciones demuestran que existen elementos que intervienen en el éxito de programas y formatos, pero aquí analizamos qué factores determinan la credibilidad de los informativos. Y también queremos conocer cómo se garantiza el pluralismo en los telediarios, porque la credibilidad y el pluralismo son valores que están relacionados entre sí y se condicionan mutuamente. Como la credibilidad es un valor subjetivo, es necesario buscar criterios informativos que permitan analizarla con rigor. El objetivo principal es averiguar si existe un consenso sobre los parámetros que sirven para definir, identificar y valorar la credibilidad en la televisión pública estatal en España. Además, interesa saber si los índices de audiencia sirven para determinar el grado de confianza en los informativos. Aquí aportamos las observaciones de investigadores, expertos académicos y profesionales, que ofrecen una visión de las diferentes perspectivas que integran los múltiples aspectos que condicionan la lectura y la interpretación de las noticias. Una conclusión transversal que se extrae de esta investigación es que la credibilidad es un concepto con componentes multidimensionales, fruto de un proceso en el que intervienen varios filtros que condicionan la percepción de los hechos. Por eso un relato puede tener múltiples significados, que se corresponden con los diferentes puntos de vista de los ciudadanos.

KEYWORDS | PALABRAS CLAVE

Credibility, pluralism, public service media, audiences, journalism, newscast.
Credibilidad, pluralismo, televisión pública, audiencias, periodismo, informativos.

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1. Introduction and the state of the issue

The convergence of factors that define the current media ecosystem has increased mistrust towards the media and created distance between media outlets and the public (Edelman, 2022; Newman et al., 2022). The crisis of trust in, and credibility of, Western media systems have all been exacerbated by the proliferation of digital media (Samuel-Azran & Hayat, 2019), changes in information consumption habits, including incidental news exposure (Goyanes, 2020) and news avoidance (Edgerly, 2022), as well as the intensification of social polarization (Hameleers & Brosius, 2022; Masip et al., 2020; Suiter & Fletcher, 2020) and the rise of populist movements that question democratic institutions and accuse the media of spreading fake news (Holtz-Bacha, 2021).

Despite the findings of recent studies that indicate that the evolution of mistrust in the media is not a universal trend (Hanitzsch et al., 2018), the increase in citizen disaffection towards the media system is cause for concern as credibility is essential for the proper functioning of modern democracies. These societies are based on informed participation in civil life and trust in the institutions and activities that structure the public sphere (Arlt, 2019).

Research on the credibility of news media has long been conducted. This originated with the emergence of the mass media and has been approached from different fields. According to Calvo-Porral et al. (2014), from a social psychology perspective, credibility is understood as a subjective variable linked to the circumstances of the recipient of the information. However, from a communication sciences perspective, credibility is defined by the seeking of objective criteria that measure and assess the degree of accuracy of the information transmitted. As early as 1953, studies from Yale University also addressed credibility as one of the variables that influence the efficiency of communication (Hovland et al., 1953). Furthermore, through the economic lens of the information company, credibility is a coveted asset of an organization since it defines its reputation and influences economic outcomes (Vanacker & Belmas, 2009).

Nonetheless, though the study of credibility is nothing new (Lee, 2010; Jakobsson & Stiernstedt, 2023), there is a lack of consensus over the definition of credibility. This is similar to the debate on quality (Camacho-Ordóñez, 2005). One of the main problems comes from the multidimensional nature of the idea of media credibility. Appelman and Sundar (2016) distinguish between trust in information sources, trust in the message, and trust in the media. Stromback et al. (2020) go further and develop a conceptualization of media confidence that spans from the general to the specific and includes the following dimensions: news media in general, types of media, individual media brands, journalists, and media content.

Among the multiple interpretations of the meaning of media credibility, the tendency to define the concept based on its characteristics or subcomponents is apparent. Appelman and Sundar (2016) view this as problematic because it generates difficulties when one tries to differentiate whether the term used for the definition is a synonym or a component. Even so, in scientific literature the credibility of media is often associated with concepts such as reliability and honesty (Engelke et al., 2019), objectivity and the clear separation between information and opinion (Gaziano & McGrath, 1986), as well as with fairness, comprehensive event coverage, accuracy, and balance (Thorson et al., 2010).

In addition to the efforts to define the concept of credibility, investigations carried out on this topic have also analyzed the factors that gauge the strength of the media's credibility. First of all, one must consider which aspects of credibility should be analyzed. Studies such as that of Daniller et al. (2017) confirm that surveys asking about the public's trust in news media in general indicate much lower levels of trust than those in which the questions relate to specific media outlets. On the other hand, the relationship between media consumption and media credibility has also been questioned. While some research (Arlt, 2019; Roses & Farias-Battle, 2012) suggests that trust in the media is linked to the consumption habits of citizens, –meaning the more time they dedicate to a media source, the more credible they view it–, others consider it necessary to distinguish between following, loyalty and credibility (Callejo-Gallego, 2015; Picone & Donders, 2020).

The credibility of the media can also be affected by the sources used in the configuration of the information. Miller and Kurpius (2010) show that official sources are more credible than citizen sources, and that hard news stories grant media outlets with greater credibility than soft news stories. In contrast,

Calvo-Porral et al. (2014) affirm that the construction of an attractive and solid image is something that can boost media credibility. In any case, the use of plural and diverse sources is essential to build the credibility of news media (Moran & Nechushtai, 2022).

Public media are the information sources that European citizens trust the most (European Parliament, 2022). This means greater social expectations (Mateos-Martín et al., 2021; Mateos, 2021) and thus the increased importance of perceived credibility. In addition, credibility is directly linked to many core values of public service broadcasting, such as impartiality, independence, quality, diversity, integrity or accuracy (Biltereyst, 2004). For this reason, a change in the evaluation and accountability methods of public broadcasters is currently needed, moving the focus from audience data to credibility levels (Picone & Donders, 2020). As Picone and Donders (2020) argue, given the particularities of public media, a priori independent of political and economic interests, they have an advantage in achieving a balance between quality information, reach, and trust. On the other hand, having credible public media outlets that citizens trust is important not only for these corporations, but for the entire media and democratic ecosystem (Campos-Rueda & Goyanes, 2022). Indeed, research such as that of Arlt (2019), focused on the Swiss context, argue that the consumption of news from public service media is associated with higher levels of trust in journalistic quality.

2. Material and methods

The main objective of this research is to verify whether there is a consensus among researchers, academics, and communication professionals on the basic parameters that serve to define, identify, measure, and assess information credibility. The specific objectives entail identifying the elements and factors that determine credibility and pluralism in public television news.

The hypothesis is that credibility, for experts and professionals, is a subjective factor that is linked to an external perception of the media outlet over and above the perception of the actual contents. For this reason, credibility does not always coincide with journalistic rigor or with the truth of the facts. We are aware of the difficulties involved in measuring and assessing something as apparently intangible and subjective as credibility. It also must be recognized that it is difficult to analyze pluralism, one of the elements that determines credibility (Suárez-Villegas et al., 2020), because quantitative and qualitative factors are at play here.

The nature of the object of study makes this a complex project. Nonetheless, a methodology is employed that is designed to guarantee the rigor of the results. Firstly, as a result of the demand for qualitative research on media credibility (Garusi & Splendore, 2023; Jakobsson & Stiernstedt, 2023), a focus group was formed (Lunt & Livingstone, 1996; Krueger & Casey, 2014) at the University of Santiago de Compostela. It was made up of 17 Communication Sciences researchers from eight different universities who were members of an R&D project on the values of public audiovisual media. All the participants are experts in public broadcasting and therefore are highly qualified to comment on credibility and pluralism in the news. To investigate the extent to which consensus exists regarding the object of study, the interventions of the participants were developed in three rounds in which there were a series of questions derived from the scientific literature on credibility. The session was recorded, transcribed and analyzed with Atlas.TI.

In the first round, the experts were asked what credibility means to them as a means to evaluate the value of information presented by public service broadcasters. They were also asked for a definition of credibility and what characteristics and conditions it entails. In the second round the participants were asked if the audience data can be used to determine the degree of credibility of the information. In the third round, they are asked about the relationship between credibility and pluralism and what factors favor or undermine each concept. The responses of the participants are coded as G1, G2, G3, etc. G2 acted as moderator.

To broaden the perspective of the focus group and to obtain the most qualified opinions, 20 academics were interviewed online. They were all professors of Audiovisual Communication and Journalism and all experts in public television, audiovisual information and audience analysis. Academic experts were asked the following: what parameters determine credibility? how is it achieved? how is it maintained? why is it

lost? what elements guarantee it? and what procedures favor it? Their responses are coded as A1, A2, A3, etc.

Lastly, these same questions were put, also online, to five RTVE editors who have worked in the national, international, political, economic and society news departments (these five sectors are the ones that provide a structure for the information services of public television) in order to find their opinions on credibility from the professional field. The responses are coded as P1, P2, P3, P4 and P5. RTVE was selected as it has state coverage. Furthermore, we argue that it is representative of all public channels because the structure and production routines of news services are very similar to those of regional television.

The questions put to the members of the focus group, the academics, and editors are consistent with the lines of work developed in the R&D project on the values of the public audiovisual media mentioned above. We believe that this investigation is necessary and is justified by the ongoing changes that are apparent within the news broadcasting leadership. An emblematic example of this is the TVE newscasts, which went from being audience leaders until 2014 to occupying third place in 2022.

3. Analysis and results

3.1. Focus group

In the first round of the focus group, the G10 expert states that credibility is something subjective that helps to shape attitudes towards and opinions regarding facts or media. For this reason, a news outlet or a piece of news can have different evaluations according to the perception of each citizen. On the other hand, for G1, credibility is multidimensional, meaning that trust, independence, veracity and transparency are all involved.

For G4, credibility is also something multidimensional, but with many nuances. For this reason, a piece of news is credible or not depending on the characteristics of each person. Factors such as emotion, format and the news outlet itself must be taken into account when attempting to define such a complex concept. G7 and G16 agree on the importance of G4's point as they contend that trust (G7) and legitimacy (G16) are also necessary elements. G17 argues that the credibility of a media outlet or a journalist does not depend only on the approach or the informative treatment of the facts, stating that external conditioning factors inherent to each viewer can also be influential. Thus, G4 contends it is very important to think about the value chain when trying to define credibility, something that includes the different phases of the information process (sources, writing, editing and consumption). G4 further states that a series of values must be present in each stage of the process (including independence, quality, diversity of sources, verification, veracity, credibility, pluralism, transparency, general interest, objectivity and innovation).

Most of the experts (G1, G3, G4, G5, G7, G9, G11, G12, G13, G14, G15, G16, G17) associate credibility with trust. Nonetheless, taking a closer look at the finer details reveals the lack of consensus about the object of study. For G3 and G9, credibility depends on the trust generated by the source, but for G9 and G15 the number of sources is very important. On the other hand, G5, G12 and G14 do not mention the trust in the source, but do refer to the trust generated by the media outlet, something that transcends the news as it affects all the contents. Furthermore, G14 says that conversations about credibility are really conversations about content, and that when we talk about trust, we are talking about the medium. And this expert gives an example: if we trust TVE, we believe the news on its news programs. G6 agrees with this assessment and raises the possibility that the audience links a brand, in this case TVE, with news credibility. Thus, there would be two levels of credibility that can coexist and are not exclusive: on the one hand, the credibility that the personal signatures of the editors bring to each piece of news, and, on the other, the credibility that the medium generates at a global level, a quality that also affects the news.

The expert G13 introduces a new concept, objectivity, arguing that it influences credibility in the same way as transparency, and thus must be taken into account in the definition. However, G9 and G11 believe that it is more accurate to speak of veracity than objectivity. G5, G11, G12 and G17 also agree on the issue of transparency.

In the second round, all focus group participants agree that audience ratings are not always linked to credibility. G1 and G14 state that credibility cannot be measured solely by audience metrics because there

are many subjective factors of influence that are not taken into account by people meters. For G14, in order to measure beyond perceptions, ideology must be taken into account as consumers often gravitate towards, and trust, media outlets and informative stories that complement their pre-existing views. For this reason, people will sometimes believe stories that aren't true.

From the audience's point of view, G10 says that it is necessary to differentiate between the official/public discourse and what each citizen really thinks. According to this expert, societal norms dictate the ways that we think and act, so much so that some people would rather not express certain views in public for fear of social rejection. He further states that veracity and credibility must be differentiated, as veracity can be objectified by establishing criteria that certify whether something is true or not, while credibility is a subjective factor that cannot be measured (G10). Instead, G4 prefers to differentiate between objective and perceived credibility, because for him credibility is not the main factor that determines whether information is consumed. G14 and G17 also agree that watching a newscast does not necessarily imply lending it credibility as it has not been proven that the most watched newscasts are the most credible (G4).

For G14, reputation should be gauged using informative criteria. From there, it will be possible to assess credibility with more rigor and precision. G9 maintains that it is very difficult to establish uniform criteria with universal value if the reference values used by the audience to grant credibility to a piece of news or a media outlet are not known. Conversely, G1, G6 and G12 suggest analyzing the segmentation of the audiences to verify if the credibility ratings are consistent across all sectors.

All the experts who participated in the third round of the focus group agreed that credibility and pluralism are two values that condition each other and that there is a tendency to focus observations of pluralism on issues of a political nature.

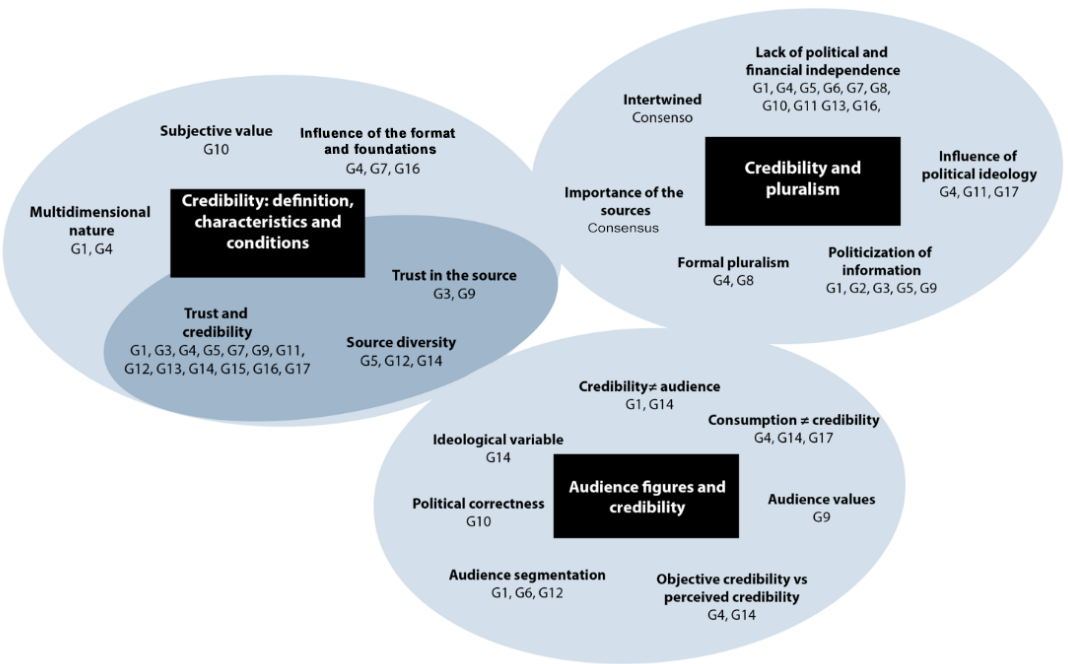
For all 17 researchers, the relationship between credibility and pluralism is permanent and direct as both principles are contingent on the number of sources and, to an even greater extent, on the quality of the sources. Nonetheless, they also believe that it is necessary to differentiate between quantitative and qualitative aspects, the latter of which are those that make up the essence of pluralism. The following example is provided: in a piece of news, all the protagonists can have the same involvement, yet the contents of the arguments that represent each point of view, if they are not determined with rigorous criteria, can sway the focus of the facts towards a positive or a negative reading. For G1, G2, G3, G5, G9 and G11, the differences between the quantitative and qualitative aspects of a fact are what allows for the manipulation and politicization of information, and this harms credibility. In addition, according to G4 and G8, a lot of attention is paid to formal pluralism on public television where parties are assigned a length of time proportional to their parliamentary representation. Of course, this formula favors the larger parties and undermines the diversity of experiences that form our daily reality. G1, G6, G7, G8, G13 and G16 state that the credibility of information on public television is determined by politicization and, more specifically, by dependence on the ruling party. For this reason, G4 argues that public television is governmentalized, with G10 contending that this dependency is strengthened by the current model that exists in Spain.

According to this expert, citizens think that news media are controlled by the Government to favor certain political options, and thus lack credibility. G1 shares this statement and recalls that the indicators show that electoral periods are the time in which the public views the media as least credible due to the treatment of information being overtly biased from the qualitative point of view. However, television is not only subject to a political dependency. G1 and G11 mention the economic dependencies that affect the treatment of and approach to content. In fact, G9 links the loss of credibility to weaknesses in government, as well as poor reputation management and corporate communication, all of which are key elements in transparency, accountability and participation.

G11 and G17 argue that since credibility is a subjective value, the political ideology of each person becomes a filter and the news will be more or less credible depending on the overlap between the viewer and the direction of the news. G4 also believes that credibility depends a lot on political sympathy and says that people like approaches that coincide with their own ideas because they reinforce individual positions. Thus, without taking into account other more appropriate factors such as pluralism or the quality of the

sources, the extent to which a consumer views a story as credible or not may be based on their affinity with the dominant political philosophies of the medium. G11 relates quality to credibility, as if they were two associated concepts, and G17 highlights consistency, arguing that credibility is something longitudinal that is measured and valued by its permanence over time. Instead, G1 points out the independence of government and the autonomy of the media as two necessary factors for credibility, as do G5, G6 and G11. G5 and G6 also believe that it is necessary to maintain good management, set independent criteria that guarantee quality throughout the information process, and transmit it to the audience through transparency. G11 also holds this opinion and mentions reputation as a necessary factor for credibility. The results are visible in Figure 1.

Figure 1. Experts' opinions on credibility and pluralism



Regarding the causes that affect pluralism, all the participants agree that the current model favors the control of the news because formal pluralism does not always equate to an adequate approach to the facts and timely news treatment. G6 says that the European Pluralism Monitor reflects how citizens link the lack of independence in the management of public television in Spain with the low credibility ratings of its news, as does G1. G3 also believes that it is necessary to differentiate between political pluralism and social pluralism, which is what guarantees diversity in the news.

3.2. The academic experts and the professionals

3.2.1. The parameters that determine credibility

Amongst both academics and television professionals interviewed, there is a lack of consensus regarding the concept of credibility. However, despite the disagreements, several are in agreement regarding certain values and parameters. For A1, A2, A3, A4, A6, A9, A11, A13, A14, A15, A16 and A19, and for P1, P2, P3 and P5, credibility is a principle related to the confidence that the audience in general, a sector or a particular person, entrusts in a news outlet, format or journalist, granting veracity to a piece of information or a news story. A5, A8, A14, A15, A19, A20, P1, P3 and P5 believe that veracity is necessary for credibility to exist. For A7, this implicit veracity means that the viewer does not need to check the information as they assume that the facts have been verified and that the opinions have been selected from among the most reliable sources possible. A9 and A18 also agree with this. At the same time, A1, A3, A5, A9, A10, A14,

A16, A19, A20, P1, P2, P3, P4 and P5 indicate the importance of the reputation of the media outlet, its trajectory, experience and authority.

