Neuroeducation, Classroom Interventions and Reading Comprehension: A Systematic Review of the 2010-2022 Literature

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Abstract

Reading comprehension is the cornerstone of human development, and consequently a fundamental and indispensable tool for communication and social interaction. In recent years, the field of reading comprehension research has been tightly connected with educational neuroscience, which has produced a growing number of interventions aimed at turning theoretical ideas of neuroeducation into practical efforts applicable to the classroom. The aim of the present systematic review was to analyze the state of neuroeducational research, to identify the main characteristics of the interventions developed, and to propose suggestions on the main findings that contribute to neuroeducation research on reading comprehension. Based on the guidelines of the PRISMA method, an exhaustive search was carried out in high impact databases. The selection process yielded 13 eligible studies and they were analyzed in terms of, for instance, theoretical focus, context and participants, and main findings. Results show that these studies most frequently addressed the emotional principle of self-regulation, the importance of the social principle of neuroeducation and its impact on the development of reading comprehension skills through activity breaks, holistic environment and physical exercise, and sensory cognitive development of attention and memory skills. Despite the homogeneity of the interventions presented in these studies, they showed significant effects on reading development, displaying higher research development concerning emotional and social aspects. The present study discusses the contributions of neuroeducational classroom interventions towards the development of reading comprehension skills, offering practical recommendations for teachers.

Keywords: reading literacy, educational neuroscience, neuroeducation, reading comprehension, neuroeducation intervention

1. Introduction

One of the main objectives of basic education is to ensure that students acquire sufficient skills and strategies to be competent in their schoolwork and in their everyday life more broadly (Santiago et al., 2007), which makes the teaching and learning of reading comprehension one of the greatest challenges of the first educational stages (Wise et al., 2016; Vital et al., 2020). Reading is an extraordinary and fundamental tool for intellectual work and should be promoted from early ages because it facilitates the development of fundamental skills (such as observing, defining, characterizing, comparing, analyzing, arguing, interpreting and discussing, among others), which becomes useful through all stages of life. Highlighting the importance of learning reading comprehension strategies as key to school success, reading is defined as a higher order mental process, which involves extracting and constructing meaning from a text through a process that requires skills and strategies that depend on levels of motivation and attention (Figueroa & Tobías, 2018). The reading process involves mastering several neurocognitive skills, such as prior knowledge, vocabulary, fluency, cognitive skills and critical thinking, so reading comprehension is a multidimensional skill and it is present throughout the arc of human development (Fonseca et al., 2019; Martínez-González et al., 2018). Thus, mastering these neurocognitive abilities is an inherent need of human beings and is recognized as a prerequisite for meaningful learning (Fonseca et al., 2019; Mora, 2013) and, consequently, it is necessary to broaden our knowledge of the factors that contribute to the development of this skill (Tegmark et al., 2022).

In this light, Álvarez et al. (2021) discuss the role of emotions and social phenomena in the development of reading comprehension skills, which has an impact on the intrinsic components underlying this process. In this sense, recent studies highlight the need to deepen the knowledge and the way emotions are approached in reading comprehension, because this is an important aspect of the learning process, since it determines students' attitude and motivations for learning. The emotions originating in the classroom are related to the assessments that students make about the control they have over the outcome of the task, as well as the value they give to the task, which, in turn, affects the way students learn (Rossi et al., 2015).

Moreover, recent interdisciplinary research on reading comprehension presents the link between neuroscience and education as a contribution to the reading process because it offers the possibility of integrating brain, social, cognitive and cultural perspectives into a beneficial way of teaching reading comprehension (Hruby, 2012; Compton-Lilly et al., 2020). It also recognizes the importance of emotion as fundamentally linked to cognition, since a myriad of studies show that this dyad contributes to the development of reading comprehension processes (Dehaene, 2020; Nasir et al., 2021). For example, Andreola et al. (2021) and their team point out that reading and the related neurocognitive components are involved in dynamic processes that are developed throughout the entire school stage, and, thus, they require the integration of multiple cognitive systems. It is essential then that educators become aware of the deep relationship that exists between affectivity, cognition and reading, which is connected to one's performance in society and a sense of personal reward that occurs at the cognitive level, for achieving optimal learning outcomes (Immordino-Yang & Damasio, 2007).

In addition, several studies identify the genetic and epigenetic influences involved in reading comprehension skills, which require affective and cognitive support, such as motivation, attention, memory, and self-regulation for their development. Such studies support the need to enhance these skills through mediated teaching that adopts these principles in the classroom (Li et al., 2018; Milicic et al., 2020; Xia et al., 2022). In this regard, the Organization for Economic Cooperation and Development (henceforth, OECD) supports this claim explaining that for today's society it is a requirement to master reading processes, prompting teachers to integrate pedagogical practices grounded on scientific evidence, through a dialogical interaction among the disciplines that impact education, through the development of specificities that give theoretical consistency to the teaching praxis (OECD, 2017).

