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(REVIEW ARTICLE)

A new era of ICTs for combating symptoms of neurodevelopmental disorders

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Abstract

Information Communication Technology (ICT) is an umbrella definition, where the purpose of its creation and use is to facilitate communication, storage, and transfer of big data and the development and use of the technology that supports it. In contemporary research, several studies have observed attempts to incorporate them in populations with neurodevelopmental disorders (NDDs) to detect/assess, intervene, and improve deficits for the inclusion of these individuals in education and society. This review attempts to explore new universal and mainstream technology and to broaden and provide data for employing it in future research or intervention in the school setting as a complementary addition to education combating core symptoms of the three most recurring NDDs including autism spectrum disorder (ASD), attention deficit hyperactivity disorder (ADHD) and developmental coordination disorder (DCD).

Keywords: ICT; NDDs; ASD; ADHD; DCD; New technologies; IOT; Assistive Technology

1. Introduction

Neurodevelopmental disorders (NDDs) are congenital disorders with neurological underpinnings that lead to lifelong conditions that include autism spectrum disorder (ASD), intellectual disability, attention deficit hyperactivity disorder (ADHD), and developmental coordination disorder (DCD) among others (Parenti et al., 2020). These disorders can cause language, behavioral, and learning challenges and may require a combination of treatments and interventions (Morris-Rosendahl & Crocq, 2020).

One of the main characteristics of NDDs is that they usually start to present prominently mainly in childhood, before puberty affecting boys more often (Thapar et al., 2017). However, both clinical and epidemiological studies suggest that the co-occurrence of all NDDs is very common, and that the co-occurrence of these disorders is much higher than would be expected. Of these, DCD is a disorder involving multiple conditions, with up to 69% of affected children having a diagnosis of one or more NDDs such as ADHD, dyslexia, specific language disorder, or ASD (Pergantis & Drigas, 2023b; Pergantis, 2023). Up to 50% of children with ADHD have motor function difficulties, while 10-40% have a mood disorder and 20-30% have a tic disorder. In studies of twins with ADHD, high rates of comorbidity with reading and math disorders (10-40%) and (28-64%) were also found. Finally, regarding the comorbidity of ASD with other disorders, it is estimated to be between 30 and 50% with ADHD and over 70% with motor function deficits. Based on data and findings from genetic, imaging, and environmental epidemiological studies, NDDs can be interpreted as deficits that belong to a common neurodevelopmental spectrum (Dewey, 2018).

The predominant problems experienced by people with ASD involve a variety of repetitive and sensory behaviors, limited interests, and difficulties in social communication that may arise from early childhood (Pergantis & Drigas, 2023a; Pergantis & Drigas, 2023c). Data reported by the CDC indicate that ASD will be diagnosed in approximately 1 in 36 children, with boys being four times more likely to be affected (Maenner et al., 2023) with reported results involving a related study in Greece of children aged 10 to 11 years being 1.15% (Thomaids et al, 2020). ASD is a disorder that is

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highly diverse and can occur in combination with other conditions such as intellectual disability, ADHD, and DCD which can significantly affect the individual's functioning in daily life.

ADHD is one of the most prevalent neurobehavioral NDDs of childhood. The predominant symptoms presented by the individual involve deviant levels of inattention and hyperactivity/impulsivity, which causes significant impairment in the individual's functioning and participation in daily life. This disorder can cause functional deficits which can significantly affect the individual's social, emotional, and academic skills. In addition, children with ADHD may experience a higher incidence of specific learning disorders, movement disorders, and psycho-emotional disorders compared to the typical population. ADHD is also a disorder associated with deficits related to executive functions. The executive functions are located in the frontal lobe and some of their main functions involve sustained attention, working memory, problem-solving, and the inhibition and regulation of behavior (Roshania et al., 2021). Finally, they appear to have a high rate of comorbid conditions with other NDDs such as ASD and DCD (Rajaprakash & Leppert, 2022).

DCD is a category of NDDs that also seriously affects the functioning of the individual in daily life. Like all NDDs, it appears and manifests in early childhood with difficulties mainly related to motor learning. More specifically, the difficulties presented are related to both gross and fine motor skills which negatively affect the individual's autonomy. Although this disorder occurs at a rate as high as 5-6% in the global literature, it has been considered a hidden disability (Caçola, 2016; Zwicker et al., 2018; Blank et al., 2019). In addition to the primary movement problems that the individual experiences, secondary problems can also occur which are related to low social interaction and self-esteem (Kirby et al, 2013; Harris et al., 2021), emotional disturbances, depression, and obesity which follow the individual throughout their life. This disorder is also presented as one of the most comorbid conditions with other NDDs dominated by ADHD with studies reporting up to 70% co-occurrence (Goulardins et al., 2017; Lachambre et al.,2021).

Rapid technological developments in recent years have provided information and communications technology (ICT), technological tools, and resources used to transmit, store, create, share, or information exchange, which can help students with Special Educational Needs (SEN) in various school activities. According to literature reviews, ICT, such as tablets and smartphones with a range of software and applications, can be beneficial for students with SEN because it can enhance learning outcomes and lead to better learning (Yngve et al., 2021). The purpose of this literature review is to broaden and examine the use of modern and emerging universal technologies that can potentially be or already have been used as ICT and analyze research data that provides evidence of their use, examining their effectiveness in combating symptoms in three of the most prevalent and frequently occurring categories of disorders which are ADHD, ASD, and DCD.