For A10, A11, A13, P1, P2 and P5, while career path is important, the attitude of the informants is also crucial. Conversely, A17 believes that the credibility granted by the audience, in addition to experience, is also based on contrast and comparison with the competition, further adding that credibility is cumulative, subjective, dynamic and volatile. A11 concurs with this, stating that credibility can be temporary or long-lasting, as the media outlet or the professional must possess qualities to earn and maintain it. The ability to promptly rectify mistakes is an example of this. For experts like A1 and A14 there are different levels of trust, which translate into different levels of credibility. A1 and A2 also link credibility to the image of the news outlet, something that goes beyond the quality of the content. For A1, A7, A13, A16, A18, P1 and P3, it is important that the informative stories are rigorous and clear, that they are well explained, contextualized with effective data and that there is a separation between information, opinion and analysis. A8, A9 and A19 include transparency and A11, A13 and A18 believe that accountability is important.

3.2.2. Achieving credibility

For A12 and A13, the basis of credibility is good audiovisual regulation, with the existence of external oversight and control bodies (Citizenship Councils) and a rigorous and plural Audiovisual Council, made up of reputable experts and professionals. This regulation guarantees the independence of the media outlets, directors and editors. According to A13, in the latter case, the Informative Councils play a very important role. A1, A2, A4, A7, A8, A9, A11, A12, A13, A14, A16, A18, A20, P1, P2, P3, P4 and P5 also include the independence of political and economic powers as a crucial factor in establishing credibility, stating that it has a significant impact on professional autonomy and the quality of information provided. P1, P2, P3, P4 and P5 also assert that, in order to establish credibility, the information provided must be truthful, reliable and verified. They maintain that the pursuit of truth with tools or procedures that allow certifying and proving all the facts that make up a story is paramount. In this sense, for A4, A5, A11, A12, A13 and A16, the quality of the sources is very important. This includes the source's characteristics, full identification, reputation, evidence that the information has been contrasted, that they have travelled to the relevant sites to explore the environment where the events took place and, if possible, broadcasted live from there. A11 and A13 mention transparency in the management and accountability of internal and external procedures as ways for media outlets to bolster their reliability and credibility. For A5, A8 and A10, public television should not gatekeep its information based on the pursuit of higher audience ratings. According to them, credibility is achieved simply by offering citizens useful information, without catering to the demands of the audience. Nonetheless, experts like A9 believe that audiences give credibility to the public service media and legitimize them.

3.2.3. Maintaining credibility

There is consensus among most of experts regarding the elements, parameters and actions that contribute to preserving credibility. A1, A3, A4, A5, A6, A8, A11, A13, A16, P1, P2, P3 and P4 all state that professional criteria and quality protocols must be applied and reinforced with strict professional routines that guarantee the rigor of the content. For A1, A5, A6, A8, A12, A18, P1, P2 and P5 it is also important to take care of the institutional image of the media outlet so that it conveys impartiality. A

3 and A12 believe that it is necessary to be in tune with the audience. This should always be done from a critical and respectful perspective and, above all, taking into account audience expectations. In addition, A15 believes that it is necessary for the audience to verify that the sources are reliable and verified. This guarantees truthful information and allows the audience to perceive it as such. In contrast, in the section referring to the parameters, A7 maintains that when information is given credibility, one already trusts that the sources are reliable and have been verified. A17 states that it is necessary for the reality portrayed to match the reality experienced by viewers, and A13 adds that the audience must perceive news programs as a public service. Thus, A3 and A4 stress the significance of the background of the media and the journalists as they believe that credibility stems from establishing legitimacy with the audience and having the professional resources to maintain it.

3.2.4. Why credibility is lost

Credibility is lost, little by little, when the news ceases to be a benchmark for the audience due to a gradual and continuous loss of quality (A10). Conversely, as A4 points out, credibility can be lost rapidly or even instantaneously regardless of a media outlet's long-standing reputation, especially when poor news coverage is provided, and even more so during significant events (A3). When the audience perceives that changes to the organization chart are made based on political interests rather than professional criteria, it has the same effect in undermining credibility (A10). A12, A14, A16 and A17 argue that credibility is lost when the 'trust contract' with the audience is breached, violating the deontological codes of a public service, which are those that safeguard independence and impartiality (A1). A8 attributes the loss of credibility to the neglection of production routines. This oversight is sometimes due to political or economic interests and other times because media are too standardized and do not promote quality content.

A3, A5, A9, A12, A13, A17, A18, A20, P1, P2, P3 and P4 agree that one of the factors that most undermines credibility is when the audience detects the media's desire to manipulate public opinion through the politicization of information, and news stories are treated differently (thematic selection, informative approach, order and duration) depending on the social agent or the political party that features in the events. According to A10, this makes a portion of the audience feel left out and unrepresented as, according to A12 and A13, they view the news outlet as at the behest of the Government or a party. A4 also attributes the loss of credibility to the use of sources that are not very reliable and to when they are even intentionally sought to build a story that does not correspond to reality.

3.2.5. The elements that guarantee credibility

A1, A2, A6, A7, A9, A10, A12, A18, P1, P4 and P5 all point out two elements that guarantee credibility: the first is that the profile of management positions and the organizational structure of the newsroom must both respond to professional criteria; the second is the existence of adequate mechanisms so that the news management does not intervene in the work of the editors beyond what is necessary. In addition, A12 and A13 state that the self-control mechanisms, the Information Councils (or Editorial Councils), the Audiovisual Councils and the Citizenship Councils, to which they already assigned an important role to achieve credibility, are responsible for making a follow-up, for making a control of journalistic work and for the quality of the information. This is all so that newsrooms do not become politicized and trust is maintained. For this reason, these mechanisms must be made up of independent people with accomplished backgrounds.

On the other hand, A3 argues that the accumulated social capital of the media outlet provides a form of social authority, lending legitimacy to the credibility of the contents. According to A4, A5, A6, A7, A9, A12, P1, P3 and P4, this must be complemented with the capability and reputation of the editors' professional career. For A10, another key strategy is to maintain the idea of public service at all times, outside of political changes. A2 suggests combining the topics that are of interest to the majority with those that are relevant for minorities, which A12 refers to as social responsibility.

3.2.6. The procedures that favor credibility

A1, A3, A4, A5, A6, A8, A9, A12, A13, P1, P2 and P4 consider it necessary to have procedures that make it possible to assess pluralism and rigor of contents with methods that are as objective as possible, as well as productive routines based on professional criteria that guarantee the quality of the information. For A1, A4, A5, A6, A7, A11 and P5, the selection of editors is important, a process that must be based exclusively on merit and ability. A10 extends this requirement to the appointment of directors. A12 and A19 mention working and professional conditions as a determining factor, and A7, A8, A10, A11, A19, P1, P4 and P5 highlight that the independence of political and economic organizations must be maintained so that there is no interference in the selection, approach or treatment of the news, or in the access to the sources. A9 and A12 recommend prioritizing investigative journalism, while A19 emphasizes the importance of accountability. On the other hand, A6, A7, A8, A12, A16 and A17 recommend the existence of style books that contemplate the application of ethical codes, a viewer ombudsman with full capacities and periodic external audits. A18 even proposes a specific law to guarantee that television

remains a public service. Compliance with this law would be monitored by professionals unrelated to political institutions and economic sectors.

4. Conclusions

The theoretical arguments made by the different authors regarding credibility and pluralism make it possible to identify and analyze both concepts at a basic level. However, these same arguments also expose a lack of consensus in regard to establishing universal parameters to carry out an accurate assessment. This is because both concepts have an inherently subjective dimension. There is also no consensus on the determining factors, neither among academic experts nor among the professionals interviewed.

Most of the principles associated with credibility are not objective, or even verifiable for the audience since they often lack resources to verify them. The same difficulties arise when analyzing pluralism, which is one of the elements that determines credibility. Quantitative and qualitative factors related to the news approach and informative treatment are involved, making it challenging for the audience to evaluate. The experts agree that in many cases there is no correspondence between the formal treatment of the points of view and the informative approach of the news.

The results of the focus group and the interviews show that there is a tendency to link pluralism with content of a political nature, despite the fact that pluralism affects all areas of society. On public television, much attention is paid to formal pluralism and this practise favors the control of the news because it makes it possible to manipulate the facts and politicize the information. As such, it is necessary to differentiate between the quantitative and the qualitative features, those that constitute the foundation of pluralism. It is also important to differentiate between political pluralism and social pluralism.

Most experts agree that credibility, in addition to being a subjective value, is a multidimensional phenomenon involving trust, independence, veracity and transparency, and that the role of personal perception is complex and affected by many different factors. For this reason, it is not an absolute or definitive value. Rather, it is a temporary value, and there are many factors that come into play in the achievement, maintenance, and loss of credibility. At the same time, it is important to keep in mind that there are different degrees of credibility and different levels of trust. In addition, credibility can be attributed to the news outlet, the program, the editor, and the content of the news.

Credibility does not depend only on the approach or the informative treatment of the facts. A media outlet or a piece of news can have different evaluations according to the characteristics of each person because the perception process is influenced by external factors and conditions inherent to each viewer. These factors include a person's training (it is necessary to differentiate between a passive audience and a critical audience) and ideology, and even context, which also conditions perceptions and opinions. It is important to take into account the ideological variant because experts recognize that there is a tendency to gravitate towards like-minded approaches. This is why viewers often believe informative stories that are not true, but do agree with their constructions of reality.

Another of the conclusions drawn from this research is that, for experts, audience ratings are not always linked to the degree of credibility. A particularly relevant idea was proposed underlining the importance of differentiating between official/public discourse and private discourse. This reality makes it difficult to gauge the degree of credibility that many viewers give to the news as their social behavior falls in line with the norms established in their social or professional environment. Hence, many are not willing to publicly express their opinion on controversial issues for fear of being ostracized or criticized by others. It is true that there are no conclusive investigations that show that being a regular viewer of a program (in this case a news program) guarantees that that person grants credibility, whether total or partial, to its contents. In addition, the experts also agree that credibility cannot be measured by audience numbers alone because there are many subjective factors at play that are not taken into consideration by people meters.

The great challenge of public television is to find a mechanism that reveals the extent to which its news programs are viewed as credible by different sectors of society, and to detect the causes that determine credibility, based on proposals such as that of Medina et al. (2023). This information would be very useful for making sound decisions in the Editorial Boards. In this way, an adequate response could be given to the information needs of society and the obligation of public service fulfilled with greater rigor

and more guarantees. In this sense, it would be interesting to take advantage of the possibilities offered by the algorithms and public value assessments that are becoming popular among the European public media in order to develop new formulas that could make it possible to measure aspects of the audience that cannot be accurately assessed using the current metrics, including credibility. It would also be necessary to establish control mechanisms so that the TVE organization chart, which, from a theoretical point of view, has the necessary elements and resources to guarantee the quality and plurality of information, performs its functions with strictly informative criteria.

Authors' Contribution

Idea, X.S; Literature review (state of the art), M.R; Methodology, F.C., M.R; Data analysis, X.S., M.R; Results, X.S; Discussion and conclusions, X.S., F.C., M.R; First draft, X.S., M.R; Final revisions, X.S., M.R., F.C; Project design and sponsorships, F.C.

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The four P's on the Internet: Pornography, plagiarism, piracy and permission

Las cuatro P en Internet: Pornografía, plagio, piratería y permisos

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ABSTRACT

Access to youth culture by adolescents has changed as new communication technologies have found new ways of offering media content to viewers. Adolescents today access more content more frequently. However, the greater their exposure, the higher the likelihood of this leading to risk behaviors such as access to pornography, plagiarism, piracy and copyright violation. The aim of the present study is, therefore, to determine the frequency of these risk behaviors linked to the Internet content accessed and downloaded by minors, analyzing this variable in accordance with gender, age and context (Spain, Italy and Greece). We analyzed the responses provided by 2,529 adolescents (1,264 girls/1,262 boys) aged between 10 and 17 years from Spain, Italy and Greece. In general, adolescent boys, especially those aged 16 and 17 years, reported engaging more frequently in risk behaviors, particularly in reference to accessing youth culture content. Likewise, in terms of context, the highest means were observed among participants from Attica (Greece) and the Madrid Region (Spain), whereas the lowest means were observed in the Marche Region (Italy) and Navarre (Spain). The results revealed statistically significant differences in terms of gender, age and context. Thereby, they highlight the importance of focusing on media education from a gender perspective.

RESUMEN

El acceso a la cultura juvenil por parte de los adolescentes se ha transformado en la medida en que las nuevas tecnologías en comunicación han venido introduciendo cambios en la manera de ofrecer los contenidos mediáticos. Los adolescentes acceden a más contenido y con mayor frecuencia. Sin embargo, a mayor exposición, mayores posibilidades de acciones de riesgo, como acceso a pornografía, plagio, piratería y omisión de los derechos de autor. El objetivo de este trabajo es determinar la frecuencia de estas acciones de riesgo referentes a los contenidos a los que acceden los menores y a las descargas realizadas en Internet analizando dicha frecuencia según el género, la edad y el contexto (España, Italia y Grecia). Para ello, se analizaron las respuestas de 2.529 adolescentes (1.264 chicas/1.262 chicos) de entre 10 y 17 años de España, Italia y Grecia. A nivel general, los chicos manifiestan realizar con mayor frecuencia acciones de riesgo, especialmente en referencia al acceso de contenidos de cultura juvenil, y, sobre todo, entre los 16 y 17 años. Respecto al contexto, la media más alta la presentan los participantes de Attica (Grecia) y de la Comunidad de Madrid (España), mientras que la más baja la presentan los de la Región de Marche (Italia) y Navarra (España). Los resultados indican que las diferencias en cuanto al género, a la edad y al contexto son estadísticamente significativos. Así, se resalta la importancia de trabajar en la educación en medios de comunicación desde una perspectiva de género.

KEYWORDS | PALABRAS CLAVE

Risks on the Internet, adolescence, pornography, copyright, piracy, plagiarism.
Riesgos en Internet, adolescencia, pornografía, derechos de autor, piratería, plagio.

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1. Introduction

The Internet is one of the most transformative and fastest-growing technologies humankind has ever known. The number of Internet users worldwide increased from nearly 2.4 billion in 2012 to 5.3 billion in 2022 (Statista, 2023). Use is highest among young people aged between 15 and 24 years (Kemp, 2022). According to a report published in 2021 by the International Telecommunications Unions (ITU), the percentage of those in this age group who use the Internet is 71% worldwide and 97% in Europe. Another technological development that has had a major impact is the smartphone, coupled with the almost continuous presence of diverse social media. These platforms are used by one out of every three people in the world and by over two thirds of all Internet users. With over 656 million active users, TikTok is currently the most popular social media site, followed by Instagram with 545 million users and Facebook with 416 million users (Koetsier, 2021).

The mass use of new communications technologies, or in other words, the fact that more people spend more time using some kind of digital device connected to the Internet, has generated a cyberculture model (Lévy, 2007) that has permeated most social spaces throughout the world. However, this technological development has brought with it an increase in the risks associated with the use of the Internet and digital devices, which, during adolescence, may lead to addictions and psychosocial problems (Díaz-López et al., 2020; Kurniasanti et al., 2019) suggesting that problematic Internet use may be associated with behaviors similar to those associated with other addictions or problematic uses, such as withdrawal, compulsive behavior and impairment in daily life.

The risks associated with the use of the Internet and mobile devices can be divided into four categories. First, content risks, referring to the type of information accessed. Second, contact risks, linked to the type of interpersonal relationships established over the Internet. Third, behavior risks associated with aptitudes (capacities), attitudes (behaviors) and actions that may be carried out on different platforms and applications. And finally, contract risks, referring to online purchases, sales, subscriptions and financial actions (Livingstone & Stoilova, 2021). In the present study, we focus on analyzing the first category, referring to the risks linked to the content to which adolescents may be exposed and which they access as a result of their own interest. Within this category (content risks), we will focus specifically on analyzing four different types: access to pornography; access to gambling; access to pirate content; and plagiarism within the school context. These four problem areas are the most recurrent during adolescence, since they correspond to the psychosocial development of young people during this life stage (Andrie et al. 2019; García-Holgado & García-Peñalvo, 2018; Livingstone et al., 2011).

Consequently, and bearing in mind the results of previous research into risk behaviors linked to adolescent media consumption (Chu et al., 2019; Smahel et al., 2020; Andrie et al., 2021), the aims of the present study are, firstly, to determine the frequency of online content-linked risk behaviors (linked to pornography, plagiarism, piracy and permission) and, secondly, to analyze this frequency in terms of gender, age and context.

1.1. Theoretical background

1.1.1. Access to adult content: Pornography and gambling

During adolescence, sexual exploration and identity, as well as gender construction, are vital aspects of individual development; this has repercussions for the contents that are consumed in the digital world, which may be pornographic in nature. According to a European study carried out by the EU KIDS Online Network (Barbovschi et al., 2021) with a sample of 21,964 young Europeans aged between 9 and 16 years, 33% of participants reported having accessed pornographic content online over the past year. In Italy, the percentage was lower (27%), whereas in Spain, it was higher (41%). In both contexts, more boys than girls reported accessing this type of content. Also in both countries, older participants reported accessing this type of content more than younger ones. In Spain, 25% of those aged between 9 and 11 years and 76% of those aged between 15 and 16 years reported accessing content of this nature. In Italy, these figures were 12% for the younger age group and 48% for the older one. In Greece, 27% of adolescents aged between 14 and 17 reported accessing this type of content frequently. A significant difference was also found in terms of gender, with boys being 18 times more likely to be frequently exposed to online

pornography than girls (Andrie et al., 2021). These findings are consistent with those reported by similar Europe-wide studies (Stanley et.al. 2018), which found viewing rates of between 19% and 30%.

The results outlined above indicate an increase in access to pornographic content. In 2010, in an earlier study also carried out by the EU KIDS Online Network (Livingstone et al., 2011) on the issue of accessing pornographic content both online and offline, the authors found that 14% of Spanish participants admitted to having accessed this type of content, with these figures being 12% among Italian participants and 29% among Greek youths. In that study, the mean for all participating countries was 23%. In other words, in ten years, access to pornographic content increased by 10% in Europe, 15% in Italy and 27% in Spain.

According to Ballester et al. (2019), there are three types of access to pornography: an initial, accidental access through pop-up advertising; a second, intentional access through searches on specific websites; and a third access, aided by friends or relatives. Among Spanish boys, the influence of friends is the main reason for accessing pornography, whereas accidental access is the most common among girls.

Another type of adult content that adolescents sometimes access is linked to online gambling and betting. According to a European study on gambling by Andrie et al. (2019), today's adolescents live in a society in which gambling is easily accessible and socially accepted as a form of entertainment. Legislation in many countries is weak, as are the mechanisms used by websites to prevent access by minors. In their analysis of 44 studies on the issue in Europe, the authors found gambling addiction rates of between 0.2% and 12.3% among adolescents. Similarly, the data published in the 2019 European School Survey Project on Alcohol and Other Drugs (ESPAD) revealed that 8% of adolescents had frequently gambled on the Internet (between once a day and once a month) over the past 12 months. In Spain, this figure was 4.2%, in Greece it was 4.9% and in Italy it was 7.6%. The gender differences observed in relation to online gambling are significant, with the figure for boys in Europe being 12.5%, as opposed to just 2.7% for girls (ESPAD, 2020).

1.1.2. Plagiarism

In addition to accessing adult content such as pornography or gambling websites, adolescents also engage in plagiarism linked to their schoolwork and consume media products without respecting copyright. Given the age of our participants, in this article we focus on plagiarism in the school environment. Plagiarism is understood as a risk behavior that has legal repercussions, since it basically entails stealing someone else's work, an action that violates the ethical code of scientific communication and is linked to the content-based risks to which today's adolescents are exposed. Plagiarism is understood as the intentional copying and claiming of authorship of what is known to be someone else's work and is linked to poor school behavior (Chu et al., 2019).

