Technology and Serious Gaming for Neurodevelopmental Disorders: A Systematic Literature Review

Muhammad Farooq Shaikh, Ciara Higley, Cecilia Campanile, Becky Francis, Elyssa Panja, Silvia Santacaterina, Giacomo Pratesi, Davide Piaggio

Submitted to: JMIR Serious Games
on: July 29, 2024

Table of Contents

Technology and Serious Gaming for Neurodevelopmental Disorders: A Systematic Literature Review

Muhammad Farooq Shaikh[1] BSCS, MSCS, PhD; Ciara Higley[2]; Cecilia Campanile[3]; Becky Francis[1]; Elyssa Panja[1]; Silvia Santacaterina[4]; Giacomo Pratesi[3]; Davide Piaggio[1]

[1]University of Warwick School of Engineering Coventry GB
[2]University of Warwick Coventry GB
[3]Paperbox Health S.R.L Turino IT
[4]Università Campus Bio-Medico di Roma Rome IT

Corresponding Author:
Muhammad Farooq Shaikh BSCS, MSCS, PhD
University of Warwick
School of Engineering
Coventry, CV4 7AL
Coventry
GB

Abstract

Background: Neurological development in children aged 3-11 is highly sensitive and variable. Critical skills for daily and professional
life depend on the development of executive functions, and difficulties in this process can manifest as learning disorders such as ADHD, Dyslexia, and Dysgraphia, affecting 5-10% of children worldwide. Early screening is crucial to ensure timely intervention and enhance the quality of life for affected individuals. However, challenges include high costs, lengthy wait times, and logistical barriers, leading to underdiagnosis and delayed intervention.

Objective: To systematically review technological solutions for early screening and improve diagnosis and intervention strategies
for neurodevelopmental disorders in children

Methods: Relevant studies were selected using specific inclusion and exclusion criteria to assess the effectiveness of various technologies and methodologies. Technologies evaluated included gamified eye-tracking tests and machine learning algorithms. The review employed quality appraisal tools such as the MMAT table and PRISMA flow chart to synthesize findings from the included studies.

Results: The review highlights the efficacy of technologies such as gamified eye-tracking tests and machine learning algorithms in screening for learning disorders. Despite promising results documented in the literature, there is a significant gap in translating these technologies into clinical practice. Current practices rely heavily on paper-based tests, which are inefficient for continuous monitoring and vary widely across regions. No specific sample sizes, response rates, P values, or Confidence Intervals were detailed in the abstract.

Conclusions: Integrating advanced technologies into clinical settings could significantly enhance early diagnosis and intervention for
learning disorders. This aligns with the UK NHS Long Term Plan, advocating for digital and personalized healthcare solutions to improve access to services, enhance patient experiences, support clinical decision-making, and optimize care delivery. Future research should focus on bridging the gap between technological advancements and clinical application. Clinical Trial: Not applicable (No RCTs involved).

(JMIR Preprints 29/07/2024:64627)
DOI: https://doi.org/10.2196/preprints.64627

Preprint Settings

1) Would you like to publish your submitted manuscript as preprint?

✔ **Please make my preprint PDF available to anyone at any time (recommended).**
Please make my preprint PDF available only to logged-in users; I understand that my title and abstract will remain visible to all users.
Only make the preprint title and abstract visible.
No, I do not wish to publish my submitted manuscript as a preprint.

2) If accepted for publication in a JMIR journal, would you like the PDF to be visible to the public?

✔ **Yes, please make my accepted manuscript PDF available to anyone at any time (Recommended).**
Yes, but please make my accepted manuscript PDF available only to logged-in users; I understand that the title and abstract will remain v
Yes, but only make the title and abstract visible (see Important note, above). I understand that if I later pay to participate in <a href="http

Original Manuscript

Technology and Serious Gaming for Neurodevelopmental Disorders: A Systematic Literature Review

Muhammad Farooq Shaikh[1,*], Ciara Higley[2], Cecilia Campanile[3], Becky Francis[1], Elyssa Panja[1], Silvia Santacaterina[4], Giacomo Pratesi[3], Davide Piaggio[1]

[1]Applied Biomedical Signal Processing Intelligent eHealth Lab, School of Engineering, University of Warwick, Library Road, CV47AL, Coventry, UK

[2] The Beacon Academy Internship, Warwick Medical School, University of Warwick, CV4 7AL, Coventry, UK

[3] Paperbox Health S.r.l, Torino, Italy

[4]Speech therapist, Unità Operativa Complessa di Otorinolaringoiatria (U.O.C), Fondazione Policlinico Universitario Campus Biomedico di Roma, Roma, Italy

Corresponding Author:

Muhammad Farooq Shaikh

Applied Biomedical Signal Processing Intelligent eHealth Lab, School of Engineering, University of Warwick, Library Road, CV47AL, Coventry, UK

Email: muhammad-farooq.shaikh@live.warwick.ac.uk

ORCID iDs:

Muhammad Farooq Shaikh: 0000-0001-8695-4590

Declarations:

Ethical Approval

Not applicable.

Informed Consent

Not applicable.

Statement Regarding Research Involving Human Participants and/or Animals

Not applicable.

Consent to Participate

Not applicable.

Consent to Publish

Not applicable.

Funding

This project was funded by a Warwick Industrial Fellowship agreement with Paperbox Health. C.H. was supported by the Beacon Academy, University of Warwick.

Author's Contribution

Muhammad Farooq Shaikh[1,*] contributed the most to this work. All other authors contributed equally to the study and manuscript preparation.

Competing Interests

The authors declare that they have no competing interests.

Availability of Data and Materials

All data generated or analyzed during this study are included in this published article (and its supplementary information files).

Abstract

Background:

Neurological development in children aged 3-11 is highly sensitive and variable. Critical skills for daily and professional life depend on the development of executive functions, and difficulties in this process can manifest as learning disorders such as ADHD, Dyslexia, and Dysgraphia, affecting 5-10% of children worldwide. Early screening is crucial to ensure timely intervention and enhance the quality of life for affected individuals. However, challenges include high costs, lengthy wait times, and logistical barriers, leading to underdiagnosis and delayed intervention.

Objective:

To systematically review technological solutions for early screening and improve diagnosis and intervention strategies for neurodevelopmental disorders in children.

Methods:

Relevant studies were selected using specific inclusion and exclusion criteria to assess the effectiveness of various technologies and methodologies. Technologies evaluated included gamified eye-tracking tests and machine learning algorithms. The review employed quality appraisal tools such as the MMAT table and PRISMA flow chart to synthesize findings from the included studies.

Results:

The review highlights the efficacy of technologies such as gamified eye-tracking tests and machine learning algorithms in screening for learning disorders. Despite promising results documented in the literature, there is a significant gap in translating these technologies into clinical practice. Current practices rely heavily on paper-based tests, which are inefficient for continuous monitoring and vary widely across regions. No specific sample sizes, response rates, P values, or Confidence Intervals were detailed in the abstract.