Given the complexity of reading, studies have emphasized the need to strengthen the links between neuroscience and education, with the aim of promoting strategies based on empirical scientific research, yet contextually situated to highlight the specific affective and cognitive processes required for developing reading comprehension skills (Domínguez Márquez, 2019; Sánchez, 2018; Figueroa & Tobías, 2018). Scholarly efforts to strengthen the links between neuroscience and education have resulted in what today is known as the field of neuroeducation, which is a science that is interested in the application of neuroscientific research into educational practice, with the aim of improving teaching practices based on empirical evidence (Dekker et al., 2012). Neuroeducation takes the verifying aspects provided by research in the natural sciences, including knowledge on neuronal plasticity, executive functions, brain modifications, homeostasis and the emotional system as fundamental topics, and articulates them with the social sciences in a generative way, reformulating their application in the classroom. This discipline interprets these fundamental topics in terms of human potential, motivation, metacognition, bodily systems and social environment in educational contexts that help to conceive new pedagogical concepts for the classroom (Cumpa Valencia, 2020; Dubinsky et al., 2019).

Neuroeducational research indicates that teaching actions should enhance cognitive skills such as attention, self-regulation and memory, among others, through educational practices that are meaningful, identifying the influence of neuroeducational stimulation in the initial, trajectory and final state of learning (Yusmaliana et al., 2020). Several neuroeducational researches conclude that the application of neuroscience to pedagogical process contributes to the development of cognitive skills in students (Azeka et al., 2020; Muchiut et al., 2021; Prado, 2020). These investigations also provide empirical evidence on the impact of situated inquiry on classroom climate with the purpose of promoting students' and teachers' critical views on the teaching-learning process, because the more educators understand the relationship between emotion and cognition, the better they will be able to design meaningful and productive learning environments for their students (Elouafi et al., 2021; Tapia & Arias, 2021).

In this way, neuroeducation articulates interdisciplinary research developed in the areas of cognitive neuroscience, cognitive psychology and education to bridge the gap between science and teaching practices in terms of the connections between cognitive, social and emotional development (Edelenbosch et al., 2015; Hermida et al., 2016; Ayvaz et al., 2017; Martínez-González et al., 2018; Hobbiss et al., 2019; Rahman & Woollard, 2019; Tan & Amiel, 2019). Studies in the field discuss teachers' motivations to know the contributions that neuroscience can make to

education, because this information would allow them to identify the affective and cognitive aspects that are at the basis of their students' learning, which sparks an interest that "can be understood due to the daily challenges faced by teachers in the classroom" (Ferreira Campos & Gómez Álvarez, 2019, p. 50). In this regard, for Grospietsch and Mayer (2019), it is irrefutable that the knowledge provided by neuroeducation about the processes needed to achieve effective teaching is fundamental for teachers to employ teaching and learning strategies that enable students to perform better in the various educational areas. Thus, both cognitive and affective principles of neuroeducation, as well as their biological and environmental foundations, contribute and are fundamental towards the construction of a comprehensive evidence-based model of education (Malanchini et al., 2020). This is also sustained by Mora (2020) when they explain that "no one is born with a brain genetically designed for reading" and highlight the need for reading literacy and research on the scientific/pedagogical articulation of neuroeducation and the development of reading comprehension skills (p.16).

In this light, although there are a variety of systematic reviews in neuroeducation to date, these investigations have focused on synthesizing the theoretical aspects explored in the field, without carrying out a critical analysis of the practical contributions of this research to teaching (Cumpa Valencia, 2020; Hernández & Camargo, 2017; Martínez-González et al., 2018). The present study aims to narrow this gap by analyzing the research findings in this field and identifying the main contributions of neuroeducational interventions at different academic levels to propose suggestions that contribute to neuroeducation research and teaching practices on reading comprehension. In addition, in view of the fact that during the last few years a large body of research in neuroeducation has been developed, identifying the main contributions that empirical neuroeducational studies have made to educational science allows us to outline future lines of research that are relevant to and applicable by teachers and researchers.

2. Methods

The present study is guided by the methodology proposed by Carl et al. (2022) in order to identify, select and evaluate the findings reported in neuroeducational intervention studies, through the rigorous use of two stages (Figure 1) to promote its replicability (consider Restrepo et al., 2019; Crisol-Moya et al., 2020). The first stage involved an advanced search conducted in English in the electronic databases of Web of Science (WoS) and SCOPUS. The second phase involved an advanced search conducted in Spanish in the electronic database Scielo, which is considered representative of Latin American research. In both cases, the search key was entered (Figure 1), through the advanced option in the title fields, and subsequently, the exploration search was narrowed by filtering the years comprising the 2010-2022 interval. Both searches were limited to the title, abstract and key descriptors of each article. In addition, a search in English was performed in the EBSCO database, but no articles were found that were relevant to the topic of study.