The most frequent cause and motivation for plagiarism by students is lack of interest in the subject matter, followed by lack of knowledge and/or failure to understand the subject, poor writing skills and little likelihood of being caught by teachers. According to Šprajc et al. (2017), other reasons that may prompt students to plagiarize someone else's work are linked to their exposure to information technology, the ease with which they are able to appropriate information and the paradox between academic success, fraud and teachers' inability to detect such actions. Family and social pressure to get good grades, as well as the prestige associated with academic excellence may also be factors motiving plagiarism among school-age adolescents, along with financial pressure linked to the high cost of education (Hayes & Introna, 2005; Ramzan et al., 2012).

1.1.3. Piracy

Regarding piracy and a failure to respect copyright, digital culture enables access to information of a wide range of different qualities and origins, in many different languages. Access may be free or by subscription only, but in all cases, it is fast and interconnected. Users are presented with many different ways of selecting content; however, in the music, audiovisual, film and videogame industries, alternatives have emerged to avoid paying for content, based on platforms or websites that offer free access. The free nature of these services is linked, for the user, to payment evasion, as well as to access to platforms

containing hazardous software. Both distribution of and access to this content are considered criminal offenses. However, this issue also entails debates about free access to information (García-Holgado & García-Peñalvo, 2018). Furthermore, some adolescents may opt to access ad-free content by subscribing to preferential access online services through payments made fraudulently or without their parents' consent.

Notwithstanding the association between the Internet, free access and piracy, in which users refuse to pay for content, these debates decreased as the range of legal access options has expanded. Video on demand (VOD) platforms such as Netflix, HBO and Movistar+ have become increasingly popular, enabling legal access to TV shows, films, documentaries and videos on a subscription basis. Subscriptions enable access to a menu and cost relatively little, particularly in the case of those that enable shared access between several users (Sanz, 2020). Software and videogame companies also generate ongoing obsolescence in the different versions of their products, which has further served to reduce the prevalence of piracy.

Listening to music is a key activity in the lives of adolescents, who mainly access this content on their mobile devices or over streaming platforms offering legal content (Soler & Oriola, 2019). The music industry has adapted to this and subscription-based music consumption has largely displaced MP3 downloads, which were very popular in the year 2000. The principal reasons for subscribing to these platforms include uninterrupted access to content, access with and without Internet, the availability of millions of songs and on-demand music consumption. The success of these platforms has resulted in the illegal consumption of music being limited to just 30% of the general population. However, among young people worldwide, the figures are slightly higher, with 38% of those aged between 16 and 24 years in the world reporting having accessed music content without respecting copyright; and 35% of the same age group reporting having used illegal sites or having violated copyright in order to listen to or obtain music (IFPI, 2021).

1.1.4. Permissiveness and the ubiquitousness of technology during adolescence

The experience of being an adolescent in the information era is linked to the constant use of the digital media, all of which compete with each other to attract users' attention through notifications (De-Bérail et al., 2019). Leisure, entertainment and learning exist together in the midst of ongoing competition between platforms and social media sites that adolescents explore within the privacy and ubiquitousness of their mobile telephones, with no adult supervision. A single device provides access to a range of different traditional media, including television, radio and the written press, and adolescents manifest their development and independence by accessing and publishing content. From their personal devices, adolescents engage in a range of different activities, including accessing culture, maintaining friendships and interacting with different social circles (Buckingham, 2020). However, adolescent actions and behaviors are characterized by the fact that they often skirt close to what is perceived as risky or prohibited, a characteristic that is reflected also in their use of the Internet (Díaz-López et al., 2020, Kurniasanti et al., 2019).

Studies focusing on adolescents' and young people's access to inappropriate content coincide in asserting that there are certain cross-cutting aspects of technological development that facilitate risk behaviors linked to content. These aspects include accessibility over the Internet and smartphones, the speed and immediate nature of access to information, constant connectivity to content online, on-demand access to information and the privacy of access bestowed by personal digital devices (Andrie, 2019; Barbovschi et al., 2021).

According to the studies by Gairín-Sallán and Mercader (2017) and Díaz-López et al. (2020), most adolescents report a low level of supervision by their parents and a lack of limits regarding the time for which they are allowed to use their various devices. Curiously, both these studies conclude that younger adolescents are subject to less adult supervision than their older counterparts while they browse the Internet or play online with other people.

Equally, from a feminist perspective, it has been suggested that gender differences exist in terms of online experiences, with these differences being linked to the patriarchal beliefs and values still present in today's society. For example, women are exposed to sexist attitudes in the form of harassment and

insults, and their perceptions of Internet use are associated with vulnerability, prevention and self-censure (Torrecillas-Lacave et al., 2022).

However, despite the seriousness and urgency of the issue, European public media education policies tend to focus on aspects linked to Internet security, overlooking those associated with the development of critical thinking about the online world and information in general (Vuorikari et al., 2022). As a result, media literacy lacks the means necessary to guarantee its development in the school curriculum and to ensure the inclusion of new teaching outlooks. In this context, it is important to analyze adolescents' risk behaviors in the digital environment, particularly those linked to accessing risk contents, such as pornography or pirated material, for example. The question that needs to be asked is: what is the association between the frequency of these risk behaviors and other variables such as gender, age and context?

Bearing in mind the results of previous research into online risk behaviors among adolescents (Andrie et al., 2021; Chu et al., 2019; Smahel et al., 2020), the aims of the present study are, firstly, to determine the frequency of online content-linked risk behaviors (linked to pornography, piracy, permission and plagiarism) and, secondly, to analyze this frequency in terms of gender, age and context.

2. Methodology

2.1. Research design

To achieve these aims, we carried out a descriptive ex post facto, cross-sectional, quantitative and exploratory study. The aforementioned phenomena were analyzed and studied, and the associations between the different variables were identified. We used an online questionnaire (White et al., 2001) that was designed following the recommendations provided by Lumsden (2007) and Norman et al. (2001). This questionnaire has been used and validated in several other studies (Lareki et al., 2017a; Lareki et al., 2017b; Martínez-de-Morentin et al., 2021).

2.2. Sample

The sample comprised 2,529 participants aged between 10 and 17 years from seven different regions: Autonomous Community of the Basque Country (ACBC, Spain) (n=972, 38.4%), Navarre (Spain) (n=389, 15.4%), Galicia (Spain) (n=512, 20.2%), Cantabria (Spain) (n=149, 5.9%), Madrid Region (Spain) (n=114, 4.5%), Marche Region (Italy) (n=102, 4%) and Attica (Greece) (n=291, 11.5%)[1]. The population range selected for the sample was consistent with the World Health Organization (WHO) classification of early (10-14 years) and late adolescence (15-17 years). Moreover, previous research into adolescent Internet and mobile telephone use has reported that said use tends to start at age 10 years (George et al., 2020).

In terms of gender, 50.0% were girls (n=1,264), 49.9 % boys (n=1,262) and 0.1% (n=3) did not respond to this question. In terms of age, 191 participants (7.6%) were ten, 317 (12.5%) eleven, 507 (20%) twelve, 462 (18.3%) thirteen, 443 (17.5%) fourteen, 415 (16.4%) fifteen, 139 (5.5%) sixteen and 54 (2.1%) seventeen years of age. In all contexts, samples were selected using a convenience method, and all came from the Mediterranean region in Southern Europe.

2.3. Instrument

The data collection instrument was an online questionnaire entitled "Digital Anomy. The use of digital technology and inappropriate behavior", comprising 39 items grouped into 5 dimensions: use, content and downloads, data management, relationships, and posts (Martínez-de-Morentin et al., 2018). In all the contexts studied, the protocol included an explanation of the instrument and any doubts participants had regarding the meaning of the statements or the response scale for each item were resolved. To adapt to our specific research aims, in the present study we used only the dimension referring to content and downloads, which comprises 6 items. These 6 items refer to: consumption of adult content (first item), copyright (second item), piracy (third item), and online actions without parental permission (fourth, fifth and sixth items). Participants rated the frequency with which they engaged in the different actions described in the items on a 4-point Likert-type scale: (1) never, (2) rarely, (3) often and (4) always. The Cronbach's alpha value obtained for the whole questionnaire was .66, and the value obtained for the Content and

downloads dimension was .76. The reliability value given is the result of the scores obtained on the questionnaire and includes all items under study. In general, values of over 0.6 indicate a reasonable level of internal consistency (Huh et al., 2006; Malhotra, 2008).

2.4. Procedure and data analysis

The management teams and students at the participating schools were informed of the study and agreed to take part in it. In accordance with the favorable report on the questionnaire issued by the Ethics Committee and that stipulated in Organic Law 3/2018, of 5 December, on the Protection of Personal Data and Guarantee of Digital Rights, students' informed consent was also obtained. The questionnaire was completed by students during class time, under the supervision of a teacher and a member of the research team. In all contexts, parental consent was obtained for all minors participating in the study. In the first item about access to adult content, we clarified that adult websites referred to websites containing pornography.

The SPSS Statistics program (version 24) was used to analyze the data gathered. Descriptive statistics were calculated for each variable and the means for independent groups were compared (*t*-test). Effect sizes (Cohen's *d*) were also calculated and an analysis of variance (ANOVA) was performed.

3. Results

In this section we present the results obtained in the study. First, we will present the descriptive statistics for risk behaviors referring to content and downloads (Table 1). Next, we will analyze these behaviors in accordance with gender (Table 2), age (Tables 3 and 4) and context (Tables 5 and 6).

Table 1 shows the results for risk behaviors referring to content and downloads. Three behaviors had a higher mean than the rest (minimum=1; maximum=4): the consumption of adult content ("I access adult content", M=1.59), failure to recognize copyright ("I copy work from the Internet without mentioning the author", M=1.69) and pirate downloads and consumption ("I download films, music, etc. from places on the Internet that are not allowed", M=1.80). With a difference of between 0.5-0.6 points between the two groups, a lower mean was found for inadequate behaviors linked to permission: "I download paid-for applications or programs without my parents'/teachers' permission" (M=1.19), "I use passwords belonging to my parents or other adults to access the Internet without permission" (M=1.13) and "I shop on the Internet without permission, using an adult's accounts or passwords" (M=1.08).

Table 1. Risk behaviors referring to contents and downloads: descriptive statistics

	M	(SD)	Never		Rarely		Often		Always		Total	
			N	%	N	%	N	%	N	%	N	%
I access adult content (adult games, adult pages, etc.).	1.59	.95	1,653	66.3	416	16.7	219	8.8	207	8.3	2,495	100
I copy work from the Internet without mentioning the author.	1.69	.89	1,362	54.5	685	27.4	312	12.5	139	5.6	2,498	100
I download films, music, etc. from places on the Internet that are not allowed.	1.80	1.05	1,399	56.3	477	19.2	322	13.0	285	11.5	2,483	100
I download paid-for applications or programs without my parents/teachers' permission.	1.19	.60	2,210	88.6	155	6.2	64	2.6	65	2.6	2,494	100
I use passwords belonging to my parents or other adults to access the Internet without permission.	1.13	.46	2,258	90.4	169	6.8	45	1.8	25	1.0	2,497	100
I shop on the Internet without permission, using an adult's accounts or passwords.	1.08	.37	2,362	94.8	90	3.6	16	.6	23	.9	2,491	100

If we analyze the items in more detail in terms of the frequency with which participants engage in each behavior, two groups emerge: over 30% of participants' report having accessed adult content (item 1), having failed to respect copyright (item 2) and having engaged in digital piracy (item 3). In this group, 8.3% (n=207) said they always accessed adult content, 5.6% (n=139) said they always copied work from the Internet without mentioning the author, and 11.5% (n=285) said they always carried out illegal downloads.

In contrast, in relation to the three remaining items, referring to actions carried out without permission, around 90% of participants said they never engage in such actions: 88.6 % (n=2,210) said they had never

downloaded paid-for applications without adult permission, 90.4% (n=2,258) said they had never used passwords belonging to their parents or other adults to access the Internet without permission, and 94.8 % said they have never shopped on the Internet without permission, using an adult's accounts or passwords.

Table 2 shows the risk behaviors studied in accordance with gender. The results revealed that boys engaged in more risk behaviors than girls (with means of 1.49 and 1.32, respectively). This difference is statistically significant: p<.00; and its effect size (d=.37) ranges from weak (d=.20) to moderate (d=.50) (Cohen, 1988).

Table 2. Risk actions referring to contents and downloads, in accordance with gender

Gender	N	Mean	SD	Mean standard error	t	Sig. (bilateral)	Cohen's d
Boys	1,214	1.49	.53	.01	9.30	.00	.37
Girls	1,233	1.32	.37	.01			

We also analyzed differences in accordance with age (Table 3). The results revealed that older participants engaged in more risk behaviors, with the mean increasing with age. The main difference was observed from age 12 to age 13, with an increase of 0.21 points, followed by the change from age 15 to age 16, with an increase of 0.19 points, and the change from age 14 to age 15, with an increase of 0.1. The statistics indicate that these differences are significant (p=.00; η^2=.20).

Table 3. Risk behaviors referring to contents and downloads, in accordance with age

Age	N	M	SD	Standard error	ANOVA		
					F (between groups)	Sig. (between groups)	Eta squared
10	185	1.12	.23	.01	88.45	.00	.20
11	306	1.13	.24	.01			
12	493	1.23	.32	.01			
13	451	1.44	.46	.02			
14	432	1.52	.47	.02			
15	397	1.62	.48	.02			
16	136	1.81	.54	.04			
17	49	1.86	.58	.08			
Total	2,449	1.41	.46	.00			

We also analyzed the similarities and differences observed between different age groups. As shown in Table 4, four subgroups were identified. The first, with the lowest means, encompassed the youngest participants (10, 11 and 12 years of age). The second, with medium values, encompassed participants aged 13 and 14 years. The third, also with medium yet increasing values, encompassed those aged 14 and 15 years. And finally, the fourth group encompassed those aged 16 and 17, with higher means. The results therefore indicate that risk behaviors increase progressively between the ages of 10 and 17.

Table 4. Group means for the homogeneous subgroups, in accordance with age

Age	N	Subgroup for alpha = 0.05			
		1	2	3	4
10	185	1.12			
11	306	1.13			
12	493	1.23			
13	451		1.44		
14	432		1.52	1.52	
15	397			1.62	
16	136				1.81
17	49				1.86

We can therefore say that boys (M=1,49) engaged in more risk actions linked to content and downloads than girls (M=1.32), and that risk actions increased gradually from age 10 to age 17 years, with older adolescents engaging in more risk actions. Consequently, older boys constituted the group that engaged in most risk actions. Table 5 shows risk actions linked to content and downloads in accordance with context. The highest mean was observed among participants from Attica (M=1.69), followed

by those from the Madrid Region (M=1.57) and Cantabria (M=1.51). In contrast, the lowest mean was observed among participants from the Autonomous Community of the Basque Country (ACBC), (M=1.29), followed by the Marche Region (M=1.38) and Navarre (M=1.39). These differences were statistically significant: F=31.76; p=.00; η^2=.07.

Table 5. Risk behaviors referring to contents and downloads, in accordance with context

Context	N	Mean	SD	Standard error	ANOVA		
					F (between groups)	Sig. (between groups)	Eta squared
ACBC (Spain)	942	1.29	.40	.01	31.76	.00	.07
Navarre (Spain)	378	1.39	.39	.02			
Galicia (Spain)	505	1.42	.47	.02			
Madrid (Spain)	109	1.57	.48	.04			
Attica (Greece)	278	1.69	.57	.03			
Marche Region (Italy)	96	1.38	.46	.04			
Cantabria (Spain)	142	1.51	.47	.03			
Total	2,450	1.41	.46	.00			

Finally, we determined whether the association between the means for each context was statistically significant (Table 6). In the case of the ACBC, all cases were statistically significant (ACBC – Navarre, p=.00; ACBC – Galicia, p<.00; ACBC – Madrid Region p<.00; ACBC – Attica, p<.00), except for the association between the ACBC and Italy. In relation to both Navarre and Galicia, three cases were found to be statistically significant in each (Navarre – ACBC, p=.00; Navarre – Madrid Region, p=.00; Navarre – Attica, p<.00; and Galicia – ACBC, p<.00; Galicia – Madrid Region, p<.05; Galicia – Greece, p<.00). In the case of the Madrid Region, in addition to those statistically significant cases mentioned above (Madrid Region – ACBC; Madrid Region – Navarre; Madrid Region – Galicia), another case was also observed (Madrid Region – Marche Region, p<.05). The results for Attica and the Marche Region (p<.00) and Attica and Cantabria (p<.05) were also statistically significant. Finally, in addition to the associations mentioned above between the Marche Region and other contexts, the association between the mean for this region and that of Cantabria was not statistically significant. In general, the effect size ranged from weak (d=.20) to moderate (d=.50) (Cohen, 1988).

Table 6. Associations between the means of each context

Context (I)	Context (J)	Difference between means (I-J)	Standard error	Sig.	Cohen's d
Autonomous Community of the Basque Country	Navarre	.10*	.02	.00	0.25
	Galicia	.12*	.02	.00	0.29
	Madrid	.27*	.04	.00	0.67
	Attica	.39*	.03	.00	0.88
	Marche Region	.08	.04	.58	
	Cantabria	.21*	.04	.00	0.52
Navarre	Galicia	.02	.03	.97	
	Madrid	.17*	.04	.00	0.41
	Attica	.29*	.03	.00	0.60
	Marche Region	.01	.05	1.00	
	Cantabria	.11	.04	.13	
Galicia	Madrid	.14*	.04	.03	0.30
	Attica	.26*	.03	.00	0.51
	Marche Region	.04	.05	.97	
	Cantabria	.08	.04	.37	
Madrid Region	Attica	.11	.05	.23	
	Marche Region	.19*	.06	.03	0.40
	Cantabria	.06	.05	.94	
Attica	Marche Region	.31*	.05	.00	0.56
	Cantabria	.17*	.04	.00	0.32
Marche Region	Cantabria	.13	.05	.29	

4. Discussion and conclusions

The risks linked to the contents accessed by adolescents are related to the activities they engage in most assiduously on the Internet. Accessing leisure and entertainment content is the action adolescents carry out most frequently using their mobile devices. The risk actions found to be most closely associated with this frequent use are accessing websites or platforms for consuming music, TV shows, films and games (Soler & Oriola, 2019). This finding is consistent with the results of the present study, in which the highest means were found for downloading music and films from places on the Internet that are not allowed,

followed by plagiarism and access to adult content. Similar to previous research reports, in our study, 30% of participants admitted to having accessed adult content, having failed to respect copyright and having consumed pirated content. In terms of accessing adult content, the contextual factors linked to adolescence, such as the exploration of one's sexuality, interest in risk-taking, pushing boundaries and disobedience, should be taken into account when interpreting the results. Lack of interest, the ease with which it can be done and the low likelihood of being found out are linked to the item on respecting copyright; and the results regarding pirate content may be interpreted as one of the consequences of the high cost of transmedia content prior to the emergence of VOD platforms. Our results contribute to shaping the theory of Internet-related risks among adolescents, specifically in relation to accessing content and information, as well as behavioral risks linked to actions carried out on different platforms and applications (Livingstone et al., 2011; Winstone et al., 2022). They also enabled the aims of the study to be fulfilled, providing insight into the frequency of risk actions, particularly in relation to content and downloads (pornography, plagiarism, piracy and permission), in accordance with gender, age and context.