Conclusions:

Integrating advanced technologies into clinical settings could significantly enhance early diagnosis and intervention for learning disorders. This aligns with the UK NHS Long Term Plan, advocating for digital and personalized healthcare solutions to improve access to services, enhance patient experiences, support clinical decision-making, and optimize care delivery. Future research should focus on bridging the gap between technological advancements and clinical application.

Trial Registration:

Not applicable (No RCTs involved).

Keywords

Neurodevelopmental disorder; learning disorder; serious gaming; ADHD; dyslexia; mHealth; digital health

1. Introduction

Neurodevelopmental disorders are a group of disorders causing deficits in cognition and delayed brain development due to various causes, including dysregulation of mechanisms governing the development of the cerebral cortex (Damianidou et al., 2022). Currently, it is reported that 5-11% of children under 18 have been diagnosed with attention-deficit/hyperactivity disorder (ADHD), 3-10% with a specific learning disorder and 0.63% with an intellectual disability. There is limited data available from low-income countries on neurodevelopmental disorders (Hadders-Algra, 2021), which accounts for a discrepancy between the accurate prevalence of neurodevelopmental disorders.

Neurodevelopmental disorders are costly to both the individual and to society. Disability adjusted life years (DALYs) are a quantification of years of full health lost to an individual. The DALYs associated with ADHD are 13.78 (Jepsen and Younossi, 2021), and data suggest that the quality of life for individuals suffering from dyslexia, dyscalculia and dysgraphia was significantly lower in all domains than neurotypical subjects (FragaGonzlez et al., 2018, Hen-Herbst and Rosenblum, 2022, Reddy and Reddy, 2016). Individuals suffering from a learning disorder are twofold less likely to gain a degree qualification after a full education. Such individuals are also more likely to be unemployed than healthy ones (Aro et al., 2019). In addition to this, poor mental health, emotional and behavioral issues are associated with specific learning disorders (Sahoo et al., 2015).

The overall cost to an individual due to the burden of learning disorders can be categorized into medical (for diagnosis, treatment, and rehabilitation), non-medical (transport to appointments) and indirect costs (productivity losses, loss of earnings and academic enhancement measures). In 2012, the average cost to an individual with ADHD was estimated to be between £8422.68 and £12,371.77, however, as more individuals are being diagnosed with multiple neurodevelopmental disorders, this burden is increasing (Kularatna et al., 2022). More recently, the economic burden is estimated to be around £97,823.09 per individual personally (Karande et al., 2019) (converted from Indian Rupees to Great British Pounds), and £569,481,000 per individual, to the government (Arora et al., 2020), annually (converted from Australian Dollars to Great British pounds).

UK NICE guidelines currently state that the diagnosis of ADHD is through assessing qualitatively the actions of an individual. There are dedicated methods such as the Strengths and Difficulties questionnaire or Conners' rating scale (NICE, 2019). Conners' rating scale is for the teacher, parent, and child self-report of conduct, self-care, and academic performance, and literacy level. Specific Learning Disorders can be diagnosed by assessing intelligence, memory, and other cognitive skills of a child for basic reading, writing, and counting abilities using this rating scale (Mather and Schneider, 2023).

These assessments are currently carried out by an educational psychologist neurodevelopmental healthcare professional (Roberts et al., 2012). This reduces the accessibility for individuals in low-income countries, remote areas, or those without access to adequate healthcare services being able to achieve a diagnosis and receive treatment. Early screening is paramount, as it allows treatment to begin earlier, which is conjectured to reduce the costs to the individual and society and allowing the individual to receive support from an early age (Sonuga-Barke et al., 2011).

The current most effective treatment for ADHD is stimulants (methylphenidate and amphetamine) alongside behavior therapy, boosting both dopamine and noradrenaline levels (Nazarova et al., 2022). Currently, there are no medications that treat dyslexia, dysgraphia, or dyscalculia. Instead, treatment includes educational accommodations, fine motor skill training and reading and writing lessons with trained professionals, both online and in person (Verwimp et al., 2024).

In recent years it has been proposed that 'serious gaming' (Khaleghi et al., 2022) and 'visual training' (Bucci, 2021) can be used for the treatment of dyslexia, whilst eye tracking has been identified as a potential diagnosis tool in both ADHD (Stokes et al., 2022) and dyslexia (Vajs and Papi, 2023). This study examines the literature on the use of serious gaming and technology to diagnose neurodevelopmental abnormalities in children aged three to eleven at an early stage. The research results will help guide the creation of diagnostic software that leverages AI and consumer-grade electronics (e.g., smartphones and tablets) to assist Paperbox Health's endeavors.

1.1. Learning Disorders and ADHD

The main neurodevelopmental disorders we focused on were dyslexia, dyscalculia, dysgraphia, and ADHD. DSM-5 classifies dyslexia as the inability to link word patterns and pronunciations, affecting reading ability both internally and externally (Snowling and Hulme, 2012). People with dyscalculia struggle with 'numeric and arithmetic' concepts (Castaldi et al., 2020), whilst those with dysgraphia have lower abilities in fine motor coordination, than neurotypical individuals (Chung et al., 2020). Finally, ADHD is diagnosed when an individual exhibits reduced attentiveness and hyperactivity with actions of impulsivity (Braithwaite et al., 2020).

2. Methods

The methodology followed the PRISMA statement for systematic literature review (Yepes-Nuez et al., 2021).

2.1. Search strategy

To perform a systematic review, meaningful keywords were identified forming the basis of the search string. These keywords were selected based on experts' input and relevant articles. The final search string was reviewed and approved by an interdisciplinary team of experts in biomedical engineering, medicine and speech and language therapy (SALT). The following terms were combined with Boolean operators (e.g., AND, OR); "Dyscalculia", "dyslexia", "reading disorder", "learning disorder", "dysgraphia", "ADHD", "neurodevelopmental disorder", "executive functions", "writing skills", "reading skills", "videogame", "machine learning", "ML", "AI", "artificial intelligence", "Eye", "Video games", "Educational games", "Machine learning", "Vocal analysis", "Deep learning", "Reinforcement learning", "Bayesian estimation", "Applied gaming", "Clustering", "Serious gaming", "child", "children", "school", "infant", "paediatric", "preschool", "screening", "monitoring", "diagnosis", "clinical decision support", "assessment", "epidemiology", "test", "testing", "therapy". The search string was inputted into the Scopus database identifying research papers from January 2013 to November 2023.

2.2. Inclusion/exclusion criteria

After assessing existing reviews, we continued our work, including only English papers from the last ten years on screening neurodevelopmental disorders in children aged 3-11. We excluded reviews, conference papers, book chapters, editorials, notes, studies on children over 11, and those focusing only on epidemiology or using EEG/fMRI. Two authors appraised articles by title, abstract, and full text, with a third-party resolving discrepancy.

Table 1 – inclusion and exclusion criteria.

Inclusion criteria	Exclusion criteria
Publications in last 10 years – article	Publications before 10 years ago
Articles only	No conference paper, book chapter, reviews
Children 3-11	Any other ages
English language	Any other language
Any paper related to the use of technology for screening neurodevelopmental disorders	No use of electroencephalogram (EEG) or functional magnetic resonance imaging (fMRI)

2.3. Data extraction and quality appraisal

Relevant data was extracted and collated into an ad-hoc Excel spreadsheet. The quality appraisal was conducted using the MMAT tool (Hong et al., 2018), as the finalized selection included multiple study types. The MMAT tool allows for analysis of quantitative and qualitative studies.