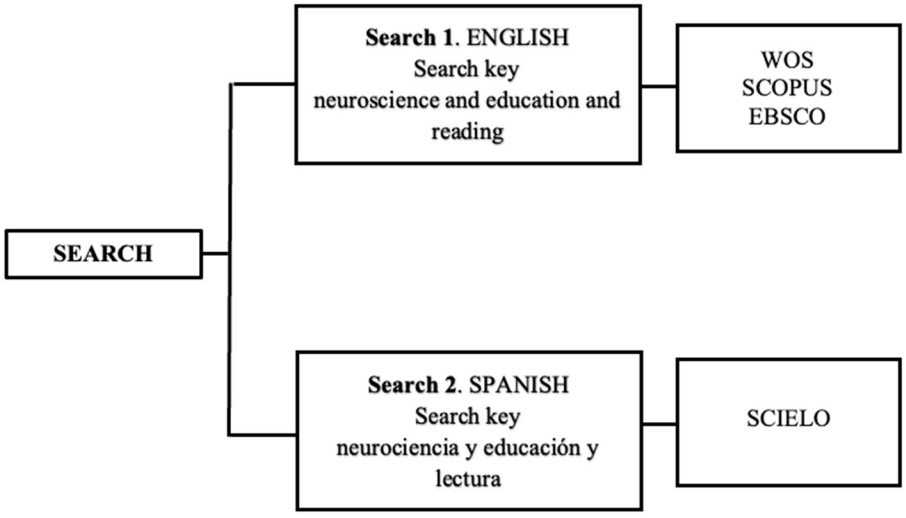

Figure 1. Database Search Stages

2.1 Eligibility Criteria

The selected articles were stored in a specific collection created for this systematic review, classifying them according to their database, which allowed the identification of duplicates. For both stages, articles that met the following criteria were included: (a) the article reported empirical research findings; (b) it involved human participants; (c) the intervention was developed in an educational context; and (d) it focused on reading comprehension skills. In both stages, book reviews, reflective articles, review papers and letters to the editor were excluded.

Regarding the first stage, the search resulted in the identification of 1,022 articles, while phase 2 yielded 11 articles (Figure 2). After a detailed analysis of all the selected articles (reading the title, abstract and key words), a total of 13 research studies that met the inclusion criteria were included in the present review, excluding duplicates and those that did not meet the aforementioned criteria (see results section below).

2.2 Data Extraction and Synthesis

The data extraction task for each article was performed using a template where the information was filtered following the suggestions of Carl et al. (2022) in relation to the following aspects: basic information (e.g., year of publication, author, geographic region), context and participants (e.g., age and school group of participants), intervention characteristics (e.g., intervention description, frequency, design, measurement tests, analysis, intervening variables), and theoretical and/or conceptual foundations (intervention theories or programs), among others. Subsequently, the 13 articles were analyzed and summarized in a descriptive manner (consider Lazzaro-Salazar & Pujol-Cols, 2022) according to the focus of this review.

3. Results and Discussion

Based on the design of the PRISMA diagram, Figure 2 presents the selection process from the initial identification of N=1,033 to the N=13 articles that met the eligibility criteria. The identification and selection diagram of the research analyzed is presented below.