The statistically significant difference ($p.<.001$) found in terms of gender (Boys=1.49; Girls=1.32) is consistent with that reported previously by other studies, which found that boys and young men access pornography and gambling sites to a greater extent and more frequently than their female counterparts (Ballester et al., 2019; Mateu, 2016). These gender differences may be associated with cultural stereotypes about men exploring sexuality through sexually explicit content, and about gambling as a socially and culturally accepted practice, identified as low risk (Andrei et al., 2019). When interpreting these results, it is also important to bear in mind the conclusions drawn by previous studies, which found that teenage boys tend to access adult content as a result of an intentional search, whereas teenage girls tend to access it through pop-up adverts on websites, and indeed, in some cases, this exposure has negative repercussions on their mood (Barbovschi et al., 2021). These differences in both use and access pathways should be taken into consideration in the design of education policies or digital literacy strategies focusing on appropriate Internet use. Interventions should include a gender perspective, since, as Estanyol et al. (2023) point out, males and females interact with the media in different ways, at least during adolescence. Educational policies should include strategies designed to raise awareness of the harm caused by risk behaviors during adolescence, to empower people to cope with any disagreeable experiences they may have had and to encourage them to explore the possibilities offered by the Internet in terms of personal growth and development (Buckingham, 2020, Torrecillas-Lacave et al. 2022). In other words, educational policies should seek to strengthen resilience to negative experiences involving the digital media (Livingstone & Stoilova, 2021).

In terms of age differences, the results are also consistent with those reported by previous studies (IFPI, 2021), which found that young people aged between 16 and 25 years are more likely to engage in risk actions linked to accessing online leisure and entertainment content. In terms of sexually explicit content, Barbovschi et al. (2021) and the ESPAD (2020) found that risk actions are more frequent among young people aged between 15 and 16 years. These results may be interpreted based on the characteristics of the different stages of adolescence proposed by Sullivan (1974): pre-adolescence, early adolescence and late adolescence, the last of which includes more traits inherent to adult life.

The results obtained in the present study regarding gender and age differences in the consumption of inappropriate content are consistent with those found by Lareki et al. (2017a), who observed the existence of two different adolescent user profiles in terms of the perceived risks involved: a majority group, made up of younger adolescents, mainly girls, and a minority group, made up of older adolescents, mainly boys. The latter group generally perceived inappropriate behavior in the use of technology as being less serious than the former. One may assume that viewing certain behaviors as less serious may result in adolescents engaging in them more frequently.

In relation to risk behaviors linked to engaging in activities without one's parents' or teachers' permission, it is worth highlighting that 10% of the participants in our study claimed to have downloaded applications or programs without permission, used passwords belonging to their parents or other adults to access the Internet without permission and shopped on the Internet without permission, using an adult's accounts or passwords. Although no prior research exists in Spain and Europe in relation to this specific type of action,

these results are associated, in percentage terms at least, with the frequency of access rates reported for the other items in this dimension. It may therefore be assumed that, at least in terms of frequency, all the risk behaviors analyzed in the present study are related.

Regarding context, a significant difference was observed by contexts (F=31,76; p.<.00; η^2=.07). In the post-hoc test, however, not all cases were statistically significant. Previous research in the European context (Andrie et al., 2019; Barbovschi et al., 2021 and Livingstone et al., 2011) has shown the need to develop education policies that, rather than being general in nature, respond to contextual needs, since all regions, even those located in the same country, have their own specific social-cultural dynamics, as indeed the results of the present study confirm. Furthermore, in the results reported here, the social-cultural similarities that exist between the Mediterranean regions of Europe were not found to have a statistically significant impact. Our results therefore indicate that despite the cross-cultural nature of the study, this variable does not explain the differences and similarities observed. One of the study's limitations is the convenience sampling method used to recruit the samples in the different contexts. Future research may wish to use the instrument with statistically broader samples in order to enable the results to be generalized.

Notes

[1] The harmonic mean sample size was used=175.771. The size of the groups differed. The harmonic mean of the group sizes was used. Type I error levels are not guaranteed.

Authors' Contribution

Idea, S.C., I.E.; Literature review (state of the art), S.C.; Methodology, I.E.; Data analysis, I.E.; Results, I.E.; Discussion and conclusions, S.C..; Writing (original draft), S.C., I.E.; Final revisions, S.C., I.E.

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Parents' meta-reflexivity benefits media education of children

La meta-reflexividad de los padres beneficia la educación mediática de los niños

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ABSTRACT

The paper explores the effects of the sociological concept of reflexivity to parents' media education of preschool children. It draws upon the recommendations of the American Academy of Paediatrics referring to the restrictions of screen exposure based on different age groups, coviewing and discussing media content. It applies a social survey on the Slovenian national sample of parents to (1) review their media education practices, (2) identify the factors affecting these practices through regression analyses and (3) use path analysis to provide an explanatory model of the factors affecting children's screen exposure. A Reflexivity Measurement Tool is applied to assess the parents' meta-reflexivity scores. The hypothesis that meta-reflexivity is one of the key factors affecting media education is confirmed. The results show differences in screen exposure between age groups and higher exposure of boys when compared to girls. Children of the divorced/separated parents are more exposed to screens. Setting restrictions is quite common but it is also the quality of media content and the interaction with children that matters. Meta-reflexivity not only decreases the quantity of screen exposure. but it also makes coviewing and discussing media content with children more likely. Moreover, the significance of parents as role models is confirmed.

RESUMEN

El artículo explora los efectos del concepto sociológico de la reflexividad en la educación mediática de los padres en niños preescolares. Se basa en las recomendaciones de la Academia Estadounidense de Pediatría que se refieren a las restricciones de exposición a las pantallas en función de los diferentes grupos de edad, la visualización conjunta y la discusión del contenido de los medios de comunicación. Aplica una encuesta social a la muestra nacional eslovena de padres para: revisar sus prácticas de educación en los medios de comunicación; identificar los factores que afectan estas prácticas a través de análisis de regresión; y utilizar el análisis de ruta para proporcionar un modelo explicativo de los factores que afectan la exposición a las pantallas de los niños. La herramienta de medición de reflexividad se aplica para evaluar las puntuaciones de meta-reflexividad de los padres. Se confirma la hipótesis de que la meta-reflexividad es uno de los factores clave que afectan a la educación en los medios de comunicación. Los hijos de padres divorciados/separados están más expuestos a las pantallas. Establecer restricciones es bastante común, pero también es importante la calidad del contenido de los medios y la interacción con los niños. La meta-reflexividad no solo disminuye la cantidad de exposición a las pantallas, sino que también hace que sea más probable que los niños vean y discutan en conjunto el contenido multimedia.

KEYWORDS | PALABRAS CLAVE

Reflexivity, parental behavior, pre-school, children exposure, screen, quantitative analysis.
Reflexividad, comportamiento parental, preescolar, exposición de los niños, pantalla, análisis cuantitativo.

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1. Introduction

Digital media have become a regular part of children's everyday lives. Even babies are often confronted with digital media for longer periods of time every day, although paediatricians and psychologists strongly discourage the use of such media by children under two years of age. In these early years of a child's upbringing, parents play a crucial role in raising and educating children on the smart ways of using and living with digital media and preventing damage that the overload of screen exposure or age-inappropriate media content can create (Christ & Abreu, 2020; Lemish, 2015; Livingstone et al., 2017; Rek, 2019). They also significantly influence a child's knowledge and experience of digital media through examples, conversations, and experiences. They themselves are role models that children imitate (Rek & Kovačič, 2018). However, the process of media education is become a challenging and ever-changing task for parents to achieve.

Adopting habits of strengthening their own media literacy and aligning media related skills with current technological development have become a norm for good quality life. Media literacy refers not just to skills enabling us to use new emerging media or create online messages, but also to understanding how media works in this changing environment and to the ability to analyse and evaluate the media content and deal with credibility of mediated information (Hobbs, 2010; Kubey, 2001; Livingstone, 2004; Tommasi et al., 2021; Adam & Gorišek, 2020). Furthermore, it also highlights the necessity to comprehend the intents and consequences of media messages and the ability to critically analyse multiple codes (Buckingham, 2007; Rivera-Rogel et al., 2017).

In current fast-paced processes of digitization that are radically changing the communication of people and social groups, adults themselves are often faced with figuring out and adopting new digital media, related practices, and attitudes. Fast social and technological dynamics prevent primary socialisation from being prescribed by pre-given norms and parents hardly rely on certain established fixed patterns of behaviour, norms, or values, passed down from generation to generation in upbringing and educating their children about media. While there are some expert media education guidelines available for parents, it is the ability of parents to critically observe and reflect the social order that we find crucial for their actual media education implementation. Therefore, we argue that it is a parent's critical reflexivity that plays an important role in media education.

In that regard, we rely on the sociological theoretical framework of Archer (2007, 2012) which states that reflexivity is the intrinsic feature of human psyche. Through inner dialogue, individuals are able to consciously and strategically orient their actions to achieving their goals, and thus, they also have the potential to alter social settings to meet their needs. Through reflexive inner dialogue, individuals are able to define their concerns, develop projects and establish practices, which is constituting a bridge between social structure and individuals' agency. Individuals are analysing their ideas, concerns, and motives for actions through the on-going process of discernment, deliberation, and dedication occurring within their reflexive inner dialogues. Although everyone is reflexive, there are different modes of inner dialogue, corresponding to different individual and social contexts. The dynamics and uncertainties of the late modern society, accompanied by extensive digitalisation, encourage a specific mode of critical reflexivity – called meta-reflexivity. This mode of reflexivity, which we pay attention to, refers to a specific nexus between social settings and individuals' concerns (Archer, 2003, 2007). Meta-reflexivity refers to a critical deliberation towards the social order. This mode requires ultimate concerns referring to certain values and normative ideals providing alternatives to the mainstream information load. Therefore, it enables individuals to critically evaluate previous inner dialogues and to be critical about their effective action. In that regard, meta-reflexivity seems to be crucial for enabling one to take a critical perspective and stance towards the media content and its role in her/his life. Based on meta-reflexivity, one can actively respond to the social environment, including the rapidly transforming digital media landscape.

Previous research (Golob et al., 2021) has shown that reflexive capacities of individuals, more specifically, the ability for meta-reflection, can increase certain beneficial behaviours when identifying credible information in a digital environment. By applying Archers' theoretical framework, we investigated behaviour related to resilience against a growing presence of fake news, disinformation, and misinformation in online media. Meta-reflexivity has also proved to be an important factor in enhancing one's responsible

behaviour and empowerment (Golob & Makarovič, 2022). In this article, we draw on the sociological theoretical framework of Archer (2007, 2012) to investigate the role of reflexive capacities of parents in media education processes in primary socialisation. We further advance the consideration of reflexivity by placing it in the specific context of media education and demonstrate the applicable value of this theoretical concept. Reflexivity indicates that one can recognise the benefits and risks posed by the media while meta-reflexivity implies a critical stance towards the all-encompassing presence of the media. Without sufficient reflexive capacities, this is done without being necessarily aware of the impact the media has on various aspects of children's development.

On that basis, we explore whether meta-reflexivity supports beneficial parental behaviour in media education of young children. In identifying what we call a beneficial behaviour in media education we will rely on selected recommendations and guidelines of the American Academy of Paediatrics, which has been, in recent decades of digitalisation, one of the referential organisations in providing guidelines and policy advice in media education. We should point out that these guidelines are of changeable nature themselves as they evolve in a morphogenic manner with digital transformations and new scientific knowledge and advancements in various scientific fields related to media literacy and education. Guidelines for parents of young children on media education that we will refer to include:

- Avoid digital media use (except video-chatting) in children younger than 18 to 24 months.
- For children ages 18 to 24 months of age, if you want to introduce digital media, choose high-quality programming, and use media together with your child. Avoid solo media use in this age group.
- For children 2 to 5 years of age, limit screen use to one hour per day of high-quality programming, coview with your children, help children understand what they are seeing, and help them apply what they learn to the world around them (Hill et al., 2016).

We argue that actual implementation of these guidelines is quite loosely formulated and depends on the meta-reflexive capacities of parents. This has led us to propose our main research question regarding whether young children's parents' meta-reflexivity significantly contributes to their media education practices. Based on the empirical research, we intend to:

1) Provide a review of parents' media education practices and show how this relates to children's screen exposure.

2) Identify factors affecting parents' media education practices, including the socio-economic background, parents' attitudes to media effects on their children, parents' own media use, their familiarity with education recommendations, and the intensity of their meta-reflexivity.

3) Provide an explanatory model of the factors affecting preschool children's screen exposure.

On that basis, we hypothesise that effective media education in primary socialisation is tightly interwoven with the reflexive capacities of young children's parents.

2. Materials and methods

Based on the theoretical perspectives on media education and our on-going research on the matter, a series of survey questionnaires has been conducted targeting the parents of preschool children and educators in the kindergartens (Rek et al., 2022). For the purpose of this paper, we are using the data collected from a sample of parents of preschool children aged from one to six years. The sample consists of 1,987 survey responses, out of which 1,677 have been fully completed. The survey was administered on-line from April to June 2022 with the help of kindergartens. The parents have been sampled through a stratified random sample: for each of the ten Slovenian statistical regions, one predominantly urban and one predominantly rural kindergarten were randomly selected. The parents have been asked to report on:

- Their children's screen exposure time for different digital media as well as the parents' own media exposure.
- Their practices of media education in terms of (1) setting rules and restrictions; (2) accompanying their children while interacting with the media; and (3) discussing the media content with them – using the five-level Likert scales.

- Their attitudes about the effects of the media on children based on five-level Likert scales.
- Their familiarity with the experts' guidelines on media education for preschool children.
- Their demographic features including gender, educational level, settlement type, joint or separate living of parents, as well as the child's gender and age.

We appliedthe Reflexivity Measurement Tool (RMT) developed in our previous research (Golob & Makarovič, 2018, 2019). With this tool, we have upgraded the theoretical framework of reflexivity and made it more convenient for applied purposes. It is used to provide an approximate assessment of one's reflexivity in terms of quantitative scores for different reflexivity modes. The first set of five questions draws from Archer's ICONI combined with the contribution by Porpora and Shumar (2010) measuring the reflexivity level, namely: "during the last year, how often did you" about the following items, indicating the intensity of internal conversation:

- Plan your own future.
- Rehearse what you would say in an important conversation.
- Imagine the best and worst consequences of a major decision.
- Review a conversation that ended badly.
- Clarify thoughts about some issue, person, or problem.

Reflexivity level is thus the sum of the Likert scale responses to these five questions. This sum is combined with an indication of a certain reflexivity mode: for the purpose of our research, this is meta-reflexivity as it indicates a critical way of thinking and acting about oneself and about one's own social environment. The RMT requires the multiplication of each person's reflexivity level with her/his Likert scale responses to the question referring to meta-reflexivity: "During the last year, how often did you carefully consider the key priorities of your life and why you are doing what you are doing?". Our analysis has proceeded in three stages:

- Presenting the descriptive statistics referring to the practices of media education and children's screen exposure.
- Regression analyses on the effects of the parent's and child's demographic features, as well as parents' attitudes, media behaviour, familiarity with experts' recommendations, and meta-reflexivity towards the practices of the media education.
- Path analysis explaining how the exogeneous variables affect the screen exposure of preschool children.

3. Results

3.1. A review of media education and children's screen exposure

As shown in Table 1, setting restrictions and rules about what preschool children are allowed to watch is the most common practice of media education with the mean score of 4.45 on the 5-level scale. Almost two thirds of the parents claim that they always set restrictions for their children, while less than two per cent responded that they never do that.

Almost half of the parents' report to be present when their young child is in touch with the media – with the mean score of 4.27. Discussing the media content with a preschool child, however, is significantly less common. Less than a quarter of the parents report this practice, and the mean score is only 3.72. A comparatively high standard deviation indicates significant differences between the parents regarding this practice.

Table 1. Reported practices in media education

"Respond to the following questions on the scale from 1 to 5 where 1 means never and 5 means always."	Mean	Standard deviation	% of answers 1 (never)	% of answers 5 (always)
Do you set restrictions and rules about what your child is allowed to watch?	4.45	0.91	1.91	65.48
Are you present when she/he is in touch with the media (watches TV, video…)?	4.27	0.87	0.64	49.49
Do you talk to your child about what she/he saw in the media TV, video…)?	3.72	1.00	3.13	23.69

The recommendations of the American Academy of Paediatrics as a referential organisation in providing guidelines and policy advice in media education suggest avoiding all digital media use for children younger than 18 to 24 months and no more than one hour per day of high-quality programming, coviewing with the children (including helping children understand what they are seeing and help them apply what they learn to the world around them). Our results in Table 2 show that only 37.41 % of children younger than two years old have no exposure to screens, which is highly concerning. The deviation from the recommendations is less significant for the children from two to five years, where the screen exposure for 69.28 % of children is within the recommended time frame. For a small group of older children in our sample, the exposure is even higher – with almost a half of them being exposed to screens for more than one hour per day.

Table 2. Children's screen exposure

"How much time on average in an ordinary day does your child…?" - the sum of minutes per day for watching live TV; DVD or video on TV, computer, phone, tablet, etc; playing video games; using the web	Mean sum of total minutes per day	% of children with no exposure	% of children with up to 1 hour/day	% of with more than 1 hour/day
Younger than 2 years	25.1	37.41	53.96	8.63
From 2 years till less than 5 years old	62.7	6.48	62.80	30.72
5 years old or more	89.8	4.13	47.88	47.99

3.2. Factors affecting media education practices

The regression analyses presented in Table 3 show the independent variables that have turned out to have statistically significant effects on each of the selected media education practices. Mothers and more educated parents are more likely to impose rules and restrictions regarding media content on their children. All of the observed practices of media education are more common in urban environments.

Table 3. Factors affecting media education practices in the family

Dependent variables in the linear regression models →	Parent sets rules and restrictions		Parent's presence when child is in touch with the media		Parent talks with her/his child about media content	
Independent variables with statistically significant effects ↓	Variables	Beta Coefficients (and signif.)	Variables	Beta Coefficients (and signif.)	Variables	Beta Coefficients (and signif.)
Parent's demography	Female Urban Educated	.06 (.061) .08 (.001) .10 (.000)	Urban	.08 (.001)	Urban	.05 (.067)
Parents' behaviour	/	/	Watching TV Using computer Phone calls Playing with child TV turned on	.05 (.067) .06 (.053) -.07 (.006) .15 (.000) -.06 (.032)	Using computer Web browsing Reading press Playing with child	.04 (.094) -.07 (.009) .05 (.045) .20 (.000)
Parents' Attitudes	"Media negatively affect preschool children's mood"	0.12 (0.000)	"My preschool child learns lots of useful stuff from the media"	-.07 (.004)	"Media negatively affect preschool children's mood" "My preschool child learns lots of useful stuff from the media"	.05 (.057) - .09 (.001)
Child's age		-.08 (.001)		-.19 (.000)	/	/
Parent familiar with recommendations		.10 (.000)	/	/		.08 (.001)
Parent's meta-reflexivity		.11 (.000)		.10 (.000)		.14 (.000)

While parents' own media-related behaviour does not seem to have any significant effects on setting rules and restrictions, it does affect their presence when their child is exposed to media and the frequency of their discussions about media content with the children. Parents who watch TV and use a computer more frequently are more likely to be present while their children are exposed to screens. On the other hand, parents who spend more time making phone calls and whose TV is turned on for longer periods of time, are less likely to be present. Parents who use a computer or read the press more often are more likely to talk to their children about media content, while those who spend more time browsing the web are less likely to do so. The most significant effect, however, can be noticed for the parents' behaviour that is not

related to the media: the parents who spend more time playing with their children are much more likely to be present when the child is exposed to screens and to discuss the media content.