2.4. Data synthesis

Narrative synthesis methods (Booth et al.) were used for data synthesis of the extracted data. For each paper, the type of disorder, technology and overall aims and conclusions of the study were identified and organised by the type of neurodevelopmental disorder. This information was used to generate discussions and future directions.

2.5. Results

Search outcome

The Scopus search and study selection process is summarised in Figure 1.

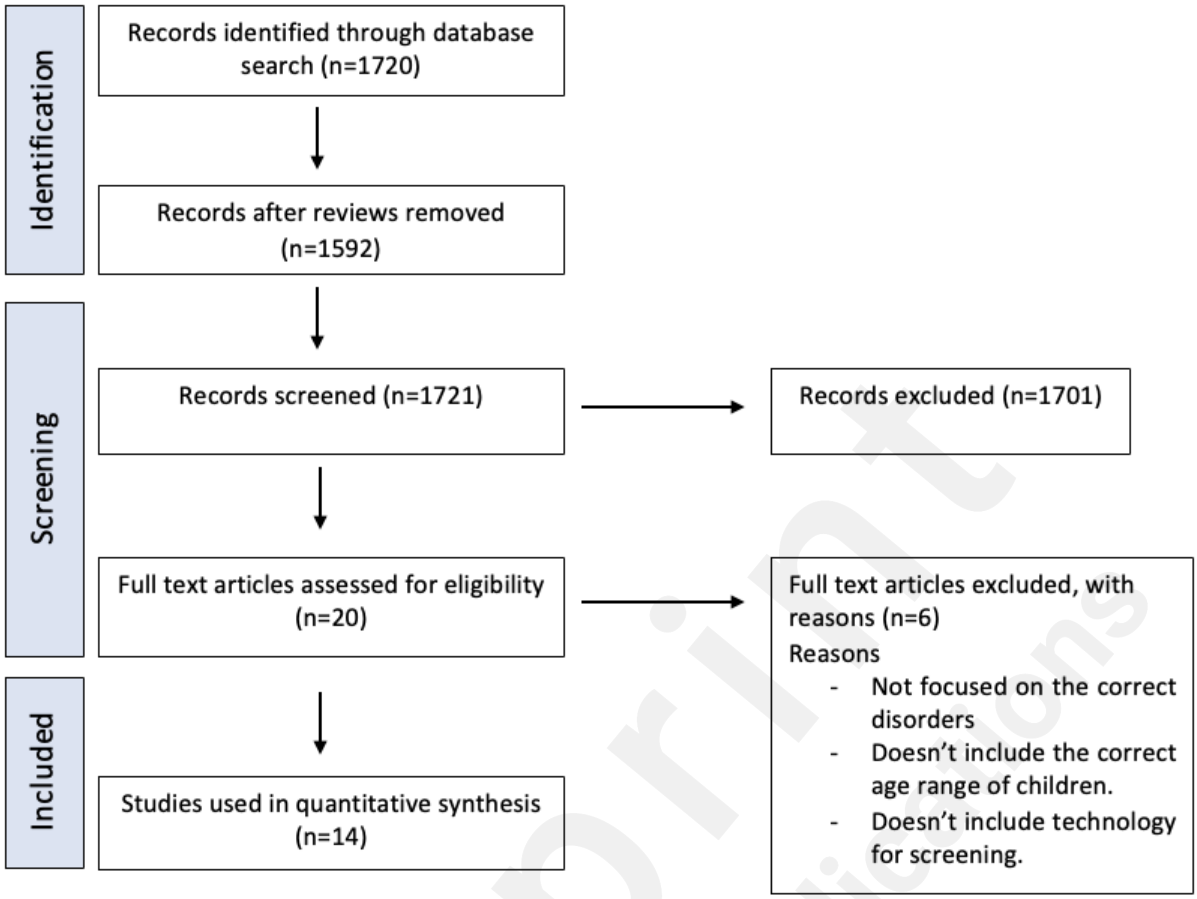

Figure *1*. PRISMA flow diagram. Study selection process used, divided into 3 sections: Identification, Screening, Included.

The search mentioned in the methodology returned 1720 hits. After reviews were excluded, 1592 articles remained. These articles were then screened by title and abstract with 20 articles meeting our inclusion criteria (table 1). After full text screening, the total number of included articles was 14.

3. Data Extraction

Table 2 contains all the data extracted from the studies included.

Article No.	Type of Disorder	Technology	Aim of the Study	Participants	Conclusion of the Study
Alt et al, 2017	Dyslexia	Computer-based word learning games	This study used word learning games to identify strengths and weaknesses in children with dyslexia by measuring their ability to link names and objects. Analyses of covariance and nonverbal intelligence scores assessed phonological-visual linking, mispronunciation detection, naming, visual difference decision, and visual feature recall.	Children with dyslexia (N=68) and typical development (N=116), monolingual English-speaking 2nd graders without oral language impairment.	The study found word learning deficits in children with dyslexia across all manipulations and most task-manipulation combinations, especially in phonological tasks. Visuospatial manipulations showed mixed effects.
de Ven et al, 2017	Dyslexia	Reading Game (Letter Prince)	To measure the impact of a multicomponent reading game on the development of reading skills and motivation in 60 first grade Dutch schoolchildren with special educational needs.	60 children (8 years and 8 months on average, Grade 2 or 3 reading levels) in the Netherlands	The short intervention (9 × 15 min) improved pseudoword and text reading fluency by increasing the number of pseudowords identified and reducing the reading time. Early intervention caused on