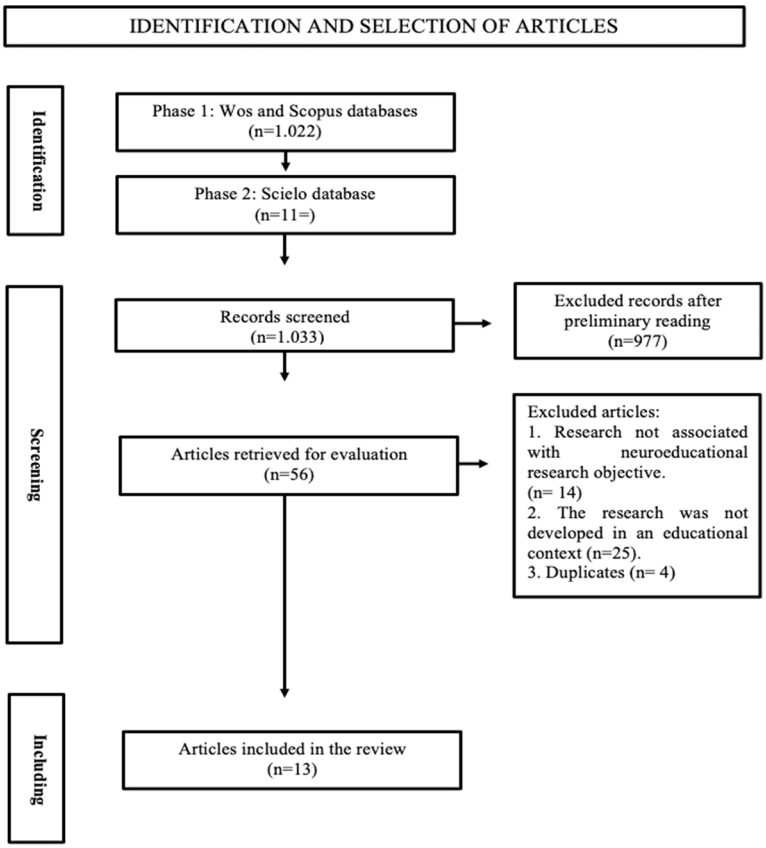

Figure 2. Diagram of Item Identification and Selection (adapted from Urrútia & Bofill, 2010).

Table 1. Summary Description of the Articles Included in the Review

Authors and year	Objetive	Participants and context	Neuroeducational principles explored
Blair & Raver (2014)	To examine executive functions and the regulation of the physiology of attention, emotion, and stress response that supports executive functions and may foster children's educational progress.	29 schools, 79 classrooms and 759 children participated in United States.	Social neuroeducational principle
Bezerra-Mota et al. (2016)	To explore the relationship between the structure of spontaneous memory reports and measures of general intelligence, theory of mind (ToM), and school performance.	The sample consisted of 76 children (40 boys and 36 girls aged 6 to 8 years old). These children belonged to six public schools in Natal, Brazil.	Cognitive neuroeducational principle
Martins & Gotuzo (2017)	To investigate the effectiveness of an EF intervention carried out by teachers in the classroom context.	58 children of six years of age of an elementary school in a public school in São Paulo, Brazil, participated in this study.	Cognitive neuroeducational principle
Soliman & Al-Madani (2017)	To examine the effects of multisensory instruction combined with brain-compatible environmental techniques.	36 fourth grade primary school students from Saudi Arabia participated.	Social neuroeducational principle
Guerra & Mellado (2017)	To implement an adaptive system based on feedback called A-book (assisted reading book).	Participants were 4th, 5th and 6th grade primary school students (aged 9-12 years) (N=90) in Chile.	Social and emotional neuroeducational principle
de Witt et al. (2018)	To provide professionals with the appropriate knowledge and skills to improve early literacy for preschool students.	The sample consisted of 230 students in preschool level in South Africa.	Social neuroeducational principle
Giofré et al. (2018)	To investigate whether verbal WM (working memory) tasks and visuospatial WM tasks are distinguishable and whether the correlations of a particular domain, with WM-V related more to reading and/or mathematics.	The sample of this study included 144 children between 11 and 13 years of age in secondary school in Italy.	Cognitive neuroeducational principle
Potier et al. (2020)	To test ELAN software, a tablet-based game designed to support reading acquisition in the classroom.	The sample consisted of approximately 1,000 French students between 5 and 10 years old.	Cognitive and social neuroeducational principles
Buono et al. (2020)	To examine the relationship between emotions, SRL (self-regulated learning) strategies, and storytelling scores.	The sample consisted of 150 elementary students between the ages of 5 and 10 in France.	Emotional neuroeducational principle
Müller et al. (2021)	To measure the effects of physical activity and mindfulness intervention on children's attention, reading comprehension, and self-esteem.	Study 1 (physical activity): involved 162 4th grade students. Study 2 (mindfulness training): involved 79 5th	Social and cognitive neuroeducational principles

		grade students in Germany.	
Álvarez (2021)	To demonstrate the influence of memory and emotion on reading habits.	The sample consisted of 326 students in their fourth year of higher education at the University of Valladolid, Spain.	Emotional neuroeducational principle
Pegado (2021)	To examine the impact of a brief causal neuroscience-informed intervention using targeted training to inhibit a visual mechanism.	The sample consisted of 71 children between 8 and 15 years old in Brazil.	Emotional neuroeducational principle
Wilson et al. (2021)	To explore neurocognitive predictors of response to intervention with the GraphoGame Rime (GG Rime).	398 second graders from different schools between 6 and 7 years old participated in this study in United Kingdom.	Cognitive neuroeducational principle

An analysis of the selected articles contributing to the different aspects of neuroeducational interventions showed that research in the field was still incipient at the beginning of the decade as only one (8%) of the selected articles published in 2014 met the established criteria (Table 1). However, an increase in the number of studies was observed during the last five years (92% of the articles that met the selection criteria). In addition, six interventions were conducted in Europe (46%), while 38% of the articles came from America (two from North America and three from South America); one intervention (8%) was conducted in Africa (South Africa) and another in Asia, specifically in Saudi Arabia (8%).