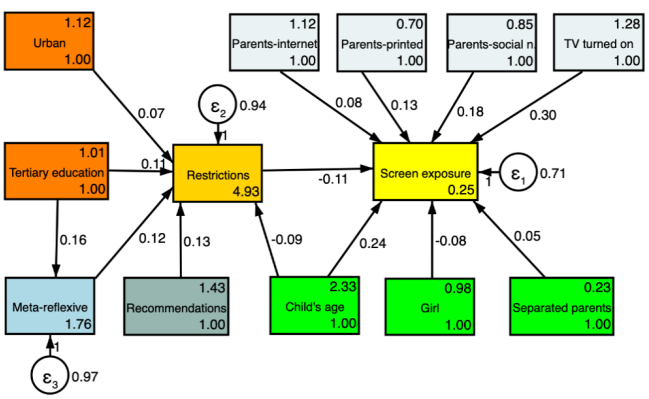
Regarding the attitudes, it is not surprising that parents who believe that media negatively affect preschool children's mood, are more likely to set rules and restrictions. Moreover, these parents are also slightly more likely to discuss media content with the children. On the other hand, parents who believe that their preschool children can gain useful knowledge from the media tend to be less present when their children are in touch with the media. They are also less likely to talk about the media content. It is not surprising that parents' rules and restrictions, as well as their presence when the children are exposed to screens, tend to decrease when children get older. Parents who claim to be familiar with experts' recommendations regarding media education of preschool children are more likely to set rules and restrictions and are more likely to discuss media content with their children.

Finally, one of the most significant findings concerns the impact of meta-reflexivity. Parents with higher meta-reflexivity scores are more likely to set rules and restrictions, to be present when their children are exposed to screens and to discuss media content with their children. In that regard, meta-reflexivity is no less important than familiarity with experts' recommendations, demographic variables, and parents' media-related behaviour. The critical stances of the meta-reflexive parents thus seem to contribute to their more cautious views on the media – encouraging them to set restrictions and observe the media effects more closely. In addition, the results show that parents with intensive reflexive inner dialogues are also more likely to engage in discussions with their children.

3.3. The effects of media education on children's screen exposure

The path analysis is intended to explain the causes of higher screen exposure of preschool children, while taking into account the demographic variables, parents' attitudes towards media effects on children, parents' media use, their familiarity with experts' recommendations, and meta-reflexivity scores. The statistically significant effects are presented in Figure 1.

Figure 1. Path analysis of the factors affecting preschool children's screen exposure



Among the media education practices presented above, only setting rules and restrictions affects the quantity of preschool children's screen exposure. It functions as an intervening variable between meta-reflexivity and demographic features on the one hand, and the children's screen exposure on the other. Consistently with the regression analysis above, restrictions and rules are more typical of the parents who live in an urban environment, are tertiary educated, and are familiar with experts' recommendations. These parents are also characterised by higher meta-reflexivity scores. Again, consistent with the findings above, older children are subjected to fewer restrictions and are much more exposed to screens. However, parents' own media use has even more important effects than their practices of media education. When parents spend more time on the internet, social media, reading printed media, and their TV is on, their children are significantly more exposed to screens.

Finally, girls are less likely to be excessively exposed to digital screens, while the children of separated parents are slightly more prone to that.

4. Discussion and conclusions

Rapid social change with the unprecedented digital media exposure of preschool children implies that media education cannot rely solely on obtained information and/or pre-given norms – instead, reflexive deliberations on the on-going challenges brought forward by social complexity and dynamics are needed.

We confirm our hypothesis that meta-reflexivity is one of the comparatively most significant factors that affects parental media education in terms of (1) limiting screen exposure, (2) accompanying children during media exposure, and (3) discussing media content with the children. Meta-reflexivity is crucial because the familiarity with the experts' guidelines alone is not sufficient. The paper indicates that expertise and its influence are clearly important, but it is essential for individuals to develop their own reflexive deliberations and act accordingly. When some general knowledge about the topic, indicated by the familiarity with experts' recommendations, is combined with the critical elaboration of the issue, more responsible media education becomes more common. Searching for proper ways to design and implement effective media-education techniques for one's own children in the era of unprecedented and overwhelming digital media exposure demands more strategic concerns for the corresponding actions – it goes far beyond routine, and involves meta-reflexivity. A meta-reflexive person critically evaluates previous inner dialogues and is critical about effective action. This mode is driven by an ultimate concern and framed by specific value orientation, which undermines existing structural and cultural hegemony – enabling us to recognise and overcome oversimplified or distorted versions of the media constructs of reality (Strutt, 2019). As Archer (2012) says, meta-reflexivity is transcendental towards the social. Those who are meta-reflexive are not just following a herd but are looking for additional information and arguments with which they are able to decide what is sensible. One of the previous studies (Golob et al., 2021), confirmed, for instance, that meta-reflexivity enables one to be more skilled in media literacy and in checking for alternative information within the media landscape. Moreover, according to Archer (Archer, 2012), meta-reflexivity is the one mode that enables individuals to cope in an effective way with the complex, ever-changing society.

Our findings on the effects of some demographic features of preschool children are consistent with previous research (Rek & Kovačič, 2018; Rideout, 2014; Wartella et al., 2014). This includes significant differences in screen exposure between different age groups and higher exposure of boys when compared to girls. The results are also in line with the existing findings that the children of divorced and/or separated parents are more exposed to screens. We may explain this by the more limited ability of such parents to successfully coordinate their media education and make it more consistent, the limited time of a single parent, as well as emotional stress resulting from parents' separation/divorce. Furthermore, our research confirms that setting rules and restrictions is a comparatively easily attainable aspect of media education of preschool children – as it characterises most parents. We have clearly demonstrated it is important because it tends to prevent excessive screen exposure in terms of quantity. However, there is also an aspect of the quality of media content and interaction which matters. For this purpose, the parents should not rely solely on restrictions but should also invest their time talking to their children and being present when they are exposed to digital screens. The parents' absence in this regard may be a particularly dangerous trap. As indicated by our results, absent parents who fail to discuss media content with their children typically blindly rely on their beliefs about the positive effects of media on their children. Time spent with the child matters, especially when it also opens the door to the worlds beyond the digital media. The time parents spend playing with their children is positively related to media education in terms of interacting with the media and discussing them together – but it is not related to restrictions.

The qualitative and quantitative aspects of media education and screen exposure are especially important as preschool children are a very vulnerable audience. Their ability to access and use different types of media has only started to develop. Their capacity to analyse, evaluate, and reflect on the media messages is limited by their young age. The same is true for their limited ability to create media content and to focus on creative problem solving. There are also other major beneficial effects of proper media education for children's mental and physical well-being. For instance, excessive screen

exposure is predominantly associated with sedentary behaviours in children and adolescents. In addition, it is considered as one of the major factors in causing non-communicable diseases and other health risks later in life (Kaur et al., 2019). Larger exposure of young children to screens also brings negative effects and challenges regarding their eating and sleeping habits, mental state, addictions, aggressive behaviour, language development, consumerism, identity building, relationships with others, etc. (Christakis et al., 2018; De-Frutos-Torres et al., 2021; Farrell et al., 2022; Hayes et al., 2015; Adam & Gorišek, 2022; Serrano-Díaz et al., 2022). It is thus encouraging to see the results of path analysis showing that meta-reflexive parents are actively engaged in media education practices and that this engagement significantly affects limiting the overuse of screens in younger children.

In line with the previous research and trends (Rideout, 2014; Wartella et al., 2014), restrictions are most common for very young children who are not even supposed to interact with the digital media. But when the children get older, it is the quality of their interaction with the media and their comprehension of the content that matters most. This is also a crucial aspect of our further research. Another crucial – though not so surprising – finding of our research is the significance of parents as role models. Their own media use affects their children regardless of media educational practices, meta-reflexivity, and other variables. Our study confirms, in many aspects, the pre-existing academic claims about the exposure to media-related activities of preschool children regarding their parents' media habits and the level of their parents' education (Rek & Kovačič, 2018; Rideout, 2014; Wartella et al., 2014). It confirms that role modelling is crucial in developing children's media habits. Parents own media habits influence their children's use of media (Rek & Kovačič, 2018). Parents not only teach their children how to use the media, but they also become their children's role models and the ones who can cultivate a critical-thinking mindset and value judgments. By setting boundaries and interpreting a media message, they can influence their child's media habits and experience. Parents' excessive use of the media is, however, not only questionable in terms of negative role modelling, but can also be related to the lack of time spent with the children, leading to their higher screen exposure. This can be exemplified by parents reading newspapers, which does not provide a harmful example for the children but may "steal" the time that might otherwise be spent with them.

In terms of practical implications, the results of our research support the need for educating parents about the specific experts' recommendations related to media education of children. We have confirmed the significance of the parents' awareness of experts' guidelines. However, parents' education in general has also been proven to be relevant since it affects their meta-reflexivity as another factor of media education. To enhance parents' meta-reflexivity and make them more capable of deploying proper media education in their families, we suggest interactive workshops, not only for delivering the guidelines, but also for encouraging critical thinking about the media.

Authors' Contribution

Idea, T.G, M.M, M.R.; Literature review (state of the art), T.G, M.R.; Methodology, T.G, M.M, M.R.; Data analysis, M.M.; Results, T.G, M.M, M.R.; Discussion and conclusions, T.G, M.M, M.R.; Writing (original draft), T.G, M.M, M.R.; Final revisions, T.G, M.M, M.R.; Project design and sponsorship, T.G, M.R.

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Digital empathy in online education: A comparison study between Portugal and Romania

Empatía digital en la educación en línea: Un estudio comparativo entre Portugal y Rumanía

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ABSTRACT

This study aims to present the extent to which online education influenced the level of empathy displayed by university students. The research relies on a self-evaluated applied survey in two European countries: Portugal and Romania. The participants in this research are 1,085 students enrolled in Communication Studies programs. The purpose of this study is to unfold the connection between gender, exposure to digital technology, empathy level according to the Basic Empathy Scale applied to young adults, and online education self-perception that involves the use of webcams. Empathy can have positive effects on students' satisfaction and increase students' outcomes. The shift from a physical environment to a digital one brought significant challenges that most students and teachers were not ready for. The digital environment influences how empathy is expressed. The present research found evidence of a relationship between exposure to technology usage, emotional contagion, and gender. This suggests that understanding the emotions of others might be inhibited during digital education. Also, the most relevant factor of empathy variation in online education is gender. The findings of the present research may contribute to the design of activities or programs that could foster empathy expression during online education for young adults.

RESUMEN

Este estudio pretende presentar la medida en que la educación en línea influyó en el nivel de empatía de los estudiantes universitarios. Basada en una encuesta aplicada y autoevaluada en Portugal y Rumanía, participaron 1.085 estudiantes matriculados en programas de Ciencias de la Comunicación. El propósito de este estudio es desvelar la conexión entre el género, la exposición a la tecnología digital, el nivel de empatía según la escala BES aplicada a adultos jóvenes y la autopercepción de la educación en línea que implica el uso de cámaras web. La empatía tiene efectos positivos en la satisfacción de los estudiantes y aumenta sus resultados educativos. El cambio del entorno físico al digital trajo importantes desafíos para los que la mayoría de los estudiantes y profesores no estaban preparados. El entorno digital influye en cómo se expresa la empatía. Se han encontrado evidencias de una relación entre el uso de la tecnología, el contagio emocional y el género. Esto sugiere que el factor más relevante de variación de la empatía en la educación en línea es el género y que la comprensión de las emociones de los demás puede inhibirse durante la educación digital. Los hallazgos de la presente investigación pueden contribuir al diseño de actividades o programas que fomenten la expresión de empatía durante la educación en línea para adultos jóvenes.

KEYWORDS | PALABRAS CLAVE

Neuroscience, digital empathy, technology, education, communication, Basic Empathy Scale.
Neurociencia, empatía digital, tecnología, educación, comunicación, Escala de Empatía Básica.

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1. Introduction and state of the art

The importance of empathy in an educational context is well documented in academic literature. Empathy increases students' satisfaction, enhances a teacher's ability to relate with students (Taylor, 2002), and has strong positive effects on students' outcomes (Feshbach & Feshbach, 2009), facilitating communication and relation (both between students and teachers, and among students) in the classroom.

Recently, the rapid adoption of digital technologies and, especially, the pandemic, obliged most organizations, including educational institutions, to urgently redesign their work models. According to UNESCO (2020), because of the pandemic, more than 90% of students worldwide (1.5 billion), had their classes suspended or transferred to an online environment, with all teaching undergoing a huge and rapid transformation (Duarte & Riedl, 2022). Technology-mediated learning (TML) facilitates students' interactions, engagement, brainstorming, and problem-solving tactics, being very efficient and indispensable during the pandemic (Joia & Lorenzo, 2021). With the migration of education to the online world, the empathic social filter, usually present in traditional communication, was overlooked. Online communication is often devoid of several of the emotional signals and cues experienced in face-to-face interactions, frequently leading to more impersonal contacts (Terry & Cain, 2016).

In a meta-analysis of studies conducted over 30 years, Konrath et al. (2011) found that past generation students used to have more empathy than current ones, given the change in interpersonal dynamics, a consequence of the rising prominence of technology and social media use as a daily communication tool. As Villarroel and González (2023: 48) stated, the level of interpersonal empathy in online education might progressively increase based on students' interests and area of study. Due to the growth of computer-mediated education, it is of paramount importance to study, understand, and outline strategies to deal and potentiate this new concept of digital empathy, especially in the educational environment.

2. Empathy

According to Batson (2009), the word "empathy" was first coined by Titchener (1909), starting from the psychological state "Einfühlung" referred by Lipps (1903), about imaginatively projecting oneself into another's situation. Half a century later, Rogers (1951: 129) defined it as the concept of the "as if", explaining that empathy enables a better understanding of another person's views and feelings (Carré et al., 2013). Although it is a multidimensional construct, applied to more than a half-dozen phenomenon (Batson, 2009), "empathy denotes a sense of similarity between the feelings one experiences and those expressed by others, without losing sight of whose feelings belong to whom" (Decety & Hodges, 2006: 107).

2.1. From interpersonal empathy to digital empathy

The rapid adoption of social and mobile technologies altered, as many other aspects of contemporary culture, society's communication patterns and, somehow, disrupted the expression of empathy (Terry & Cain, 2016). The authors referred to a new form of empathy, the digital one, that they define as the "traditional empathic characteristics such as concern and caring for others expressed through computer-mediated communication (CMC)" (Terry & Cain, 2016: 1).

If the importance and impact of technology evolve as expected, digital empathy will become an even more critical issue in all aspects of life, including education. When technology meets the online educational space, emotions become mediated. According to Ahmed (2022: 76), one of the most relevant aspects to be discussed here is "how digital tools spatialize bodies and emotions of students and teachers". Consequently, digital empathy arises as a way to connect emotions and pedagogy. Once empathy has a strong correlation with positive educational outcomes and it is a fundamental part of the student-teacher relationship, the technological advances, the increasing digitization of education and the consequent decrease of empathy may be cause for concern.

2.2. Empathy and neuroscience

In 1992, three Italian researchers found that monkeys, when watching them eating, showed the same neural activity. Deepening this insightful incident, they discovered the "mirror neurons" – nerve cells that enable humans to understand other's experiences by undergoing a kind of involuntary "echo" while

observing one another's behavior (Gerdes et al., 2011). This discovery marked the beginning of the empathy research within neurosciences. In 2004, Decety and Jackson (2004) observed specific brain activity related to empathy, being able to identify the neural mechanisms that mediate empathy in the brain.

Although D'Ambrosio et al. (2009) assumed that there is consensus on the two dimensions of empathy (affective and cognitive), Carré et al. (2013) stated that recent neurophysiological studies have allowed researchers to define empathy as underpinned by three components: cognitive empathy, emotional contagion, and emotional disconnection. According to the authors, emotional contagion involves automatic processes that allow immediate evaluation of the emotions' nature: positive or negative, pleasant, or aversive, and involves subcortical structures such as the limbic lobe. The cognitive empathy involves activations of the insular cortex, the ventromedial prefrontal cortex and medial PFC. Finally, emotional disconnection is related to executive functions based on the orbitofrontal cortex, medial and dorsolateral prefrontal cortex, and the anterior cingulate cortex (Carré et al., 2013: 681). Once modern neuroscience reveals the impact of positive emotions on cognitive processes during learning activities, this fact emphasizes the need to develop digital empathy strategies in education (Li et al., 2020: 227).

2.3. Empathy and education

Authenticity and empathy are qualities that routinely appear on an attribute list of a "good" teacher (Bialystok & Kukar, 2018) and there are numerous studies relating empathy with positive findings in prosocial behaviors such as cooperation, sharing, donating, and other altruistic acts (Batson et al., 1981), all relevant in the learning process. The classes transfer to an online environment broke many of the interpersonal connections existing in the physical classroom. As known, traditional face-to-face communication of personal thoughts and attitudes widely differs from the digital one (Terry & Cain, 2016). If learning is basically a social process (Swan & Shea, 2005) and empathy is a central concept in the context of social interactions, it is of utmost importance to understand the interaction between students and professors in online classes where communication is essentially computer-mediated (Lowenthal, 2010).

During the pandemic, some higher education institutions innovated their teaching systems by creating and implementing diverse academic models focusing on positive emotions and social inclusion in a period when many young people may have been experiencing a feeling of alienation. Okoye et al. (2021) mentioned two interesting online educational models: HyFlex+ TEC (a hybrid and innovative program) and MFD+ (a flexible digital model), highlighting the impacts on emotional health of the latter.

The preoccupation with the impact of digital education on students' performance and emotions is not new. In 2000, Garrison et al. (2000), while proposing a conceptual tool for CMC in education, presented the Community of Inquiry (CoI), developing the concept of successful educational experience based on three relevant aspects: cognitive presence, social presence, and teaching presence. This framework contextualises the relationship between education and empathy in the digital environment. The nature of online communication allows individuals to be physically invisible to others (cameras off), which invalidates the crucial non-verbal communications: facial expression and eye contact (Nelson-Jones, 2005), or possible awareness of the person's physical reaction to another person(s). As much of traditional face-to-face communication tends to be non-verbal, without cues like tone of voice or body language, digital interactions lack this essential element of understanding (Terry & Cain, 2016).

Another important issue potentially lost in online education is the emotional contagion, that is developed during the preverbal period and constitutes the first step in the empathic functioning (Carré et al., 2013). Although researchers agree on the positive role of empathy in interpersonal relationships (Stephan & Finlay, 1999), there is evidence that CMC altered interpersonal dynamics (Konrath et al., 2011) and it is currently acknowledged that empathy is influenced by age, gender, and other attributes of the individual, including situational context (Feshbach & Feshbach, 2009). Therefore, we hypothesize:

- H1. Students spending more time in online education display a lower level of empathy.
- H.1.1. Students spending more time in online education display a lower level of cognitive empathy.

- H1.2. Students spending more time in online education display a lower level of emotional contagion.
- H1.3. Students spending more time in online education display a higher level of emotional disconnection.
- H2: The level of empathy varies according to gender in online education.
- H2.1 Female students are more likely to display a higher level of empathy than male students when attending online education.
- H3: Students with low level of empathy are more likely to switch off their camera during online education.
- H4: During online education, students with a high level of empathy are more likely to need the emotional support of their colleagues.

3. Methodology

The research relies on a quantitative approach, conducted in Portugal and Romania between September 29 and November 9, 2022, that consisted in applying a survey to students enrolled in higher education courses specialized in Communication.