					average, a lower reading time for the children than the late intervention but the late intervention caused a higher number of pseudowords to be correctly identified by 'Time 3'. There was no impact on reading motivation.
García-Redondo et al, 2019	ADHD	Educational video games	To analyze the effects of a serious game based on multiple intelligences on attention in students with ADHD and SLD, using performance and observation measures.	44 students (male = 27; 61.4%) with ADHD and SLD, aged 6–16 years, from Northern Spain.	The intervention, consisting of 28 sessions using educational video games, resulted in a significant improvement in attention performance measures, particularly visual attention, suggesting the potential of serious games in addressing lack of attention in students with learning disabilities.
Rello et al, 2020	Dyslexia	Online gamified test	To design an online gamified test and a predictive machine learning model for dyslexia detection in Spanish speakers.	3,644 participants (392 with professional dyslexia diagnosis), 7-17 years old, from Argentina, Chile, Colombia, Spain, and the USA.	This study correctly detected 80% of participants with dyslexia amongst over 3600 participants. The online screening tool based on the methods has been used by over 200,000 people, showing potential for early detection and prevention of dyslexia-related challenges.
Schmitt, 2018	N/A	Web-based educational video games	To evaluate the effectiveness of an educational website in promoting the literacy skills of young children via a randomised trial over 8 weeks (about 2 months).	136 preschoolers and kindergarteners of ages 4-6.83 years from primarily low-income schools.	Overall, the children using the website had better literacy results after assessment than the control group.
Heller, 2013	ADHD	Machine Learning, video game	To test the accuracy of a game implementing machine learning at identifying ADHD.	52 children and teens aged 6-17 years. 26 with ADHD, 26 without.	The game was able to accurately detect combined type ADHD 75% of the time and inattentive type 78% of the time demonstrating the potential to create a game to detect patterns for ADHD and potentially other mental disorders.
Jafarlou, 2020	Dyslexia	Eye-movement tracking	To evaluate the effectiveness of oculomotor rehabilitation on the cognitive performance of dyslexic children.	50 dyslexic children aged 8-12 years.	There was a significant difference between children with and without dyslexia showing signs of oculomotor impairment. The early diagnosis of eye movement disabilities can improve cognitive performance of the affected children.
Larco, 2021	Dyslexia	Web and app-based learning game	To create web and mobile apps to provide learning resources to dyslexic children aged 7-10 years.	25 dyslexic children aged 7-10 years.	The 'Helpdy' app was stated to improve the symptoms of dyslexia in children.
Niemela, 2020	Reading disability	Serious Games and Clustering	A new clustering-based approach for identifying different profiles of serious	1632 players who were 6.5–8.75 years old	The results indicated that it is possible to identify different types of learners using the

			game players and this method to GraphoLearn game log data.		given clustering method.
Slobodin, 2020	ADHD	Data Collection using MOXO-CPT	To use a machine-based learning model to predict ADHD in children	458 (6-12 years old)	The MOXO-CPT assessment predicted ADHD with high accuracy, quicker and more cost effective than the current ADHD diagnosis showing 87% accuracy, 89% sensitivity and 84% specificity.
Rauschenberger , 2022	Dyslexia	Web-game	to develop a game for universal screening of dyslexia	313 children (116 with dyslexia)	There were seven separate variables that all showed a significant difference between those with and without dyslexia. This approach can optimise resources for detecting dyslexia but needs to expand training data.
Perochon, 2023	Autism and ADHD	Tablet based game	use extracted touch features from a bubble popping game to differentiate between neurotypical and neurodivergent children	233 parcicipants, aged 1.5 - 10 years	Autistic children with co-existing ADHD took longer to pop the bubble and had a longer touch length on average. Touch based games can be an efficient approach to screen autism and ADHD.
Apiquian, 2020	ADHD	Video game	to determine whether their video game (Chefmania) was a useful tool in screening ADHD	266 participants, aged 6 - 12	children with ADHD showed poorer performance in scores of Chefmania. Chefmania is a valid tool for the assessment of cognition and is suitable for use in schools.
Piazzalunga, 2023	Dysgraphia	Visual perception games, and and eye-tracking device	to investigate the rolof visual perception in handwriting skills	53 participants, average age 7.84 years	Children with dysgraphia displayed more inattentiveness and indecisiveness. This tool could predict with good results risks in handwriting

3.1. Type of Disorders

In Figure 2 a pie chart of the studies selected and classified based on the type of learning disorders can be seen. Dyslexia and ADHD alone make up for over 60% of the studies included. The remaining selected papers related to reading difficulties and dysgraphia in children, with 23.1% and 7.7% of the studies, respectively.

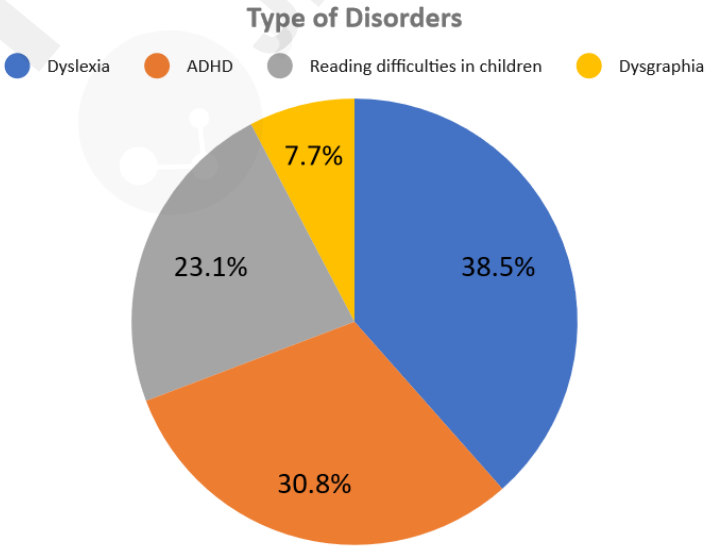

Figure 2. Pie chart of the type of disorders classified and targeted in the studies selected and used for the data extraction

in this study.

3.2. Dyslexia

Dyslexia is a learning disorder that impacts a person's ability to read and write that affects approximately 700 million adults and children worldwide. As the condition is neurodevelopmental, its cause is at least partially genetic (Shultz, 2008). Of the six articles researching dyslexia, three explored the use of computer-based games to detect symptoms of dyslexia in children. For the studies found significant differences between the children with and without dyslexia notably, a significant decline in phonological manipulation, using computer game software (Rello et al., 2020, Rauschenberger et al., 2022, Alt et al., 2017). Another study investigated a clustering method to put children whose teachers had highlighted them as having learning difficulties into categories and determine who was most at risk of being dyslexic (Niemela, 2020).

Two of the studies researching the potential of computer games aiding dyslexia, researched the effectiveness of these games in symptom management rather than diagnosis. They found a significant improvement in pseudoword naming and reading time after use of a computer game (van de Ven, 2017). and mobile app game (Larco et al., 2021) showing that computer games could be used to improve the symptoms of dyslexia as well as aiding the diagnosis process. Another paper stated the same findings but did not focus on those with dyslexia, but used a randomized group of children to assess if a website intervention would improve literacy skills (Schmitt, 2018).

The final paper researching dyslexia discussed potential forms of support, specifically oculomotor rehabilitation using eye-tracking technology, and word learning activities via a mobile application. They found that oculomotor disabilities can be identified through use of their software and differentiate between those with and without dyslexia (Jafarlou et al., 2021), suggesting that diagnosing dyslexia could be completed using eye tracking technology which would aid in the cognitive rehabilitation of children.

3.3. ADHD

ADHD is a condition that is mainly related to the behavior and expressions of people. ADHD normally causes restlessness, and patients suffering from this could have trouble concentrating and focusing and could get impulsive (NHS, 2021). The worldwide prevalence of noticeable adult ADHD is estimated to be 6.8% globally, or 366.3 million individuals (Forbes, 2023). Symptoms of ADHD could be noticed at an early age, and it could become more and more visible when the kid's circumstances change, for example going to school or trying to perform any learning task which requires focus (Frances, 2022).

Techniques like educational video games have been suggested as being effective for screening of ADHD in children (Heller et al., 2013, Perochon, 2023, Apiquian et al., 2020), as well as other studies using data from MOXO-Continuous Performance Test (MOXO-CPT) to predict ADHD with machine learning algorithms (Slobodin et al., 2020). Furthermore, another study showed that a mobile app could significantly improve the attention deficit in those children with ADHD (Garcia-Redondo et al., 2019). All these studies show promise that technological advancements in computer game and app designing could aid both the diagnosis and symptom management in ADHD.