Regarding their context and participants, some studies were conducted in pre-school stage (N=2). For instance, Blair and Raver (2014) sought to bring together advances in neuroscience research to examine an early school stage approach to executive functions. Similarly, De Witt and Lessing (2018) carried out an intervention in South Africa with the aim of improving early literacy skills in preschool learners. However, most of the studies were carried out in primary school levels (69%), with participants fluctuating between the ages of 5 and 11 years old (e.g. Bezerra-Mota et al., 2016; Buono et al., 2020). The secondary stage was explored in the United Kingdom and investigated whether verbal and/or visuospatial working memory tasks correlate with reading and mathematics performance (Giofré et al., 2018; Wilson et al., 2021). In the university context, only one study contributed to demonstrate the influence of memory and emotion on reading habits (Álvarez et al., 2021).

Regarding their design, 46% of the studies employed a longitudinal design, which implies that more than two measurements were performed throughout the studies and were developed in an interval between six months and two years (Bezerra-Mota et al., 2016; Blair & Raver, 2014; de Witt & Lessing, 2018; Müller et al., 2021; Potier et al., 2020; Wilson et al., 2021). The rest of the studies conducted their interventions within a minimum of two and a maximum of 16 weeks. Another point to be highlighted is that only 8% of the studies developed a mixed approach involving both qualitative and quantitative methods of data collection and analysis (Álvarez, 2021). The rest of the studies were exclusively quantitative, and none of the analyzed studies was purely qualitative in nature. This information is relevant because the focus of the research was centered mostly on cognitive aspects measurable through different tests, such as: Test d2-R (to measure attention); Hearts and Flowers Task; Flanker Task with Reverse Flanker; NHI Toolbox Dimensional (to measure working memory, cognitive flexibility, and inhibitory control); Span-Backward Matrices (for working memory, cognitive flexibility, and inhibitory control); Span-Backward Matrices (for the memory of visuospatial work); Preschool Trail Making Test; Attention to Nullification Test; Strengths and Difficulties Questionnaire; Columbia Mental Maturity Scale (for attention, memory and self-regulation; inhibitory control) (Blair & Raver, 2014; Buono et al., 2020; Giofré et al., 2018; Martins & Gotuzo, 2017; Müller et al., 2021).

The theoretical foundations underpinning most of the research analyzed include perspectives on the Theory of Mind (ToM), which involved developing specific strategies to support cognitive skills through the organization of cooperative activities designed to promote socio-emotional development, as well as Graph Theory that identifies personal beliefs based on short and long-term memories (Bezerra Mota et al., 2016; Blair & Raver, 2014). The Self-Regulation and Executive Functions Intervention Program, also highly used in the studies analyzed, was used to investigate the cognitive and prosocial development of students, which is in line with the A-book Program, GraphoGame Rime, Star Protocols, ELAN, FACET, PIAFEx and the Active Pause Program. These interventions

were based principles of self-regulation (emotional principle) and behavioral modulation, to investigate the way these skills and a number of correlating variable would influence students' reading abilities in terms of, for example, speed, fluency and comprehension (Buono et al., 2020; Guerra & Mellado, 2017; Martins & Gotuzo, 2017; Pegado et al., 2021; Potier et al., 2020; Wilson et al., 2021). Other studies centered on investigating reading comprehension skills through the development of social skills; such is the case of the Mindfulness Program intervention and the Brain-Based Learning and Multisensory Instruction Program, both focusing on developing the brain more holistically (Müller et al., 2021; Soliman & Al-Madani, 2017).

In addition, when comparing the neuroeducational principles explored in the analyzed studies, it is possible to observe that these interventions investigated the cognitive aspects to a lesser extent than social and affective ones. Nonetheless, such studies provide convincing information regarding the fact that promoting the cognitive principle in early school or childhood can enhance short and long-term benefits in academic, professional and social areas. In addition, the follow-up of students participating in longitudinal interventions showed that training cognitive skills through time (e.g. inhibitory control, working memory, planning, attention and self-regulation, among others) can improve prosocial behavior (Martins & Gotuzo, 2017). These articles centered their research aims mainly on memory development, showing that this skill is predictive of students' verbal work and performance in reading activities (Bezerra-Mota et al., 2016; Giofré et al., 2018).