This study respects the guidelines of the Research Ethics Commission from the University of Bucharest, the Portuguese law 58/2019 about General Data Protection Regulation, and follows the guidelines and rules imposed by the EU General Data Protection Regulation (April 27, 2016/679).

According to the Digital Economy and Society Index (DESI, 2022) published by the European Commission, that analyzes Human Capital, Connectivity, Integration of Digital Technology, and Digital Public Services of the 28 EU countries, Portugal and Romania display significant differences regarding the access and use of digital technologies. Portugal is very close to the EU average in 3 of the items, but considerably lower in Connectivity, where Romania presents better results than Portugal. Looking at the Integration of Digital Technology in society, Portugal ranks in #12, above EU average, while Romania is the last country. These differences and the similarity in long periods of online classes in both countries justify the research comparison.

3.1. Participants

The main criterion of respondents' selection was the field of study: Communication. The exact number of students enrolled every year in Portugal and Romania in Communication Studies is difficult to determine, since in both countries the only official data refer to the maximum number of places available in those study programs, not to the actual number of enrolled students. Given this limitation, a non-probability sampling technique was applied to obtain a convenient sample (Bryman, 2012; Kalton, 2020), which included 570 Portuguese and 515 Romanian students.

The sample (n=1,085) consisted of volunteers contacted personally via institutional e-mails, social media groups, and with posters with a QR code and a presentation of the research, displayed in visible places on the premises of Communication Departments/faculties in both countries.

All participants were informed about the purpose of the research and were free to withdraw from the survey at any time. The respondents had to meet the following requirements: be enrolled in Communication programs in Portuguese or Romanian universities (at any level); have a fluent level of English (language of the questionnaire); be at least 18 years old, and freely agree to participate in the survey through an expressed informed consent.

Regarding the age distribution, more than 80% of the participants were young adults, 18 to 23 years old, with most respondents aged 18-20. What is predominant in Portugal with 55.26% are Bachelor students aged 18-20 in comparison with 27.72% aged 21-23. In Romania, there is a visible age balance between the first two categories, 46.01% representing the participants aged 21-23, and 41.17% aged 18-20.

In terms of gender (Table 1), young women represent 73.36%. This can be explained by a majority among the students enrolled in both countries in Communication programs, as this field offers many opportunities for women at European level (Ross & Padovani, 2017).

Table 1. Gender of the respondents' group						
Gender	**Portugal**		**Romania**		**Total**	
	Frequency	**%**	**Frequency**	**%**	**Frequency**	**%**
Female	401	70.35%	395	76.70%	796	73.36%
Male	166	29.12%	113	21.94%	279	25.72%
Other	2	0.35%	4	0.78%	6	0.55%
Gender not specified	1	0.18%	3	0.58%	4	0.37%
Total	570	100%	515	100%	1,085	100%

3.2. Data collection procedures and tools

The questionnaire was anonymous and did not collect names, e-mail addresses or geo-locations. Data collection was conducted through a self-administered online questionnaire (Bryman, 2012), by using the link provided by the researchers or by accessing the QR code included in the poster. The questionnaire consisted of four sections: (1) demographic data regarding the age group, country of origin, gender; (2) exposure to the usage of digital technologies (number of hours spent with digital technology) and to online education (the number of semesters with online education); (3) level of empathy (see "infra"); (4) online education self-perception involving the use of webcams and self-evaluated feelings regarding online education ("online education positively impacts my life", "during online teaching sessions, I find it difficult to interact with my classmates", "after 2 years of pandemic, students are tired of being nice in online classes", "after 2 years of pandemic, I feel more disconnected emotionally").

The third section - measuring empathy - consisted of a 20-item scale entitled Basic Empathy Scale (BES), designed by Jolliffe and Farrington (2006). This scale was tested on British adolescents, and the results were interpreted using two factors: affective and cognitive empathy, which may overlap, but show a degree of differentiation (Jolliffe & Farrington, 2006: 602). In 2013, Carré et al. validated the BES for adults, and proposed a three-factor model of analysis: emotional contagion, emotional disconnection, and cognitive empathy. Emotional contagion is a form of synchronizing one's own postures and expressions with those of the persons around (Hatfield et al., 1994). Emotional disconnection refers to "a mechanism of disconnection from emotion that protects individuals from excessive emotions" (Carré et al., 2013: 686), whereas cognitive empathy means a manner of immediately detaching oneself from the other's emotions, so as not to suffer. For Gerdes et al. (2011), the coherence and combination of the 3-factor model of empathy can be justified by neuropsychological processes as well. This section made use of the BES proposed by Jolliffe and Farrington (2006) and led to the interpretation of the results using the 3-factor model of Carré et al. (2013) that excluded one item from BES, but to facilitate comparison between this study and previous similar ones, the mentioned item (4) was kept in this research.

Following both survey designs (Jolliffe & Farrington, 2006; Carré et al., 2013), the participants rated each sentence on a 5-point Likert type scale (-2 Strongly Disagree, -1 Disagree, 0 Neither Agree nor Disagree, 1 Agree, 2 Strongly Agree). To uniformly interpret the results, the Likert scale was re-coded as follows: 1 Strongly Disagree, 2 Disagree, 3 Neither Agree nor Disagree, 4 Agree, 5 Strongly Agree. In the original BES, seven items were reversed (to be empathic the respondent had to disagree with the item), therefore the scale was also reversed in the case of these 7 items to provide a uniform interpretation of the results. Therefore, the minimum level of empathy is expressed by 20 points, and the maximum by 100 points (Carré et al., 2013: 682). The statistical analysis was performed using free softwares: PSPP version 1.6.2; R version 4.1 (R Core Team, 2021); R statistical packages (Fox & Weisberg, 2020; Lenth, 2020); Jamovi Version 2.3.

4. Results

4.1. Digital technology and online education

91.61% of the respondents declared that they spent more than 4h/day using digital devices, and 36.68% spent more than 8 hours daily using computers, tablets, or smartphones. The variation between the two countries is below 3%. For example, 56.32% of the Portuguese students considered they spent between 4 and 8h/day, similar to 53.40% of Romanians. The high exposure to digital technology representing at least 8h/day unfolds similar self-estimated results, i.e., 35.09% in Portugal and 38.4% in Romania.

Regarding participation in online education, there are significant differences: 31.93% of Portuguese participants declared that they attended 2 semesters of online courses, compared to 16.12% of Romanians,

and 9.82% of Portuguese attended 4 online semesters, compared to 32.63% of Romanians. Both Portuguese and Romanian students self-assessed that they had studied 3 online semesters, representing almost the same percentage (29.82% in Portugal and 29.13% in Romania). Despite the pandemic context, 7% of total respondents considered they did not attend online classes, whereas, conversely, 1.57% self-evaluated their online studies as over 5 semesters.

4.2. The level of empathy

The level of empathy - calculated by using the total number of points for the 20-item BES as described "supra" - varies between 43 and 100 points (Table 2).

Table 2. Level of empathy by gender and country of origin

Level of empathy	Portugal					Romania					Total
	Female	Male	Other	Gender not specified	Total Portugal	Female	Male	Other	Gender not specified	Total Romania	
20-30	0	0	0	0	0	0	0	0	0	0	0
31-40	0	0	0	0	0	0	0	0	0	0	0
41-50	2	1	0	0	3	5	2	0	0	7	10
51-60	12	19	0	0	31	26	14	0	0	40	71
61-70	62	63	0	0	125	62	44	0	1	107	232
71-80	157	54	0	0	211	153	40	3	2	198	409
81-90	135	23	2	1	161	107	11	0	0	118	279
91-100	33	6	0	0	39	42	2	1	0	45	84
Total	401	166	2	1	570	395	113	4	3	515	1,085

Most participants (920, i.e., 84.79%) displayed a medium level of empathy between 61 and 90 points. The average level of empathy in Portugal is 76.20 (SD=9.69) and in Romania is 75.51 (SD=10.57).

Regarding gender, women scored higher than men, irrespective of the country of origin. For the total empathy scale women had an average of 77.63 (SD=10.11), and men 70.72 (SD=9.03). The average score of Portuguese women was 78.23 (SD=9.18), and men 71.29 (SD=9.15). In their turn, Romanian women had an average score of 77.04 (SD=10.53), and men 70.16 (SD=8.85).

The data on emotional contagion (the interval is 6-30) displayed no differences between countries, but they show significant differences regarding gender. In Portugal, the average score of emotional contagion (women and men) is 19.97 (SD=4.29), while in Romania it is 19.84 (SD=4.83). In Portugal, women's average score for emotional contagion is 20.91 (SD=3.93), and men's 17.69 (SD=4.26). In Romania, women's average score is 20.57 (SD=4.59), and men's 17.27 (SD=4.81). Women score higher than men in both countries.

The data on emotional disconnection (the interval is 6-30) also displayed no significant differences in terms of country of origin but show differences regarding gender. In Portugal, the average score for emotional disconnection (women and men) is 24.31 (SD=3.98), while in Romania it is 23.17 (SD=4.32). The difference between women and men scores within the same parameters (around 3 points out of 30). In Portugal, women's average score is 24.98 (SD=3.67), and men's is 22.71 (SD=4.24). In Romania, women's average score is 23.89 (SD=3.96), men's 20.68 (SD=4.59).

4.3. The impact of online education on students' lives

Although there is a difference between Portuguese and Romanian students, 63.50% of respondents estimated that online education had a positive influence in their life. 68.42% of the Portuguese participants "strongly agree" and "agree", compared to 58.06% of the Romanians. Only 7.37% considered that online education did not have a positive impact in their life.

During online classes, 47.85% of the participants believed that they had no difficulties interacting with colleagues. In Romania, 51.85% of the students self-assessed that online education did not make communication with classmates difficult, an opinion similar for 43.86% in Portugal.

4.4. The level of students' interaction by using a web camera

The percentage of participants who "agree" or "strongly agree" with a difficult interaction during online classes is 25.53. The difference between Portuguese and Romanian students who self-evaluated very low interaction with their fellows is less than 2%. Similarly, 19.65% of the Portuguese admitted that the interaction with their classmates during online teaching was difficult, while the Romanians self-evaluated with 16.12%. The total percentage of "neither agree nor disagree" assessment is 28.82%. More than half of the Romanian students did not agree with the difficulty of interaction with classmates, compared to 43.86% of the Portuguese. The difference of 8.99% between the Romanians and the Portuguese students is significant.

75.02% of the respondents participated in online classes with the camera off, without differences between countries. Regarding the attendance with the camera on, there is a difference between countries: 26.66% of Portuguese, compared to 19.41% of Romanians.

4.5. The level of empathy "fatigue"

44.52% of the Portuguese and Romanian participants "strongly agreed" or "agreed" with the idea that it is difficult to be nice in online classes (Table 3). This feeling could be associated with an "empathy fatigue" or empathy blocking. Even so, 15.61% of the Portuguese declared they are still willing to communicate nicely in online classes, while in Romania the percentage is 18.25. Only 10.97% disagreed with the possibility of getting tired of being nice in online classes, after 2 years of the pandemic.

Table 3. Empathy "fatigue"

After 2 years of the pandemic, I think students are tired of being nice in an online classroom	Portugal		Romania		Total	
	Frequency	%	Frequency	%	Frequency	%
Strongly agree	101	17.72%	93	18.06%	194	17.88%
Agree	157	27.54%	132	25.63%	289	26.64%
Neither agree nor disagree	172	30.18%	128	24.85%	300	27.65%
Disagree	89	15.61%	94	18.25%	183	16.87%
Strongly disagree	51	8.95%	68	13.20%	119	10.97%
Total	570	100%	515	100%	1085	100%

4.6. Self-assessed emotional disconnection after pandemic

In this research, 41.47% of the respondents self-evaluated as emotionally disconnected (Table 4). The percentage of Romanians stating that they "strongly agree" and "agree" with emotional disconnection after 2 years of the pandemic is 45.44, while among the Portuguese participants it is 37.90. In terms of disagreement and strong disagreement with emotional disconnection, the Portuguese self-assessed with 42.81%, compared to 35.73% of the Romanians. The percentage of Portuguese and Romanian students who neither agree nor disagree with this emotional disconnection is 19.08, well balanced between both countries.

Table 4. Self-assessed emotional disconnection after the pandemic

After 2 years of the pandemic, I feel more disconnected emotionally	Portugal		Romania		Total	
	Frequency	%	Frequency	%	Frequency	%
Strongly agree	69	12.11%	102	19.81%	171	15.76%
Agree	147	25.79%	132	25.63%	279	25.71%
Neither agree nor disagree	110	19.30%	97	18.83%	207	19.08%
Disagree	143	25.09%	106	20.58%	249	22.95%
Strongly disagree	101	17.72%	78	15.15%	179	16.50%
Total	570	100%	515	100%	1085	100%

4.7. Gender, empathy, and technology

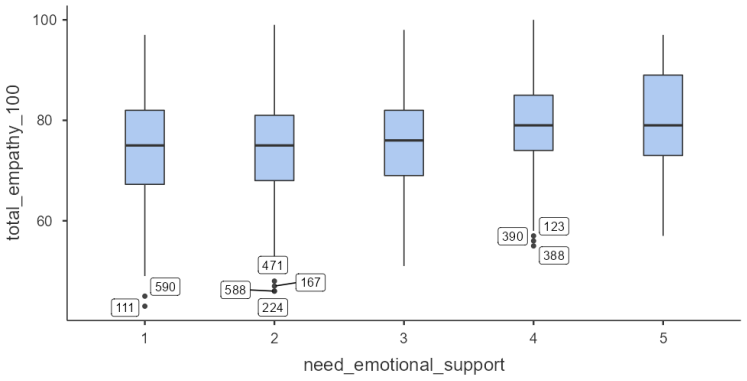
The results of the data analysis from both countries show that there is a correlation between the level of empathy, and gender (Table 5). A weak correlation can also be observed between the empathy and the hours spent online and number of years in higher education.

Table 5. ANOVA – Level of empathy					
	Sum of Squares	df	Mean Square	F	p
Camera on/off	34.8	2	17.4	0.191	0.826
Gender	9,495.8	2	4,747.9	52.061	<.001
Age group	361.6	3	120.5	1.322	0.266
Number of years in higher education	1,032.3	5	206.5	2.264	0.046
Hours spent online (exposure to digital technology)	832.8	4	208.2	2.283	0.049
Online semesters	294.6	4	73.6	0.807	0.520
Residuals	88,098.0	966	91.2		

The ANOVA test was run to investigate the impact of factors on digital empathy. With a 0.05 level of significance, gender, the number of years in higher education, and the number of hours spent online seem to impact empathy (p-values<0.05). To identify the categories that impact empathy differently, Tukey contrast tests were run, and the conclusions are the following: female empathy is higher than men's (mean difference=7.2); men's empathy is lower than others (mean difference= -11.7) and students with less than 3 years of study in higher education display a lower level of empathy (mean difference= -2.8). Furthermore, the ANOVA tests show that emotional contagion is mainly impacted by exposure to digital technology.

The participants with a higher level of empathy are more likely to need emotional support during online education (p< .001) (Figure 1). Tukey contrast tests were run, and the conclusions were that those who most agree with the need for emotional support (4 and 5) have greater empathy (for example, mean difference between 1 and 5 is -5.606, and between 2 and 5 is -5.394).

Figure 1. Level of empathy and the self-assessed need for emotional support



5. Discussion and conclusions

In the case of Portugal, exposure to digital technology correlates with emotional contagion, camera off/on, the perception of the positive effects of online education, and with the feeling that there was a low interaction with classmates online. There is also a correlation between gender and the feeling that online education brought an "empathy fatigue" (expressed by the tiredness of being nice in online classes). As Hosszu et al. (2022: 10) stated, many pupils experienced a feeling of alienation during the COVID-19 pandemic, possibly seen as an emotional disconnection, since most students attended online classes for more than one semester.

The difference of 7.08% between Portuguese and Romanian students who assessed themselves as emotionally disconnected might be seen as a better adaptation to online learning and other resources for expressing emotions beyond online "walls", as Portugal displays a better adaptation to digital technologies (DESI, 2022). Also, for Portuguese respondents, the more time spent on online education correlates with a higher level of positive feelings towards online education. In the case of Romania, gender correlates with emotional contagion (measured by BES), but it does not correlate with the self-assessed emotional disconnection. The number of semesters spent in online education negatively correlates with the emotional contagion.

- H1 is partially validated. The level of empathy is not influenced by the number of semesters spent on online education, but a significant correlation is to be found at the level of emotional contagion related to self-assessed exposure to digital technology, where weak correlation values can be observed in the case of Portuguese and Romanian respondents (H1.2). Emotional contagion is of paramount importance as it is an automatic and unconscious process, developed in the early years of life, and it refers to the affective expression of emotions (Carré et al., 2013: 679). Our findings also show that the levels of emotional contagion are correlated to the duration of exposure to digital technology.
- H1.1 (cognitive empathy) and H1.3 (emotional disconnection) are not validated.

The results validate the second hypothesis (H2) regarding the level of empathy depending on gender in online education. This is in line with results from previous studies, which underlines that women express their empathy differently from men, substantiating once more the findings of Jolliffe and Farrington (2006: 602). According to statistical analysis, in both countries, women's average score of empathy is higher than men's during online education.

- H3 is also validated. Students prefer to switch off the camera during online classes (75.02%). Women show a similarly low level of interest as men in attending classes with cameras on. 75.67% of the Romanian females stay behind the "black screen", compared to 70.76% of the Portuguese. The camera on/off variable was added to the tested model and does not seem to have an impact on the level of empathy (p-value=0.826). Previous studies showed that anxiety, intimacy, freedom, and discovering new abilities of multitasking activities may be the reasons for not switching the camera on (Hosszu et al., 2022; Deng et al., 2022).

This phenomenon of camera on/off can be explained by the students' ability to simultaneously communicate with their classmates, most likely on social platforms, such as WhatsApp. This platform is seen as a successful tool of interaction which may be integrated in online education, although researchers observed the decrease of learning engagement when using social media platforms during online classes (Deng et al., 2022: 15).

In this study, almost half of the students self-evaluated as being positively impacted by online education. Also, the level of interaction with colleagues is seen as satisfactory. These results are intriguing in the context of keeping the camera off in online classes. Other studies show that students re-create new identities in an online environment, manipulating webcams differently. While attending online classes, students prefer to have the camera off to express different types of freedom and reconstruct another social space behind it (Hosszu et al., 2022: 9-10). The same authors observed that Romanian students did not like teachers' pressure and control and kept their camera off to preserve their individuality and intimacy. The present study could not find consistent data related to a clear correlation between low level of empathy and the practice of keeping the camera off during online classes. A weak correlation was found when it came to gender, empathy, and having the camera turned off in the case of Romanian male respondents, but this does not substantiate the relationship between lower levels of empathy and participation with cameras on in online education.

- H4, regarding the emotional support needed by students with high level of empathy while attending online classes, is validated. The authors presume that students with high levels of empathy are more socially involved with their relatives, friends, and classmates. As learning is basically a social process (Swan & Shea, 2005), without the physical interaction in the online environment, they may feel the need for social presence. Social presence comprises emotional expression, open communication, and group cohesion, being expressed by emotions, risk-free expression and encouraging collaboration (Garrison et al., 2000: 89). During the pandemic, the Communication Programs in Portugal and Romania were almost exclusively online, with no hybrid activities. The need for emotional support could be justified by this lack of face-to-face connection during long periods of digital education.