3.4. Reading Difficulties in Children

Reading difficulties can arise from many different learning and developmental disorders, for example dyslexia, autism and ADHD, and other specific learning disorders. Symptoms classified as reading difficulties in primary school children include confusing similar looking letters, unusual pronunciation of words, and poor comprehension of what they have just read (NICHD, 2020). Symptoms can also come up in non-academic settings, for example difficulty in telling the time, and differentiating between left and right (Association, 2013). Around 10% of children suffer from specific learning disorders (UCL, 2013), and many of them will also have reading difficulties.

3.5. Dysgraphia

Dysgraphia is the difficulty in acquiring writing skills despite sufficient learning support and cognitive capacity. It is associated with problems with letter formation/readability, letter spacing, spelling, fine motor coordination, speed of writing, etc. It is possible to establish a link between dysgraphia and impairments in visual perception. This is a skill which enables individuals to interpret and elaborate upon the visual information they encounter (Chung et al., 2020). One study showed that gamified clinical tests improved visual perception, using an eye tracker, alongside a handwriting speed test (Piazzalunga et al., 2023).

3.6. Technologies and Techniques

In Figure 3, a pie chart of the technologies and techniques used in the studies included in this manuscript is presented. This figure clearly shows how effective video games are for screening and learning purposes in children (especially at an early age), with 61.5% of the studies dealing with them. Techniques like different machine learning and deep learning algorithms have also been used in recent studies, accounting for 23.1% of the included studies. The included articles

report the implementation of techniques like machine learning based algorithms and techniques by collecting the data from MOXO-CPT for screening ADHD using video games (Slobodin et al., 2020). Eye tracking technologies were also used and applied in 15.4% of the selected studies.

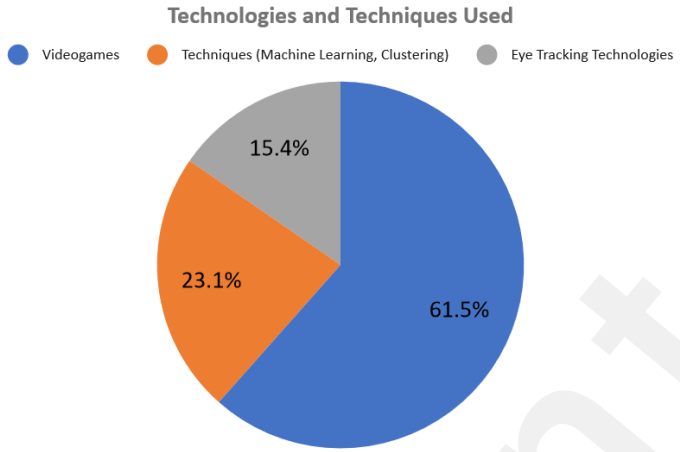

Figure 3. Pie chart of the technologies and techniques used in the studies selected and used for the data extraction in this study.

3.7. Video Games

Video Games, learning games or, to be more precise, serious games are designed and developed for learning purposes mainly. These video games in recent studies have shown some promising results and proved to be one of the most efficient ways for learning, specifically in young children. These video games/serious games have also been used to do some screening for learning disabilities in kids at an early age to diagnose these disorders so that it could help reduce future challenges and provide early treatment. The pie chart in Figure 3 clearly shows the widespread use (61.5%) of video games for screening and learning purposes in children with learning disorders.

3.8. Techniques (Machine Learning and Clustering)

Machine Learning (ML) is a branch of artificial intelligence that includes algorithms for classifying and regressing data points by analyzing their features and relationships. It uses pattern recognition and computational learning theory to make predictive decisions without direct human intervention. ML algorithms can be supervised or unsupervised, depending on whether the data used for training the algorithm is labelled. Clustering is a class of unsupervised ML algorithms, aimed at grouping data points in subsets (referred to as a cluster). Each cluster groups data points that are more similar than those in different clusters, enabling the recognition of underlying patterns and relationships in the data without pre-defined labels (Bishop, 2016).

3.9. Eye Tracking Technologies

Eye tracking is the process of recording a person's eye movements to track exactly where they are looking and for how long. Types of commonly used eye-tracking technologies in clinical settings include video-based and remote. Video-based eye-tracking consists of recording pupil movements via a camera (mounted onto eyewear) and analyzing footage. Remote tracking uses infrared light and detects corneal reflections. Screen based eye-tracking requires participants to sit some distance from the screen they are interacting with. This method limits participants' movements, but accurately tracks movements. Eye-tracking glasses have cameras mounted to them and allow participants to move freely. However, calibration can shift as the glasses move around, decreasing accuracy of tracking.

4. Quality Appraisal

The MMAT quality analysis results are shown in the Supplementary Table 1. All papers in the study had identifiable and specific research questions aligned with available data. Of the ten non-randomized studies, two were unclear about population, and none of the control of confounders due to missing or inadequate follow-up outcomes. This affects correct interpretation of data and may result in a bias. There was one randomized controlled trial however it is not clear whether the two groups were similar at the start of the study, whether the person assessing the groups was blinded and whether the participants stuck to the intervention.

5. Discussion

This systematic literature review identified the key technologies and techniques used to diagnose and treat

neurodevelopmental disorders including Dyslexia, Dysgraphia and ADHD based on the data extracted from the selected articles chosen according to our inclusion and exclusion criteria.

Most papers identified by our inclusion/ exclusion criteria focused on dyslexia screening and diagnosis, with the least amount of research found on dysgraphia. The review of selected articles showed that the technology and technique most used to diagnose and improve the symptoms of Dyslexia is computer gamified testing (Rello et al., 2020, Rauschenberger et al., 2022, Alt et al., 2017, Niemela, 2020, van de Ven, 2017, Larco et al., 2021). Two studies used eye tracking technology to evaluate the effectiveness of oculomotor recognition in the screening of children with dyslexia (Jafarlou et al., 2021) and dysgraphia (NHS, 2021). However, in this article the variability of oculomotor data has not been considered. It is also noteworthy that similar techniques and technologies have been used for screening and symptom improvement of ADHD in children (Heller et al., 2013, Perochon, 2023, Apiquian et al., 2020, Garcia-Redondo et al., 2019). There is only one selected article that used MOXO-CPT based data collection for simulation purposes using a machine learning algorithm (Slobodin et al., 2020).