In what follows, some interesting findings are highlighted here in order to support our recommendations for teachers. In this regard, abilities such as self-regulation, effective dynamics and explanatory feedback were presented as important mechanisms to work on emotions in the classroom (Buono et al., 2020; Guerra & Mellado, 2017). For example, findings showed that joy is related to increased control (self-regulation), frustration is related to the use of fewer planning strategies, so both cognitive control and planning were related to increased scores in the interventions (Buono, 2020). In addition, the use of effective dynamics enhanced self-regulated learning, which affected cognitive control, and, as a consequence, increased motivation towards the reading task. Therefore, to keep students' high motivation towards reading, authors suggest providing verbal feedback and rewards for achievement to students during the activities. Moreover, students' self-regulation and behavioral modulation influences their academic outcomes, as self-regulated students are better at delaying immediate reward after a task in order to achieve more important long-term goals (Guerra & Mellado, 2017; Pegado et al., 2021).

It is important to highlight the clear incidence of emotion in the acquisition of the habit of reading, because during childhood deep emotional links are established with this skill (Álvarez, 2021). Therefore, it was suggested that these practices should be considered in the teaching plan, since this is the backbone linking students' expectations and the objectives of the class, as a poorly planned activity can cause frustration, blocking the ability to learn (Buono, 2020). This is of utmost importance since, paradoxically, it was found that most of the adverse emotions towards reading come from the school environment and experiences, that is, it is (at least partly) the teaching practices that generate them (Álvarez, 2021).

Another aspect to highlight is the impact that social activities have been reported to have on reading skills. For instance, the studies analyzed also showed that intentional play activities promote vocabulary skills and creativity in students (Blair & Raver, 2014). Developing play-centered activities improves concentration, processing of bodily and abstract sensations (e.g. happiness and gratitude, among others). Such positive performances were reinforced for up to four months post-intervention (Müller et al., 2021; Potier et al., 2020). This shows the importance of promoting a positive learning environment and of presenting diverse resources to students, so that they can choose what to read, which increases reading motivation and shows significant improvements in the performance of the reading skill. Likewise, when students are part of a stimulating and personalized learning context, their response accuracy tends to increase (Guerra & Mellado, 2017; Soliman & Al-Madani, 2017). In this light, the development of reading skills should not be taken for granted, because it involves intentional input from the educator and the environment (De Witt & Lessing, 2018).

Moreover, these studies show that cognitive skills remain significant predictors of children's progression as readers (Wilson et al., 2021) and confirm that poor reading comprehension may be due to low language comprehension and proficiency, rather than to language decoding; and students with poor vocabulary are more prone to underperforming in their reading skills. One further aspect developed from the view the cognitive principle was explored by Müller (2021), who measured the impact of a physical activity interventions (active breaks) on students' reading skills. The research shows that active breaks were only effective if they were carried out together with some activities requiring cognitive engagement, and it was suggested that these should be longer than 10 minutes (Müller, 2021). Interestingly, the research findings also show an improvement in the cognitive skill of attention, while the mindfulness intervention

enhanced reading comprehension. In addition, the classroom context, several motivational aspects of students, and the reduction of mind wandering allowed teachers to foster awareness during the interventions and with it an improvement in students' reading skills.

4. Suggestions for Teachers and the Development of Future Interventions

From the analysis of the selected articles presented in the previous section, we put forward some neuroeducational recommendations that we believe are the most useful to support the teaching-learning process of reading skills and designed a working model to articulate its components (Figure 3). The model is organized thematically into each of the neuroeducational principles as follows: 1) brief description of the cognitive principle and suggestions, focusing on memory and attention variables; 2) brief description of the affective principle, with an emphasis on the ability of self-regulation; and 3) brief description of the social principle, exploring ideas for the holistic development of students as a way to articulate the neuroeducational triad of principles.

