Comunicar, n. 76, v. XXXI, 2023 | Media Education Research Journal | ISSN: 1134-3478; e-ISSN: 1988-3478
www.comunicarjournal.com

Application of neurotechnology in students with ADHD: An umbrella review

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

Dr. Antonio-R. Hidalgo-Muñoz. Associate Professor, Department of Basic Psychology, Psychobiology and Methodology of Behavioural Sciences, University of Salamanca (Spain) (arhifdalgom@usal.es) (https://orcid.org/0000-0002-0457-5114)
Dr. Daniel Acle-Vicente. Assistant Professor, Department of Sociology and Communication, University of Salamanca (Spain) (dav@usal.es) (https://orcid.org/0000-0003-3852-2384)
Alejandro García-Pérez. PhD Candidate, Department of Sociology and Communication, University of Salamanca (Spain) (alejandrogp@usal.es) (https://orcid.org/0009-0004-6753-7870)
Dr. Carmen Tabernero-Urbieta. Full Professor, Department of Social Psychology and Anthropology, University of Salamanca (Spain) (carmen.tabernero@usal.es) (https://orcid.org/0000-0003-4338-7367)

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.

Received: 2022-12-26 | Reviewed: 2023-02-02 | Accepted: 2023-02-23 | OnlineFirst: 2023-05-30 | Published: 2023-07-01
DOI https://doi.org/10.3916/C76-2023-05 | Pages: 59-69

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

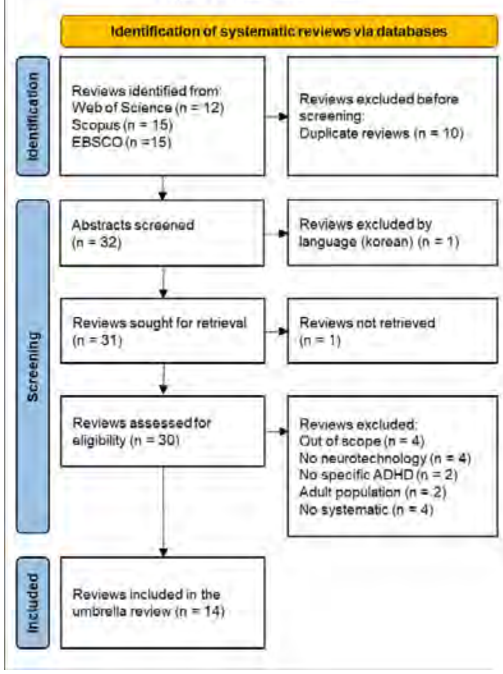
To carry out the present review, we followed the PRISMA (2020) recommendations for conducting systematic reviews (Page et al., 2021), as well as the method proposed by Smith et al. (2011) for the specific case of systematic reviews of existing systematic reviews, also known as umbrella reviews. The search 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.

Figure 1. PRISMA flowchart



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.

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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.

Funding Agency

Recognized Research Groups of the University of Salamanca (GIR-PROMOSALUD and GIR-NAES); Consolidated Research Unit of the Junta de Castilla y León (UIC-249); Research Project (Ref TED2021-130924B-I00) funded by the Ministry of Science and Innovation, Government of Spain.

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