In conclusion, the present research found evidence of a relationship between exposure to technology usage, gender, and empathy. The authors argue that understanding others' emotions might be inhibited during digital education. Empathy at its core will never change. However, its means of expression is naturally

evolving as the world and its form of communication become increasingly digital (Terry & Cain, 2016: 3). With the growing technological adoption, the social filters that mediate the student-teacher relationship require a deeper understanding. This study analyzed the construct of empathy in the digital educational environment, based on students' perceptions and opinions. As empathy is proven to be correlated to students' satisfaction and performance (Taylor, 2002; Feshbach & Feshbach, 2009), unpacking the digital trait of this concept is fundamental. Although this study cannot establish the causality, it might be expected that a higher exposure to digital technology usage would negatively influence the level of empathy. A weak variation of empathy levels was observed, and this process is related to the digital environment. According to this research, similar to face-to-face interaction, the most relevant factor of empathy variation in online education is gender. The findings of this research may contribute to the design of activities or programs that could foster empathy expression during online education for young adults.

Several aspects can be developed in future research, such as a comparison with students from other study fields, or an extension to other countries. Furthermore, the relationship between gender and emotional disconnection could be approached in order to refine explanations regarding the gender influence on empathy in the digital environment and online education. In addition, the phenomenon of attending online classes or other educational activities with the web cameras switched off could be investigated in depth using a qualitative research method, like the semi-structured interviews.

Authors' Contribution

Idea, A.D., R.S., M.M.; Literature review (state of the art), A.D.; Methodology, A.D., R.S., M.M.; Data analysis, R.S., M.M., V.M.; Results, R.S., M.M., V.M.; Discussion and conclusions, A.D., R.S., M.M.; Writing (original draft), A.D., R.S., M.M.; Final revisions, A.D., R.S., M.M.; Project design and funding agency, A.D., R.S., M.M.

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The COVID-19 vaccine on Facebook: A study of emotions expressed by the Brazilian public

Vacuna contra COVID-19 en Facebook: Un estudio sobre las emociones expresadas por el público brasileño

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ABSTRACT

Vaccines are an essential public health resource for disease containment and reduction of associated mortality rates. With the emergence of COVID-19, public debates on the themes of vaccines and vaccination processes became important topics on diverse media and social networking platforms. In this article, our objective was to identify and reflect on the emotions evoked in the Brazilian public with respect to the COVID-19 vaccine during 2020 and 2021 on Facebook. To achieve this, we used the Crowdtangle graphical interface to extract complete copies of posts made by public Facebook profiles during this timeframe, from which a random sample of 1,067 posts was selected for analysis. Identification of emotions was performed using the Human-Machine Interaction Network on Emotion (HUMAINE) descriptors as a baseline reference. Emotions were then grouped into categories following Core Affect Model guidelines. Data analysis and interpretation indicated a prevalence of positive emotions such as trust, interest, and hope directed toward vaccines in the Brazilian domestic scenario. Negative emotions such as worry and disapproval were also expressed, albeit in reference to contextual issues (for example, the spread of COVID-19, delays in vaccine access, and the emergence of new variants) and public figures, such as the President of Brazil.

RESUMEN

Las vacunas son un recurso de salud pública esencial para la contención de enfermedades y la reducción de las tasas de mortalidad asociadas. Con la aparición de la COVID-19, los debates públicos sobre los temas de las vacunas y los procesos de vacunación se convirtieron en temas importantes en diversos medios y plataformas de redes sociales. En este artículo, nuestro objetivo fue identificar y reflexionar sobre las emociones evocadas en el público brasileño con respecto a la vacuna COVID-19 durante 2020 y 2021 en Facebook. Para lograr esto, utilizamos la interfaz gráfica de Crowdtangle para extraer copias completas de las publicaciones realizadas por los perfiles públicos de Facebook durante este período de tiempo, de las cuales se seleccionó para el análisis una muestra aleatoria de 1.067 publicaciones. La identificación de las emociones se realizó utilizando los descriptores de Red de Interacción Hombre-Máquina en la Emoción (Human-Machine Interaction Network on Emotion, HUMAINE) como referencia. Luego, las emociones se agruparon en categorías siguiendo el Modelo de Afecto Central (Core Affect Model). El análisis y la interpretación de los datos indicaron una prevalencia de emociones positivas relacionadas a las vacunas, como confianza, interés y esperanza, en el escenario doméstico brasileño. También se expresaron emociones negativas como preocupación y desaprobación, aunque en referencia a cuestiones contextuales (por ejemplo, la propagación de COVID-19, retrasos en el acceso a la vacuna y la aparición de nuevas variantes) y figuras públicas, como el presidente de Brasil.

KEYWORDS | PALABRAS CLAVE

Vaccine, vaccination, emotions, social networks, Facebook, Brazil.
Vacuna, vacunación, emociones, redes sociales, Facebook, Brasil.

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1. Introduction and state of the art

Vaccines were demonstrated to be an essential public health resource during the COVID-19 pandemic in terms of disease containment and mortality rate reduction. Developed rapidly and garnering high expectations from the public (Bok et al., 2021), the first COVID-19 vaccine – developed by Pfizer/BioNTec – was approved globally by the World Health Organization (WHO) in December 2020 for emergency use[1].

In Brazil, the National Health Regulatory Agency ("Agência Nacional de Vigilância Sanitária") (Anvisa) first approved the Astrazeneca (as part of an accord between Oxford University and the Brazilian Oswaldo Cruz Foundation) and Coronavac (developed by Sinovac in collaboration with the Butantan Institute) vaccines for domestic use on January 17th, 2021[2]. Shortly thereafter, nurse Mônica Calazans became the first Brazilian to be vaccinated with Coronavac, a moment that was widely covered by the media and generated copious amounts of content on social networks that revealed the public's interests, perceptions, sentiments, and emotions regarding the vaccine's approval and the beginning of the COVID-19 vaccination process in Brazil.

Based in this context, in this article we aim to identify and reflect on the feelings and emotions shared by the Brazilian public regarding vaccines during 2020 and 2021, a period in which the theme received extensive attention in the public sphere, which in turn generated expectations and interest. To achieve this aim, 1,067 posts made by public Facebook profiles were selected for analysis using the Crowdtangle graphical interface.

Though often left unexplored, emotions have been indicated by numerous studies as important to the understanding of historical and social events (Ahmed, 2014; Potkay, 2007), being described as constitutive elements of motivations, perceptions, and both collective and individual attitudes. As such, the study of the emotions evoked by the COVID-19 vaccine and related vaccination processes, specifically on Facebook, can be considered a productive strategy in the analysis of how this public health resource is seen and evaluated by the public.

According to a study by Avaaz (a network focused on global social mobilization) and the Brazilian Immunization Society ("Sociedade Brasileira de Imunizações") (SBIm) (2019), networks such as Facebook play important roles as spaces for debate and sources of information on vaccines. Orr et al. (2016) and Oliveira et al. (2020) corroborate this assertion, demonstrating that Facebook has indeed been used as a tool for the search for and sharing of health-related content.

In Brazil, this usage and the potential it represents are accentuated, as the Brazilian population, 77% of which has internet access, represents the sixth most intense user of social networks worldwide according to a report by We Are Social (2022). Searches for information are highlighted as one of the most important use cases for Facebook, which is one of the most popular social networks in the country, in this same report.

Understanding discussions about the COVID-19 vaccine and related vaccination processes on Facebook, from the perspective of the analysis of and reflections on the emotions they evoke, can, in turn, be considered paramount to the understanding of how the public perceives one of global society's key tools for the containment and eradication of diseases, especially in a context of growing reluctance to vaccinate on a global level (Kennedy, 2020) and the circulation of anti-vaccine discourse (Costa & Silva, 2022).

1.1. Vaccines, emotions, and social networks

Vaccine development and mass vaccination processes are society's principal means of prevention, control, and, in some cases, eradication of diseases, thereby reducing their morbidity and mortality (Kennedy, 2020).

In recent years, however, there has been a reduction in the number of vaccinations administered worldwide. This has provoked a resurgence of outbreaks of diseases that were previously considered to have been eradicated, sounding an alarm that must be answered by public policy (Dubé et al., 2015). Brazil, which makes WHO-recommended vaccines available free of charge to the public, has historically enjoyed high vaccination rates, though rates have recently been dropping. According to DataSus, Brazil's

2021 overall vaccination rate was 59.8%, lower than in 2020 (67.2%) and 2019 (73.4%)[3]. There are numerous potential explanations for this reduction, including lack of access to vaccinations or even the pandemic itself, which destabilized numerous public services[4]. Aside from these factors, researchers have also indicated vaccine reluctance as a contributing phenomenon (Nobre & Guerra, 2021; Milani & Busato, 2021). The global scenario was also already concerning before the pandemic, with the WHO naming vaccine reluctance as one of the top ten threats to global health in 2019 (World Health Organization, 2019).

Investigation of the public's attitudes toward, and perceptions of, vaccines on social networks allows for an impactful understanding to be built regarding certain groups' approaches and stances on the issue, as well as extant focal points of disinformation and anti-vaccine narratives (Massarani et al., 2021). Such investigation also allows for an understanding of the emotions evoked by public Facebook pages on the subject of vaccines to be built, taking into consideration the fact that social networking sites are interactive spaces that incentivize and galvanize the expression of sentiments and emotions (Serrano-Puche, 2016; Papacharissi, 2014). Despite recognition of this fact, the study of emotions as a technical discipline remains underdeveloped in some aspects, be it due to difficulties in defining and measuring emotions or to conflicting theoretical approaches.

In general terms, there are three principal standpoints in the study of emotions (Clarke et al., 2006; Rezende & Coelho, 2010). The first of these considers emotions as biological elements innate to their subjects, which therefore possess universal expression. The second strand, in contrast, understands emotions as historical, social, and cultural constructions, derived from social relations rather than "human nature", with the ability to vary according to time and place. The third perspective, adopted in this study, promotes the integration of the previous two, understanding emotions as being derived as much from natural elements as they are from social, cultural, and historical ones.

Calhoun (2008) aligns with this perspective, stating that emotions mustn't be viewed as irrational reactions, but rather as categories that can shed light on certain events. Ahmed (2014) reinforces this argument by stating that emotions can reveal motivations, customs, and predispositions, as well as power relations, going so far as to characterize them as a reflection of zeitgeist.

Some studies have adopted this position in their investigation of the issue of emotion on social networks, with the aim of understanding the behavior and opinions of certain groups. One of the strategies employed in such endeavors is sentiment and emotion analysis (Benevenuto et al., 2015; Gonçalves et al., 2013), which integrates language processing and analysis in order to determine the emotional content present in a specific excerpt of text with the objective of identifying its polarity or valence (positive or negative), excitation (level of activation or deactivation), and the emotions it represents through standardized descriptions.

Some studies performed specifically on social media content produced on the subject of vaccines and vaccination processes have demonstrated the importance of analyzing feelings and emotions. When analyzing discourse related to COVID-19 vaccines on Twitter during the rollout of vaccinations in the USA, for example, Monselise et al. (2021) demonstrated the utility of evaluating public sentiment on vaccines through the way in which they are represented on social networks, applying their results in the formulation of public health policy. Chou and Budenz (2020) in turn suggest that, once identified, negative emotions such as fear and anger may come to provide explanations for vaccine reluctance, creating opportunities for the implementation of communication strategies with the potential to neutralize negative emotions and promote other, positive emotions to counteract them.

Greyling and Rossouw (2022), analyzing data concerning information about vaccines posted on Twitter in 10 different countries, observed that posts containing positive information regarding their safety and efficacy tended to amplify other positive attitudes and sentiments on the subject, demonstrating the degree to which sentiments and emotions can be important factors in the influencing of decision-making processes. Hu et al. (2021) present similar results, though they also indicate the complexity and diversity of emotions that can be associated with vaccines and vaccination, including how critical events can impact and shape public opinion on vaccines. In Brazil, despite wide circulation of vaccine-related content on social networks, studies about the emotions evoked by this content are still incipient, especially with

regard to Facebook. Among the studies carried out in the Brazilian context, the following themes can be observed: analysis of emotions and sentiments evoked during the COVID-19 pandemic using Twitter posts (Gonçalves et al., 2022), and investigations into the sentiments and emotions around vaccines, also on Twitter, in distinct temporal slices, such as during the vaccine approval process in Brazil (Penteado et al., 2021), the first few months of vaccinations in the country (Rodas et al., 2022), and specific months of 2022 (Obeica & Martins, 2022). It is noteworthy that, overall, there is a scarcity of analysis of platforms other than Twitter and longitudinal studies; the use of a wider temporal scope and an increase in the number of networks included in data sets would allow for research done on the relationship between vaccines and emotions to contribute more effectively to knowledge of how the Brazilian public processes information relevant to this theme.

2. Materials and methods

2.1. Data collection

Data for this study was extracted using the Crowdtangle graphical interface system on January 3rd, 2022, using the search terms "vaccine", "vaccines", "vaccinate", "vaccinated", "vaccinates", "vaccination", "coronavac", "pfizer", "janssen" and "astrazeneca" for posts on public Facebook pages made between January 1st, 2020, and December 31st, 2021, returning a total of 2,965,376 results.

In order to identify the emotions expressed by the Brazilian public on Facebook in such a large quantity of collected publications in light of the challenges inherent in their analysis, a simple random sample was chosen with a 95% confidence interval and 3% margin of error using the sample n () function, an element of the dplyr package in the programming and statistical analysis language R. As a result, the final data set for this study was composed of 1,067 posts, an adequate sample size for a simultaneously representative and qualitative analysis.

The choice to randomly select posts for analysis was made due to the size and diversity of the dataset, as well as to avoid limiting analysis to the most liked, commented, and shared posts, as would have been the case if selection by order of engagement were employed, and which could potentially be biased towards highly emotionally charged text according to algorithmic criteria for content circulation on the platform (Berger & Milkman, 2012).

2.2. Identification and classification of emotions

After data collection and processing, the posts were interpreted and categorized in order to determine their emotional content. Those void of emotional content were classified as "no emotions expressed", a category corresponding to informational content and other types of content without explicit emotional affect (Penteado et al., 2021). Posts that did contain explicit emotions were classified as one of two forms: "emotion expressed and identified", to which the emotional descriptors, which will be described shortly, were applied, or "emotion expressed but not identified" in cases that, despite having detectable emotional content, did not demonstrate enough clarity for classification as any specific emotion.

Of the 1,067 posts, 523 (49%) were classified as "no emotions expressed", 22 (2%) as "emotion expressed but not identified", and 523 (49%) as "emotion expressed and identified". Due to our interest in investigating posts with identifiable emotional content, those classified as "no emotion expressed" or "emotion expressed but not identified" were not analyzed further. As such, the data set for this study consisted of 523 posts.

Numerous systems for the recording and classification of emotions exist in the field of sentiment and emotion analysis, including automated (with the use of tailored software); semi-automated (employing software and manual resources) and manual (performed by researchers without the assistance of automated processes) alternatives (Aman & Szpakowicz, 2007; Siegert et al., 2014; Devillers et al., 2005). Automated and semi-automated systems, though higher in throughput, entail some negative aspects, such as difficulties in identifying emotions in text with grammatical inconsistencies or messages with ambiguous meanings (such as irony or sarcasm), as well as difficulties in recognizing cultural characteristics of some emotions. For this study, we employed a manual recording and classification process, which is recommended for smaller data sets as it reduces the potential for error in interpreting emotions and

promotes an understanding of their meanings based on specific contexts and communication dynamics (Martin et al., 2009).

In order to establish a reliable structure for categorizing the observed emotions, we used the Emotion Annotation and Representation Language (EARL) framework, a list of 48 emotions compiled by the Human-Machine Interaction Network on Emotion (HUMAINE) described in Schröder et al. (2006) and Douglas-Cowie et al. (2007), as a basis. In some cases, affective or emotional expressions other than those included in EARL were encountered during the classification process and were added to the list of descriptors. Following these steps, we listed 56 emotions in total (Table 1).

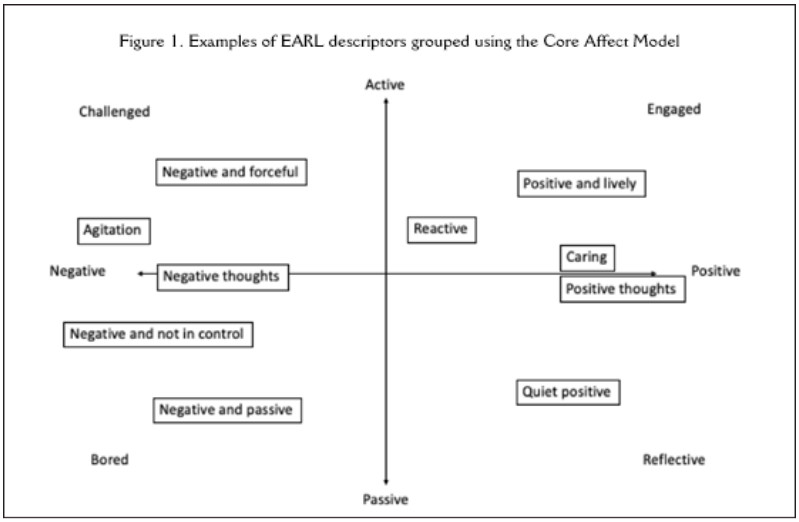
Table 1. List of emotional descriptors adapted from HUMAINE/EARL protocols

Negative and strong	20 - Shame	38 - Happiness
1 - Anger	**Negative and passive**	39 - Joy
2 - Annoyance	21 - Boredom	40 - Pleasure
3 - Contempt	22 - Despair	**Caring**
4 - Disgust	23 - Disappointment	41 - Affection
5 - Irritation	24 - Hurt	42 - Empathy
6 - Impatience	25 - Sadness	43 - Friendliness
7 - Disapproval	**Agitation**	44 - Love
Negative and not in control	26 - Stress	**Positive thoughts**
8 - Anxiety	27 - Shock	45 - Confidence
9 - Embarrassment	28 - Tension	46 - Courage
10 - Fear	**Quiet positive**	47 - Hope
11 - Helplessness	29 - Calmness	48 - Humanity
12 - Powerlessness	30 - Contentment	49 - Satisfaction
13 - Worry	31 - Relaxation	50 - Pride
Negative thoughts	32 - Relief	51 - Trust
14 - Doubt	33 - Serenity	**Reactive**
15 - Perplexity	**Positive and lively**	52 - Interest
16 - Envy	34 - Amusement	53 - Curiosity
17 - Frustration	35 - Delight/Enchantment	54 - Politeness
18 - Guilt	36 - Elation	55 - Surprise
19 - Defensiveness	37 - Excitement	56 - Enthusiasm

Note. Rowe et al. (2023) adapted from HUMAINE and EARL.

Emotional descriptors were then grouped into larger categories adapted from Russell (2003)'s Core Affect Model, as described in Rowe et al. (2023). This model classifies emotions based on excitation and valence: two bipolar, independent dimensions.

Figure 1. Examples of EARL descriptors grouped using the Core Affect Model



Note. Adapted from Rowe et al. (2023).