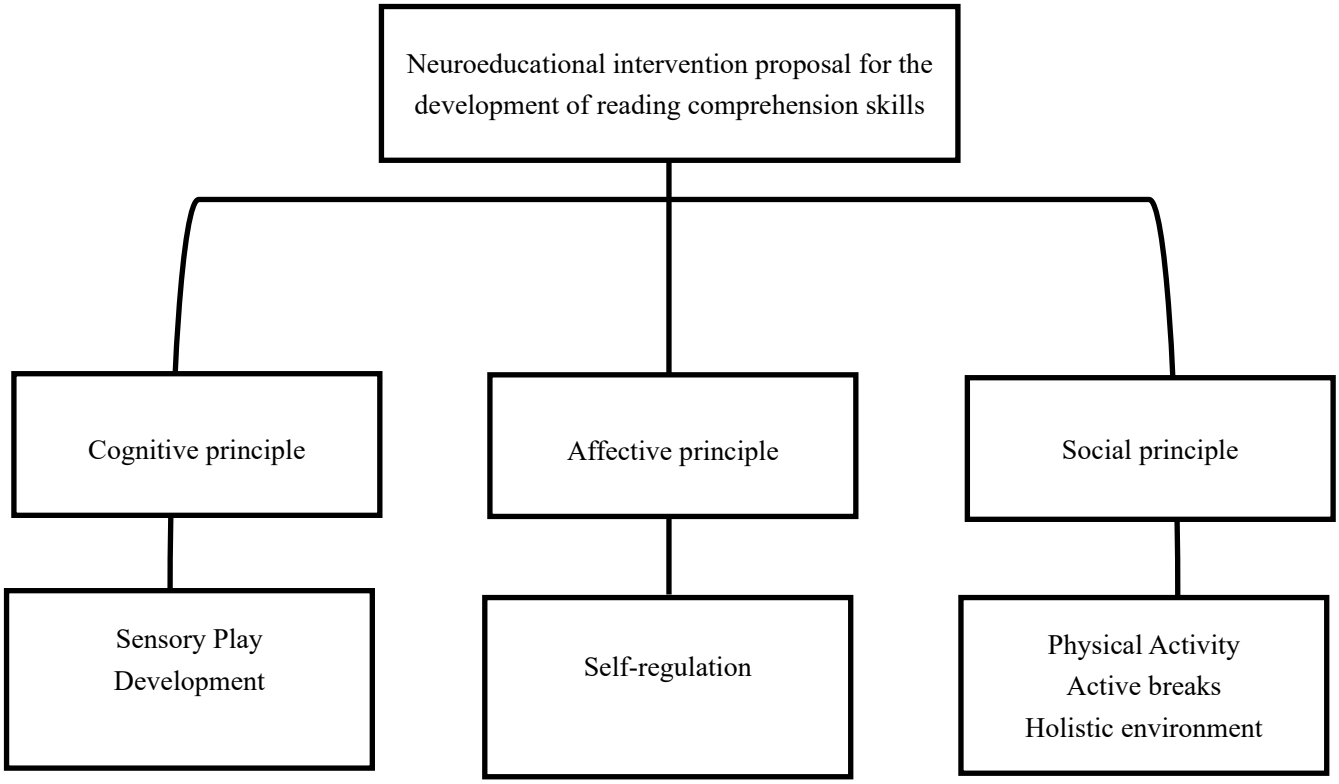

Figure 3. Model Proposed to Address the Neuroeducational Triad of Principles

4.1 Cognitive Principle

The cognitive aspects most addressed in the neuroeducational interventions analyzed in this study are the cognitive skills of memory and attention (Bezerra- Mota et al., 2016; Giofré et al., 2018; Martins & Gotuzo, 2017; Müller et al., 2021). Cognitive skills are defined as a set of abilities that allows us to control and regulate thoughts, emotions and behaviors, and that also helps to direct us towards a goal (Martins & Gotuzo, 2017). In turn, attention and memory variables are defined as follows:

- Attention is the ability to concentrate without distractions and is a limited resource that is constantly changing. In addition, it is influenced by internal and external factors such as stress, boredom and sedentary lifestyle, among others (Müller et al., 2021). Taking this into consideration, we propose to work on reading comprehension through playful practices that complement initial phonetic literacy with educational technology through game applications (Wilson et al., 2021). This is key to alleviate the difficulties inherent to slow decoding, and to anchor learning in students' memory (Potier et al., 2020).

- Memory is the capacity to manipulate and store information and is directly associated with academic performance (Giofré et al., 2018). We suggest to develop this skill in the reading practice through olfactory stimuli (sensory development) that triggers positive memories and constructs relevant meaning in students, since it has been shown that aromas remain in the brain longer than other incentive types (Soliman & Al-Madani, 2017).

4.2 Affective Principle

Positive and negative emotions play a paramount role in the cognitive processes that facilitate learning and are linked to functional aspects in the classroom (Buono et al., 2020). They also have a direct impact on students' reading preferences, as well as on the habits involved in the development of reading skills (Álvarez, 2021). In this light, the studies analyzed suggest to approach reading practices through the training of self-regulation abilities, as a metacognitive strategy used during learning tasks to monitor progress towards the achievement of a goal (Buono et al., 2020).

4.3 Social Principle

In this review, we have highlighted the fact that the analyzed research particularly emphasizes the benefits of employing social activities, such as physical activities, active breaks and games, to improve reading skills (Müller et al., 2021). With this in mind, neuroeducational interventions aim to increase visual, kinesthetic and auditory reading skills through the social development of a classroom environment that holistically articulates all the aforementioned principles (Soliman & Al-Madani, 2017).