The papers that researched dyslexia screening using computer gaming all concluded that phonological manipulation is the largest deficit seen in dyslexic children (Rauschenberger et al., 2022, Rello et al., 2020, Alt et al., 2017). Three papers researched computer games as a method of screening for dyslexia. Alt et al. (2017) found that there was a significant difference in phonological manipulation between children with and without dyslexia, showing promise in becoming a screening tool for dyslexia (Alt et al., 2017). However, the software they used included a ‘yes’ and ‘no’ button to answer the questions and, therefore, statistically the children could guess the correct answer 50% of the time. which could have biased the results (Alt et al., 2017). Similarly, (Rello et al., 2020) correctly identified 80% of children with dyslexia in over 3600 participants by assessing phonological awareness, however, they did not assess any other areas such as reading speed, confounding neurodevelopmental disorders or degree of dyslexia. For this reason, theirs can only be used as a screening tool and not as a diagnostic one (Rello et al., 2020). In addition, (Rauschenberger et al., 2022) designed a web-game, called ‘MusVis’, which was able to observe significant differences between children with and without dyslexia, relying on seven significant variables including duration round, duration interaction and average click time. However, they also highlighted weaknesses in that if this was to be used to screen a large number of children, they would need more personnel and training data, due to the complexity of the assessment (Rauschenberger et al., 2022). Differently from the studies presented so far, (Jafarlou et al., 2021) assessed the potential of eye movement tracking in the detection of dyslexia in children. They used a t-test to show a significant difference in the oculomotor movements of dyslexic children, showing that children with dyslexia have a lower accuracy and longer time to reach visual targets than those without dyslexia (Jafarlou et al., 2021). These studies all used the same style of computer-based reading games, and all concluded that the largest deficit seen in dyslexic children is in phonological manipulation, despite applying varying methods.

A similar study by (Niemela, 2020) found that using a clustering method to analyse children, who had been identified by their school teachers as having difficulty with learning letters, pronunciation and wording, playing ‘serious games’ could be an effective method to split them into different categories enabling the identification of those most at risk of being dyslexic (Niemela, 2020). They assessed these children based on their development in connecting speech sounds by playing ‘serious games’, with a total playing time across two 60-minute sessions. Those with the lowest scores were tracked for progress and if little progress was made over the sessions, then they were flagged as being most at risk of having dyslexia.

(Piazzalunga et al., 2023) found related results using the same techniques to screen for dysgraphia. They used eye tracking technology and machine learning models to identify those children with and without dysgraphia. Nonetheless, they reported an accuracy under 70% in the testing and many children complained of the intervention being too uncomfortable or easily distracting, posing a hesitance as to whether this would be a successful technique for future use (Piazzalunga et al., 2023).

Another study by (van de Ven, 2017) also found significant deficits in phonological decoding skills between children with and without dyslexia assessing pseudoword naming and reading time. In this remit, they researched whether a computer intervention could improve the symptoms of dyslexia rather than create a diagnosis (van de Ven, 2017). However, they had a small sample size, which may bias the results found, and the intervention took place at school even though their technology was designed to be used in the comfort of their own home. Finally, always according to (van de Ven, 2017), there was no significant advantage between having an early or late intervention as the early intervention improved the reading time, but the late intervention had a larger impact on the number of pseudowords correctly identified. Using the same methods, (Larco et al., 2021) designed the ‘Helpdy’ app, which proved to be effective in improving the symptoms of dyslexia, but their research did not include any test to quantify the improvements. Schmitt et al. (Schmitt, 2018) used web-based games to develop for literacy purposes in children, finding significant improvements in letter skills and vocabulary in a group using a literacy-focused website compared to an entertainment site. This suggests computer-based games can aid literacy difficulties in dyslexic children and could be a viable future intervention.

The papers that researched ADHD screening and diagnosis using computer game technologies all concluded that their interventions successfully aided either the diagnosis or improvement of ADHD symptoms (Heller et al., 2013, Perochon, 2023, Apiquian et al., 2020, Slobodin et al., 2020, Garcia-Redondo et al., 2019). Four studies, all using

different computer-generated techniques, showed that computer software was effective in aiding the diagnosis of ADHD (Heller et al., 2013, Perochon, 2023, Apiquian et al., 2020, Slobodin et al., 2020). (Slobodin et al., 2020) used MOXO-CPT to diagnose ADHD with 87% accuracy, 89% sensitivity, and 84% specificity to being more accurate at diagnosing ADHD than the current method. However, they did not include all the factors affecting CPT performance. Moreover, their study was only based on clinically referred children with ADHD from one region of Israel, a small sample size which could bias the data results (Slobodin et al., 2020). In addition, (Heller et al., 2013) used gaming software to assess its effectiveness in the diagnosis and not in the improvement of ADHD symptoms. They correctly identified 78% of those with inattentive ADHD and 75% of those with combined type ADHD (Heller et al., 2013). In a similar way, (Perochon, 2023) found that with their tablet-based game, children with ADHD showed a significantly greater motor impairment, where the accuracy and timing to 'pop the bubble' was lower and slower than neurotypical children. However, this paper focused on researching children with autism and comparing these children to those with coexisting ADHD, adding bias to the results (Perochon, 2023). Likewise, (Apiquian et al., 2020) used the scores from a video game 'Chefmania,' assessing attention, memory, and impairment in executive functions to compare children with and without ADHD, showing a statistically significant difference between children with ADHD and without, highlighting that this may be a plausible screening technique for the future. However, it is unclear how the scores of Chefmania are obtained and if there are any confounding variables that may affect these scores which could bias the data. Furthermore, they noted that artificial intelligence or neural networks could be used to allow adaptations to be made to allow subjects with cognitive impairments to take part (Apiquian et al., 2020).

Finally, (Garcia-Redondo et al., 2019) used the D2 attention test to assess if a 28-session program of two ten-minute sessions a week using their app affected attention levels. They found a statistically significant difference in the change in D2 in the experimental group, though they used a small sample size and did not include a control group of children without ADHD to show that this app specifically aids children with ADHD. This shows that computer intervention could not only act as a promising future diagnostic tool for ADHD but also offer a therapeutic advantage in the treatment of ADHD (Garcia-Redondo et al., 2019).

Overall, this systematic literature review proves that video games are the most versatile and efficient means of diagnosing and treating Dyslexia and ADHD in children. Clustering methods, eye-tracking, and ML assess the validity and analyze the efficiency, define players' profiles, and examine the handwriting.

However, this study has a few limitations. Firstly, it did not incorporate other databases (e.g., Web of Science). Secondly, the articles reviewed were only in English. Thirdly, an intrinsic limitation of reviews is publication bias, as they rely on published literature that may not represent all research conducted. Further to this, the pathology of dyslexia manifests differently with different languages due to the different orthographic complexity between language learning (Reis, 2020) and so with the studies mentioned being carried out in different countries and by our inclusion of only English publication, this could also have biased our results.

6. Conclusion

This systematic literature review thoroughly investigated and evaluated the technologies and techniques currently hypothesized to be a potential screening and diagnosis tool in the future for neurodevelopmental disorders, including Dyslexia and ADHD. Technologies like gamified computer-based testing for screening and diagnosing children at an early age are mostly used. Gamification in the selected articles is either based on web applications or mobile applications, However, the generalization of the tool acting as a vector for the application is not trivial. Indeed, several factors (such as, for example, the size of the device screen) can modify the child's response by introducing various limitations in the actual use, due to the physical conformation of the instruments, such as crowded labels (for small screens, such as smartphones) or analogic differences in how the child holds the instrument and interacts with it, that can modify reaction times and parameters in general.