The analysis of valence includes positive (agreeable) or negative (disagreeable) sensations experienced and excitation refers to the level of emotional activation, varying from excited (active) to calm (passive) (Russell, 2003, 2009). After categorization, we observed that emotions were frequently directed towards aspects only tangentially related to the vaccine or vaccination, such as relevant decisions taken (or not

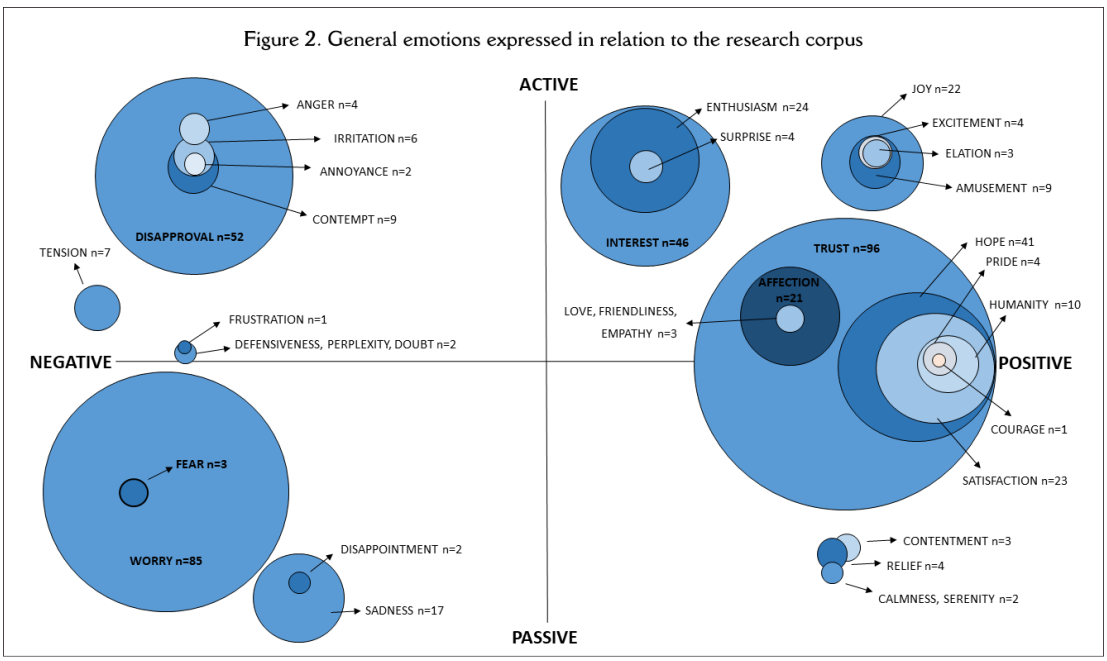
taken) by public officials. Consequently, we identified and listed the objects of each expressed emotion in order to understand which topics were most associated with the broader theme of vaccines.

3. Analysis and findings

Thirty-five distinct emotions were identified in this study's dataset, demonstrating the wide range of emotions with distinct triggers, perspectives, and expressions that vaccines and vaccination evoke. Grouping these emotions based on the Core Affect Model (Russell, 2003, 2009), we registered 142 occurrences of high excitation, positive valence emotions. High excitation, negative valence descriptors were assigned 87 times.

Among passive descriptors, 107 were negative valence and 187 were positive valence. The most frequently identified emotion was trust (18.4%), followed by worry (16.3%), disapproval (10%), interest (8.8%), hope (7.9%). enthusiasm (4.6%), satisfaction (4.4%), joy (4.2%), affection (4%) and sadness (3.3%). Other emotions were identified at lower levels of prevalence.

Figure 2. General emotions expressed in relation to the research corpus



Note. Authors' compilation. Circle size corresponds to the total number of appearances of the corresponding emotion in the dataset.

Among the positive valence emotions identified in the posts, trust (n=96) was associated with messages in which the vaccine and the vaccination process were well-received, demonstrating an association with information regarding safety and efficacy of vaccines as their principal characteristic. Interest (n=46), hope (n=41), enthusiasm (n=24), satisfaction (n=23), joy (n=22) and affection (n=21) were also expressed in reference to the vaccine, seen as an important step towards the end of the pandemic.

Among negative valence emotions, worry (n=85), disapproval (n=52) and sadness (n=17) were most prevalent. It is noteworthy that posts containing these emotions, in general, did not refer to the vaccine itself. Worry, for example, was commonly directed towards the spread of COVID-19 (n=32), new variants (n=14), delays in vaccine purchasing and administration (n=10), and insufficient amounts of vaccine (n=2).

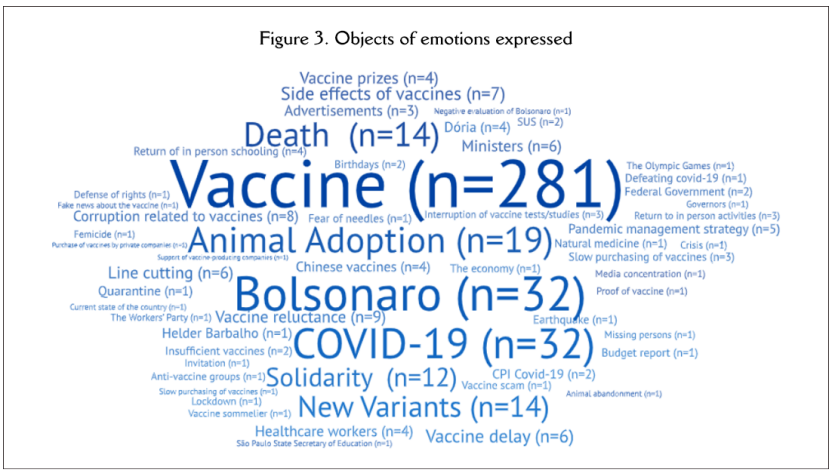
Disapproval, in turn, was directed towards the actions and speech of public figures, such as President Jair Bolsonaro (n=32), cases of corruption related to the vaccination process (n=8) and the actions of several ministers (n=6).

Other negative emotions were also directed towards the president and/or his actions, such as irritation (n=6), anger (n=4), and annoyance (n=2). Sadness was identified in posts citing deaths (n=14) caused by the absence of vaccines as a form of COVID-19 prevention.

Table 2. Representative posts of prevalent emotions (our bolding)	
Trust	Vaccines are, **without a shadow of a doubt**, a step forward for medicine and for humanity. Through vaccines, there is control and prevention of epidemics. Immunization is fundamental to quality of life, so protect yourself always. **Vaccines are safe**, get vaccinated! [5]. For three centuries, **vaccines have saved lives!** Throughout history, immunizations have contributed to the eradication and control of epidemics. Be an ethical professional and incentivize vaccination. Please run from the fake news.
Interest	Drivers **demand** covid-19 vaccines and salary adjustments. **Vaccinate now**, especially if you haven't stopped working during the pandemic. #vaccinatenow #sus[6] #maskup #pandemic #health
Hope	Through August 10th, 6,631 people have taken one dose of the vaccine, 2,772 people have taken two and 300 people have received the single dose vaccine #arautojournalism #arautoonline #immunization a breath and **expectation of better days. It is what is to be expected with the expansion of vaccination** in Sun Valley. During the week that marked the beginning of vaccinations for those 18 and over, another important moment was celebrated in the town: the slowing down of the pandemic in Sun Valley. Happy 2021 to all! **I hope that it will be the year of the vaccine**, of agglomerations and the fall of a certain president!!
Worry	Scientists **are not totally confident** that the covid-19 vaccines will work against the variant of the virus found in South Africa. Matt Hancock, Minister of Health in the United Kingdom, says that the mutation identified in South Africa is a "**very, very significant problem**". **Brazil continues in last place!** While the world advances its efforts to exterminate the Coronavirus, Brazil doesn't even appear on the vaccine map. **We are the caboose**, literally. And this "game" cannot be lost, **lives are at stake!** #coronavirus #vaccine #Brazil.
Disapproval	#thepeople the anchor is **indignant** with the country's current situation, and laments that the ex-husband and father of Sasha Meneghel wasn't afforded the opportunity to take the Covid-19 vaccine. **Xuxa blames the government** for their refusal to purchase doses when offered them. **While Brazilians suffer due to the lack of vaccines**, due to the economic crisis that has increased the numbers of the unemployed and the hungry, **Bolsonaro has decided to decree himself a Carnaval holiday.**
Irritation	In the worst moment of a pandemic, **what does a genocidal president do?** Just this! Criticize the only thing that can save lives in a country that hasn't even vaccinated 2% of its population.
Sadness	"The dreamed of vaccine that **my friend wasn't able to take**. But I carry him in my heart," said the comedian. #news106.

Among the expressed and identified emotions (Figure 2), 62.1% (n=325) had positive valence, while 37.9% (n=198) showed negative valence. The most frequent objects of these emotions demonstrate the vaccine's role as a central theme (n=281, 53.7%). The vaccine was associated with positive emotions such as trust, interest, and hope. Topics related to Bolsonaro and COVID-19 (both at n=32 or 6.1% each) appeared next most prevalently, the first being related to emotions such as disapproval, irritation, and anger, and the second to worry. Animal adoption[7] was the next most prevalent object of emotional expression (n=19 or 3.6%), and was associated with affection. Aside from these themes, deaths and new variants (n=14 or 2.7% each) appear as objects associated with sadness and worry, respectively. Other objects identified in smaller quantities of posts are expressed in Figure 3.

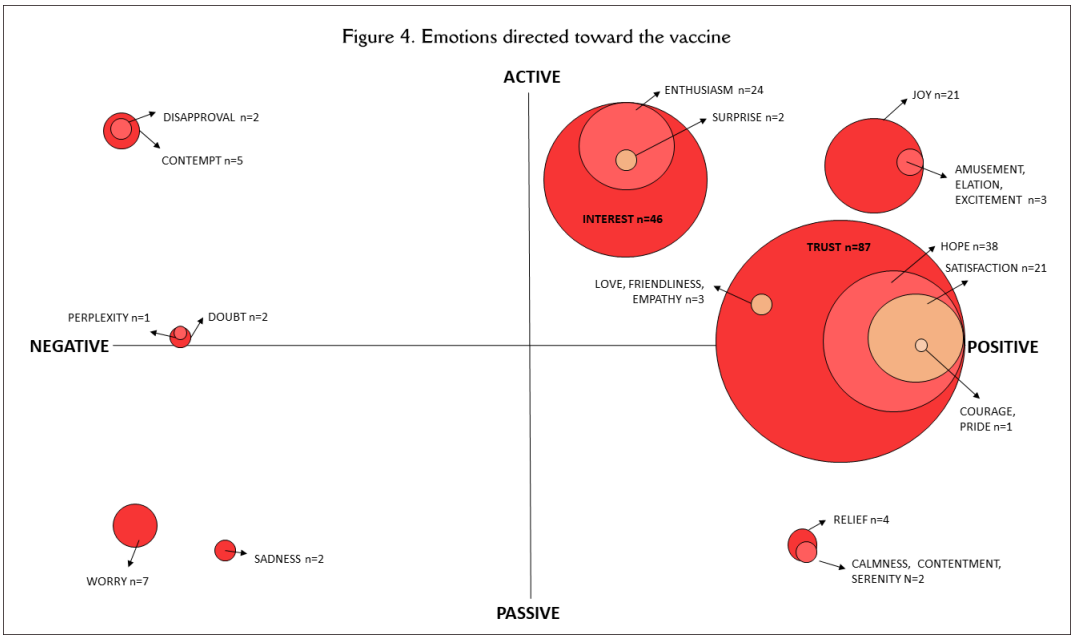
Figure 3. Objects of emotions expressed



Note. Authors' compilation. The size of each word corresponds to its total number of appearances in the data set[8].

In cases of emotion directed toward the vaccine, positive emotions were displayed in 93.1% (n=256) of posts and negative emotions in 6.9% (n=19). The most commonly expressed emotions in these cases, aside from trust (n=87; 30.9%), interest (n=46; 16.3%) and hope (n=38; 13.5%) as previously mentioned, were joy (n=21; 7.4%) and enthusiasm (n=21; 7.4%).

Figure 4. Emotions directed toward the vaccine



In the negative quadrants, worry (n=7; 2.5%), disdain (n=5; 1.8%) and disapproval (n=2; 0.7%), followed by doubt (n=2; 0.7%), sadness (n=2; 0.7%) and perplexity (n=1; 0.4%) can be observed. These emotions correspond to a smaller proportion of the results than the positive emotions.

4. Discussion and conclusions

Social networks have emerged as important spaces for the expression of ideas, stances, and attitudes by different groups on the most diverse subjects (Santos & Cypriano, 2014). They are also seen as channels through which a large variety of emotions transit (Serrano-Puche, 2016; Papacharissi, 2014). Our analysis of Facebook posts discussing the vaccine during 2020 and 2021 and their associated emotions revealed trust to be the most prevalent emotion. Despite worry being the second most frequently observed emotion by a small percentage difference, and disapproval holding third place, trust was directed specifically towards the vaccine and vaccination, whereas the negative emotions were directed towards contextual situations in the country, including difficulties in accessing the vaccine.

This result indicates broad acceptance of the vaccine among Facebook users in Brazil, considering the sample of this study, corroborating studies on perceptions of vaccines performed prior to the pandemic (Gallup, 2019). The presence of such elements as the safety, efficacy, and positive effects of vaccines have been noted as factors that may have contributed to the production of trust in public communications, seeing as they reinforce the positive bias surrounding vaccines. These points support an understanding of the vaccine as a strategy for overcoming the pandemic, as well as a form of avoiding spreading the disease and unnecessary deaths, in light of the recurrence of trust in posts that considered the vaccine as positive while simultaneously distancing themselves from possible doubts (Figure 2). Messages addressing the vaccine with a positive bias tend to engender positive public perceptions and discussions of the vaccine (Kwok et al., 2021), while messages that question its efficacy may contribute to anti-vaccine stances (Greyling & Rossouw, 2022).

Hu et al. (2021) also found trust to be the predominant emotion in their study of Twitter posts made before and after the approval of the vaccine in the USA. According to the authors, trust and other positive

emotions gained visibility during the onset of vaccination, outcompeting negative emotions such as sadness, anger, and disgust. This same dynamic was observed by Rahmanti et al. (2022) in their observation that positive emotions such as trust outweighed negative ones during the beginning of vaccinations in Indonesia, understood by the authors as a consequence of effective public communication strategies enacted by the government regarding the vaccine's safety. Similarly, trust was the most frequently observed emotion in a study performed on discussions of the vaccine on social networks in Australia (Kwok et al., 2021). These results can be used as references for the understanding of debates on vaccines as well as public responses to vaccines on social networks.

Positive bias, articulated through emotions such as hope, joy, interest, satisfaction, and enthusiasm, was the most frequently observed stance (62.1%) for posts addressing the vaccine and vaccination processes in this study. We reiterate that the majority of negative valence emotions identified (37.9%) were not directed principally toward the vaccine. Worry, for example, was mainly directed toward the spread of COVID-19, disputes regarding vaccine approval, purchases of vaccines and implementation of the vaccination process, and the emergence of new variants.

The emergence of new variants, in particular, was viewed as a risk to efforts to control the pandemic and a threat to the vaccination process. Negative emotions associated with this theme were also identified in other studies (Greyling & Rossouw, 2022; Mahyoob et al., 2022). Questions regarding eventual side effects of the vaccines, in turn, was one of the only topics directly related to the vaccine that was identified among instances of worry, though it represented a small proportion of the data set (only 1.3% in total).

Disapproval was also not typically directed towards the vaccine; it was most commonly directed toward the speech and actions of public figures such as President Jair Bolsonaro, who repeatedly vocalized his anti-vaccine stance[9]. Events such as these, in which public officials placed themselves in opposition to the development and administration of public health resources such as the vaccine, have the potential to impact discussion on vaccines, as well as the emotions evoked by the public in their evaluation of and decisions based on such information (Hu et al., 2021). Other emotions that were expressed and identified in this study were also directed toward the Brazilian president, his ministers, and their actions, specifically anger, irritation, and annoyance. This demonstrates that, while the vaccine was described positively in the majority of posts, the president, his team, and their actions were seen as hindrances to the success of the vaccination process in Brazil.

The results indicate that the vaccine evoked a wide array of emotions with different valences and levels of excitation, demonstrating what a sensitive and recurring theme it was in public debate. Among the emotions identified, those of positive valence, such as trust, interest, and hope, occurred most frequently, especially when directed specifically towards the vaccine. Negative valence emotions, such as worry and disapproval, were focused on contextual themes and issues, such as the spread of COVID-19, difficulty in accessing the vaccine, new variants, and President Bolsonaro himself.

Though fewer in number, these negative emotions should be interpreted as challenges to the recognition of the vaccine as an effective strategy for combatting the pandemic, especially in a scenario in which public figures propound anti-vaccine stances (Duarte, 2020). In this sense, the identification of distinct themes in discourse on the COVID-19 vaccine and vaccination process, as well as the emotions evoked in these instances, is shown to be an important tool for the development of tactics and strategies that aim to reinforce public trust in vaccines and increase vaccination rates.

The results obtained in this study regarding the identification of emotions related to the vaccine expand on the findings of previous studies performed in other contexts and social networks (Monselise et al., 2021; Greyling & Rossouw, 2022; Hu et al., 2021; Penteado et al., 2021), contributing to reflections on the theme, especially in the Brazilian context. It is important to highlight that this study's results, however, refer to a bounded data set which possesses both limitations and potentialities. Its limitations include the fact that the data set is representative of a specific social network, as well as the fact that it does not address the entire data set on vaccines or groups that do not have internet access. Its potentialities include the ability to shed light on an issue that, as of yet, has been little explored in Brazil, contributing as such to interpretations regarding the perceptions of a subset of the Brazilian public on Facebook regarding the COVID-19 vaccine, identifying emotions evoked, their valences, and their principal objects.

Given these aspects, taking into consideration the cut applied, as well as the diversity of publications and extant platforms, it is evident that further investigations into other time periods, post types, and social networks are necessary in order to elucidate the relevant dynamics involved, identify similarities and differences between them, and, in summary, understand the perceptions and emotions of different groups regarding the COVID-19 vaccine and vaccination processes in Brazil.

Notes

[1]WHO issues its first emergency use validation for a COVID-19 vaccine and emphasizes need for equitable global access (https://bit.ly/3Sp3iLS).

[2]Anvisa approves emergency use of first coronavirus vaccines in Brazil (https://bit.ly/3EjToap).

[3]Data from the Unified Health System Informatics Department (DataSus), an Agency of the Secretary of Strategic and Participative Management at the Ministry of Health. (https://bit.ly/3BFuJu7).

[4]Essential health services confront constant disruptions during the COVID-19 pandemic (https://bit.ly/3LBW9FM).

[5]Despite the fact that the posts in question were posted publicly, we have chosen not to identify their authors as an ethical consideration.

[6]Translator's note: SUS is an acronym for the "Sistema Único de Saúde" (Unified Health System), Brazil's public health system.

[7]As the search terms did not exclusively define the vaccine as a human health resource, some selected posts in the study's data set were on the topic of animal vaccination and adoption. In these cases, vaccines were seen as a signal of responsibility, care, and affection towards the animals.

[8]Translator's note: João Dória (n=4) was the governor of São Paulo at the time of the posts. The COVID-19 Parliamentary Commission of Inquiry (Comissão Parlamentar de Inquérito) (CPI, n=2), in turn, was convened by the Brazilian Federal Senate from April 27th to October 26th, 2021, for the purpose of investigating alleged omissions and irregularities in the activities of Jair Bolsonaro's federal government during the COVID-19 pandemic in Brazil.

[9]http://glo.bo/3C2iN79.

Authors' Contribution

Idea, L.M.; Literature review (state of the art), G.F.O., L.M., G.S., T.O.; Methodology, L.M., G.S.; Data analysis, G.F.O., L.M., T.O., G.S., M.A.S.J.; Results, G.F.O.; Discussion and conclusions, G.F.O., L.M., T.O., G.S., M.A.S.J.; Writing (original draft), G.F.O., L.M.; Final revisions, G.F.O., L.M., T.O., G.S., M.A.S.J.; Project design and sponsorship, L.M.

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