5. Limitations and Future Research Avenues

Among the main limitations identified in the analyzed articles, it was found that studies often reflected on the drawbacks stemming from having small sample sizes, which jeopardizes the generalization of their results (Bezerra Mota et al., 2016; Giofré et al., 2018; Martins & Gotuzo, 2017; Pegado et al., 2021). In addition, most interventions focused on quantitative measures of the effectiveness and implementation of a given program, rather than its influence on teachers' and students' experiences and perceptions (Blair & Raver, 2014). It is then necessary to develop research that qualitatively and interpretively assesses classroom implementations of neuroeducational principles related to the reading process, analyzing teachers' and students' perceptions in a more nuanced way.

In relation to the previous point, another important limitation is that most studies analyzed here relied on artificially designed laboratory tests aimed at isolating cognitive, affective and/or social components, so that the results obtained from this do not allow for reflections on the contextual specificities of each classroom setting (De Witt et al., 2018; Giofré et al., 2018; Pegado et al., 2021; Potier et al., 2020; Wilson et al., 2021). Thus, studies that assess and analyze how contextually relevant intervention proposals can be applied by teachers across contexts are still incipient at best. This gap in the literature needs to be addressed, since, as stated by Álvarez (2021), teachers are the main agents of implementation of strategies within the classroom and, therefore, neuroeducational interventions should be familiar to educators and developed in collaboration with them. It is expected that future studies involve teachers more actively in decision-making processes during the design of neuroeducation interventions and that their perceptions of such processes and the implementation of interventions are also critically analyzed to propose innovative ways in which to move the field forward and suggest more meaningful teaching resources.

Moreover, despite the fact that more than 90% of the articles analyzed were published in journals whose SJR-2021 impact factor placed them within the first two quartiles of the Scimago ranking, in our analysis we identified one further limitation regarding the fact that only one study is written in a language different from English and that most of them have been developed in European contexts (Table 2).

While the lack of articles in non-European contexts may be due to the fact that empirical interventions in classrooms involve extensive and costly research endeavors, it shows a socio-cultural gap in the specialized literature of this field, which we hope does not limit its scholarly interest but continues to be developed in order to make available published scientific evidence that is more representative of different classroom contexts worldwide.

Table 2. Publication Information of Each Study

Year	Authors	Language	Context	Scientific journal and impact factor
2014	Blair & Raver	English	United States	PLoS ONE Q1 SJR: 0.85
2016	Bezerra- Mota et al.	English	Brazil	Mind, Brain, and Education Q2 SJR: 0.59
2017	Martins & Gotuzo	English	Brazil	Educational Psychology an International Journal of Experimental Educational Psychology Q1 SJR: 1.235
2017	Soliman & Al-Madani	English	Saudi Arabia	Croatian Journal of Education Q4 SJR: 0.14
2017	Guerra & Mellado	English	Chile	Frontiers in Human Neuroscience Q2 SJR: 0.86
2018	de Witt et al.	English	South Africa	Early Child Development and Care Q2 SJR: 0.45
2018	Giofré et al.	English	Italy	Trends in Neuroscience and Education Q1 SJR:0.84
2020	Potier et al.	English	France	Journal of Computers in Education Q1 SJR: 1.04
2020	Buono et al.	English	France	Frontiers in Education Q2 SJR: 0.58
2021	Müller et al.	English	Germany	Trends in Neuroscience and Education Q1 SJR:0.84
2021	Álvarez	Spanish	Spain	Tejuelo Q1 SJR 2021: 0.27
2021	Pegado	English	Brazil	STAR Protocols Q2 SJR: 0.53
2021	Wilson et al.	English	United Kingdom	Frontiers in Education Q2 SJR: 0.58

6. Conclusions

With the aim of analyzing the state of neuroeducational research and identifying the main characteristics of the interventions developed to propose suggestions that contribute to neuroeducation research on reading comprehension, the present systematic review analyzed 13 articles investigating neuroeducational interventions for the development of reading skills carried out in classroom contexts at different academic levels. The articles reviewed addressed their research objectives by exploring, to different extents, three neuroeducational principles, that is, cognitive, affective and social principles. These studies recognize the important role of mediated neuroeducational interventions in the classroom for promoting reading skills and highlight the need to articulate the three neuroeducational principles to provide a holistic environment that enhances reading abilities.

However, because most of the research in the field has been developed during the last five years, the results of these studies, as discussed in the previous sections, are still very limited, and more (especially qualitative) evidence is needed to fully understand how these principles work in actual teaching practice and how they are perceived by teachers and students. In this regard, the article provides a working model for teachers to implement some of the main ideas drawn from the analyzed studies, and also discusses future lines of research that provide a more comprehensive understanding and a more socio-culturally inclusive perspective of neuroeducational interventions.

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