However, mobile apps are not limited to disease assessment and health monitoring and medical diagnosis. Smartphones can now be used for administrative purposes, (i.e., monitoring, recognition, etc.) (Baig et al., 2019) although the tablet remains a preferred tool for physical interaction with children in infant age.

Techniques like eye tracking and clustering with different machine learning algorithms are used to simulate and analyze the results of data collected during screening based on gamification to highlight the children who are showing signs of dyslexia. Furthermore, MOXO-CPT is also used for data collection purposes with the combination of machine learning algorithms for ADHD screening purposes. Other research studies showed ways in which computer-based gamification could also improve the literacy skills in those with dyslexia or those who have been identified as having low literacy skills.

Despite the presence in the scientific literature of this cutting-edge research, little to none has yet been translated into clinical practice. Speech therapists and specialists of neurodevelopmental disorders still recur to paper-based tests and examinations, which are not very efficient in terms of constant monitoring and vary significantly from country to country. With Health 4.0 under way, and Health 5.0 being the future step, digitization and personalization are key pillars for healthcare (Mbunge, 2021). This is well-aligned with the UK NHS Long Term Plan aims of improving access to services,

enhancing patient experience, support clinical decision-making, and enable more efficient and effective delivery of care (NHS, 2019).

The key findings of this review highlight possible solution paradigms, which can be used to streamline the existing processes and move towards an ever more digital approach, making the process a lot quicker and easier to attain. After all, this is one of the cores aims of Paperbox Health, which is looking after the design and validation of a serious gaming software aimed at the early diagnosis of neurodevelopmental disorders, leveraging consumer-grade electronics (e.g., smartphones and tablets) and artificial intelligence.

References

1. ALT, M., HOGAN, T., GREEN, S., GRAY, S., CABBAGE, K. & COWAN, N. 2017. Word Learning Deficits in Children With Dyslexia. *Journal of Speech, Language, and Hearing Research,* 60**,** 1012-1028.
2. APIQUIAN, R., ULLOA, R. E. & VICTORIA, G. 2020. Standardization and validity of Chefmania, a video game designed as a cognitive screening test for children. *Humanities and Social Sciences Communications,* 7**,** 51.
3. ARO, T., EKLUND, K., ELORANTA, A. K., NRHI, V., KORHONEN, E. & AHONEN, T. 2019. Associations Between Childhood Learning Disabilities and Adult-Age Mental Health Problems, Lack of Education, and Unemployment. *Journal of Learning Disabilities,* 52**,** 71-83.
4. ARORA, S., GOODALL, S., VINEY, R. & EINFELD, S. 2020. Societal cost of childhood intellectual disability in Australia. *Journal of Intellectual Disability Research,* 64**,** 524-537.
5. ASSOCIATION, A. P. 2013. *Diagnostic and Statistical Manual of Mental Disorders: DSM-5,* Arlington, VA ; Washington, DC, American Psychiatric Association.
6. BAIG, M. M., GHOLAMHOSSEINI, H., MOQEEM, A. A., MIRZA, F. & LINDÉN, M. 2019. Clinical decision support systems in hospital care using ubiquitous devices: Current issues and challenges. *Health Informatics J,* 25**,** 1091-1104.
7. BISHOP, C. M. 2016. *Pattern recognition and machine learning,* Springer.
8. BOOTH, A., SUTTON, A., CLOWES, M. & MARTYN-ST JAMES, M. Systematic approaches to a successful literature review.
9. BRAITHWAITE, E. K., GUI, A. & JONES, E. J. H. 2020. Social attention: What is it, how can we measure it, and what can it tell us about autism and ADHD? *Progress in Brain Research,* 254**,** 271-303.
10. BUCCI, M. P. 2021. Visual training could be useful for improving reading capabilities in dyslexia. *Applied Neuropsychology: Child,* 10**,** 199-208.
11. CASTALDI, E., PIAZZA, M. & IUCULANO, T. 2020. Learning disabilities: Developmental dyscalculia. *Handbook of Clinical Neurology,* 174**,** 61-75.
12. CHUNG, P. J., PATEL, D. R. & NIZAMI, I. 2020. Disorder of written expression and dysgraphia: definition, diagnosis, and management. *Translational Pediatrics,* 9**,** S46-S54.
13. DAMIANIDOU, E., MOURATIDOU, L. & KYROUSI, C. 2022. Research models of neurodevelopmental disorders: The right model in the right place. *Frontiers in Neuroscience,* 16**,** 1031075.
14. FORBES 2023. ADHD statistics and facts in 2024.
15. FRAGAGONZLEZ, G., KARIPIDIS, I. I. & TIJMS, J. 2018. Dyslexia as a Neurodevelopmental Disorder and What Makes It Different from a Chess Disorder. *Brain Sciences,* 8**,** 189.
16. FRANCES, L. 2022. Current state of knowledge on the prevalence of neurodevelopmental disorders in childhood according to the DSM-5: A systematic review in accordance with the Prisma Criteria. *Child and Adolescent Psychiatry and Mental Health,* 16.
17. GARCIA-REDONDO, P., GARCA, T., ARECES, D., NEZ, J. C. & RODRGUEZ, C. 2019. Serious Games and Their Effect Improving Attention in Students with Learning Disabilities. *International Journal of Environmental Research and Public Health,* 16**,** 2480.
18. HADDERS-ALGRA, M. 2021. Early Diagnostics and Early Intervention in Neurodevelopmental Disorders---Age-Dependent Challenges and Opportunities. *Journal of Clinical Medicine,* 10.
19. HELLER, M. D., ROOTS, K., SRIVASTAVA, S., SCHUMANN, J., SRIVASTAVA, J. & HALE, T. S. 2013. A Machine Learning-Based Analysis of Game Data for Attention Deficit Hyperactivity Disorder Assessment. *Games for Health Journal,* 2**,** 291-298.
20. HEN-HERBST, L. & ROSENBLUM, S. 2022. Handwriting and Motor-Related Daily Performance among Adolescents with Dysgraphia and Their Impact on Physical Health-Related Quality of Life. *Children,* 9**,** 1437.
21. HONG, Q. N., SERGI, F., GILLIAN, B. & FELICITY, B. 2018. The mixed methods appraisal tool (MMAT) version 2018 for information professionals and researchers. *Education and Information Technologies,* 34**,** 285-291.
22. JAFARLOU, F., AHADI, M. & JAROLLAHI, F. 2021. Eye movement patterns in Iranian dyslexic children compared to non-dyslexic children. *Auris Nasus Larynx,* 48**,** 594-600.
23. JEPSEN, P. & YOUNOSSI, Z. M. 2021. The global burden of cirrhosis: A review of disability-adjusted life-years lost and unmet needs. *Journal of Hepatology,* 75**,** S3-S13.
24. KARANDE, S., D'SOUZA, S., GOGTAY, N., SHILEDAR, M. & SHOLAPURWALA, R. 2019. Economic burden of specific learning disability: A prevalence-based cost of illness study of its direct, indirect, and intangible costs. *Journal of Postgraduate Medicine,* 65**,** 152-159.

25. KHALEGHI, A., AGHAEI, Z. & BEHNAMGHADER, M. 2022. Developing two game-based interventions for dyslexia therapeutic interventions using gamification and serious games approaches entertainment computing journal. *Entertainment Computing,* 42**,** 100482.
26. KULARATNA, S., JADAMBAA, A., SENANAYAKE, S., BRAIN, D., HAWKER, N., KASPARIAN, N. A., ABELL, B., AULD, B., EAGLESON, K., JUSTO, R. & MCPHAIL, S. M. 2022. The Cost of Neurodevelopmental Disability: Scoping Review of Economic Evaluation Methods. *Clinicoeconomics and Outcomes Research,* 14**,** 665-682.
27. LARCO, A., CARRILLO, J., CHICAIZA, N., YANEZ, C. & LUJN-MORA, S. 2021. Moving beyond Limitations: Designing the Helpdys App for Children with Dyslexia in Rural Areas. *Sustainability,* 13**,** 7081.
28. MATHER, N. & SCHNEIDER, D. 2023. The use of cognitive tests in the assessment of dyslexia. *Journal of Intelligence,* 11**,** 79.
29. MBUNGE, E. 2021. Sensors and healthcare 5.0: Transformative SHIFT IN virtual care through Emerging Digital Health Technologies. *Global Health Journal,* 5**,** 169--177.
30. NAZAROVA, V. A., SOKOLOV, A. V., CHUBAREV, V. N., TARASOV, V. V. & SCHITH, H. B. 2022. Treatment of ADHD: Drugs, psychological therapies, devices, complementary and alternative methods as well as the trends in clinical trials. *Frontiers in Pharmacology,* 13**,** 1066988.
31. NHS. 2019. *NHS Long Term Plan* [Online]. Available: https://www.longtermplan.nhs.uk/ [Accessed].
32. NHS. 2021. *Attention deficit hyperactivity disorder (ADHD)* [Online]. Available: https://www.nhs.uk/conditions/attention-deficit-hyperactivity-disorder-adhd/ [Accessed].
33. NICE. 2019. *NICE Guideline NG87 -- Autism spectrum disorder in under 19s: support and management* [Online]. Available: https://www.nice.org.uk/guidance/ng87 [Accessed].
34. NICHD. 2020. *What are reading disorders?* [Online]. Available: https://www.nichd.nih.gov/health/topics/reading/conditioninfo/disorders#:~:text=Reading%20disorders%20occur%20when%20a [Accessed].
35. NIEMELA 2020. Game learning analytics for understanding reading skills in transparent writing system. *British Journal of Educational Technology,* 51**,** 2376--2390.
36. PEROCHON, S. 2023. A tablet-based game for the assessment of Visual Motor Skills in Autistic Children. *npj Digital Medicine,* 6.
37. PIAZZALUNGA, C., DUI, L. G., TERMINE, C., BORTOLOZZO, M., MATTEUCCI, M. & FERRANTE, S. 2023. Investigating Visual Perception Impairments through Serious Games and Eye Tracking to Anticipate Handwriting Difficulties. *Sensors,* 23**,** 1765.
38. RAUSCHENBERGER, M., BAEZA-YATES, R. & RELLO, L. 2022. A universal screening tool for dyslexia by a web-game and machine learning. *Frontiers in Computer Science,* 3.
39. REDDY, S. M. & REDDY, K. J. 2016. A comparative study of the knowledge, attitude and quality of life about dyscalculia among adolescents with and without dyscalculia. *Journal of Contemporary Psychological Research,* 4**,** 36.
40. REIS, A. 2020. Reading and reading-related skills in adults with dyslexia from different orthographic systems: A review and meta-analysis. *Annals of Dyslexia,* 70**,** 339--368.
41. RELLO, L., BAEZA-YATES, R., ALI, A., BIGHAM, J. P. & SERRA, M. 2020. Predicting risk of dyslexia with an online gamified test. *Plos One,* 15**,** e0241687.
42. ROBERTS, G., PRICE, A. & OBERKLAID, F. 2012. Paediatrician's role in caring for children with learning difficulties. *Journal of Paediatrics and Child Health,* 48**,** 1086-1090.
43. SAHOO, M. K., BISWAS, H. & PADHY, S. K. 2015. Psychological Co-morbidity in Children with Specific Learning Disorders. *Journal of Family Medicine and Primary Care,* 4**,** 21-25.
44. SCHMITT, K. L. 2018. Learning through play: The impact of web-based games on early literacy development. *Computers in Human Behavior,* 81**,** 378--389.
45. SHULTZ, J. J. 2008. Is Dyslexia Hereditary? *Family Education Network*.
46. SLOBODIN, O., YAHAV, I. & BERGER, I. 2020. A Machine-Based Prediction Model of ADHD Using CPT Data. *Frontiers in Human Neuroscience,* 14**,** 560021.
47. SNOWLING, M. J. & HULME, C. 2012. Annual research review: the nature and classification of reading disorders--a commentary on proposals for DSM-5. *Journal of Child Psychology and Psychiatry,* 53**,** 593-607.
48. SONUGA-BARKE, E. J., KOERTING, J., SMITH, E., MCCANN, D. C. & THOMPSON, M. 2011. Early detection and intervention for attention-deficit/hyperactivity disorder. *Expert Review of Neurotherapeutics,* 11**,** 557-563.
49. STOKES, J. D., RIZZO, A., GENG, J. J. & SCHWEITZER, J. B. 2022. Measuring Attentional Distraction in Children With ADHD Using Virtual Reality Technology With Eye-Tracking. *Frontiers in Virtual Reality,* 3**,** 855895.

50. UCL. 2013. *Learning disabilities affect up to 10 per cent of children* [Online]. Available: https://www.ucl.ac.uk/news/2013/apr/learning-disabilities-affect-10-cent-children [Accessed].
51. VAJS, I. & PAPI 2023. Accessible Dyslexia Detection with Real-Time Reading Feedback through Robust Interpretable Eye-Tracking Features. *Brain Sciences,* 13**,** 405.
52. VAN DE VEN, M. 2017. Early reading intervention by means of a multicomponent reading game. *Journal of Computer Assisted Learning,* 33**,** 320--333.
53. VERWIMP, C., VAESSEN, A., SNELLINGS, P., WIERS, R. W. & TIJMS, J. 2024. The COVID generation: Online dyslexia treatment equally effective as face-to-face treatment in a Dutch sample. *Annals of Dyslexia*.
54. YEPES-NUEZ, J., URRUTIA, G., ROMERO-GARCIA, M. & ALONSO-FERNANDEZ, S. 2021. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *Revista Espa \~ n ola de Cardiolog \'i a (English Edition),* 74**,** 790-799.

Supplementary Files

Multimedia Appendixes

The MMAT table, which provides detailed quality appraisal information for the studies reviewed, should be included in the Multimedia Appendix. This section allows for supplementary materials that support the main text of the manuscript, providing additional data and tools such as the MMAT table for quality assessment.
URL: http://asset.jmir.pub/assets/3b932b23b9f87ccf31d45c440f61a1b7.xlsx