2. Materials and Methods

This literature review attempts to create a framework for professionals and to provide data and information about the use of recent universal technologies according to their effectiveness in the NDDs population by answering the following research questions. 1)How does recent and universal technology help combat the symptoms of the most common NDDs of childhood? 2)What is the evidence behind their use in special settings or schools?

The purpose of this literature review was to examine recent data across ten years from January 2013 to December 2023. The method used to conduct this literature review was based on a literature search through multiple platforms, including Google Scholar, ResearchGate, and PubMed, using a snowball search method to select articles. The following keywords were used for the selection process “NDDS”, “Neurodevelopmental Disorders”, “ICT”, “New Technologies”, “Assistive Technology”, “IOT”, “ASD”, “ADHD”, “DCD” and the combination of them.

The inclusion criteria for the selected articles of the main part were the following: 1) articles and research from 2013 and above 2) articles and research written in English 3) technologies that can be affordable and accessible to the main public.

3. Virtual Reality

Virtual reality (VR) can take many forms, from the presentation of highly interactive virtual worlds on desktop computers to fully immersive multi-sensory environments in study labs. Using a VR-based learning environment, participants practice social skills while learning in a controlled and varied environment that is non-threatening, and holistic, but realistic and motivating. In addition, VR technology can and does present authentic and plausible scenarios and social encounters that mirror real-life events and ensure that people in the virtual world act and react similarly to

people in the real world (Ke et al., 2020). People with ASD appear to have reduced levels of anxiety when in a virtual reality environment designed to promote calmness (Pergantis and Drigas, 2023a)

In a related study by Ip et al. (2018) to create a program that aims to improve skills related to emotional and social adjustment in children with ASD using VR, the researchers concluded after comparing the results that significant improvements in key measures of emotional expression and regulation in children's social-emotional reciprocity occurred. For the study, six unique learning scenarios were created using appropriate psychoeducational procedures and protocols. One of them was related to emotion regulation and relaxation strategies, four simulating different social situations and one promoting integration and generalization. These scripts were administered to a sample of 94 children diagnosed with ASD, aged 6-12 years, in a 28-session, 14-week program.

Further findings were also added in related research by Ke et al. (2020) using VR technology to develop their social skills. The researchers used OpenSimulator to create a tabletop virtual reality-based learning environment that supports socially oriented role-playing, games, and planning for children with ASD. The study sample consisted of 7 children aged 10-14 years with ASD and on average participated in the program for over 20 hours. Data were collected through screen recording and observation of social skills and design implementation, as well as social communication and skills questionnaires before and after the intervention. Results showed that participants demonstrated increased levels of success in social skills from the initial to the final phase of the intervention.

Finally, in a related recent systematic review by Liu (2023) to investigate the literature on the effectiveness of VR on the social skills of children with ASD, it was revealed in all included studies based on PRISMA that the use of VR was effective and feasible for social skills interventions. Regarding the school environment and its integration into it, relevant research was conducted by Newbutt et al. (2020) to investigate how VR technology helps and what children's perceptions and preferences are around its use in classrooms concerning the sensory challenges they may encounter. The participants of the study were 31 children with ASD aged 6-16 years. The results of the survey which examined the use of VR head-mounted displays concluded through a mixed methods analysis approach that the children in the sample described them as physically and visually fun, easy to use, and exciting, wanting to use them again, identifying many benefits around relaxation and calmness, the ability to explore locations before visiting the real world and the development of learning opportunities.

Shema-Shiratzky et al. (2018) used VR technology to study the effect of combined cognitive-motor training with use to improve behavior, cognitive function, and dual-task performance in children with ADHD. For the study, 14 school-aged children with ADHD who were not taking medication received 18 sessions over 6 weeks. Training included walking on a treadmill while overcoming virtual obstacles. Behavioral, cognitive, and gait symptoms were assessed before and after exercise and at a 6-week follow-up. The results of the study showed that treadmill training using VR is feasible and may be an effective treatment for improving behavioral, cognitive, and dual-task functioning in children with ADHD.

Virtual Reality is an emerging tool for DCD with which researchers can examine motor imagery (MI). Motor imagery refers to the mental representation of specific body parts without including actual movement. This skill involving the internal modeling of body movements helps in anticipating, handling situations, and planning actions to be resolved. This ability has been investigated and correlated with weaknesses that arise due to the motor learning difficulty that occurs in individuals with DCD (Adams et al., 2016).

Ebrahimi Sani et al. (2020) in their study investigated the predictive ability and control of boys with DCD (n = 40, a = 7-10 years old) who were divided into two groups (control group and VR group). For the study, VR was used in combination with the X-box 360 Kinect. The results of the study showed that the children who received the VR significantly improved and performed better than the control group in their ability in MI, motor planning, and motor control within 8 weeks, with the results being maintained at re-test.

Similar findings were concluded by Marshal et al. (2020) examining predictive motor control in children with DCD (n=20). These children were randomly divided into two groups: Action Observation and MI (who watched videos of people performing the task while imagining the motor sensations associated with performing the action) and a control group (who randomly watched videos that had no motor content). The results showed that the MI and action observation group performed significantly better on the required task than the control group suggesting that these types of treatments would have significant benefits in improving the symptoms of children with DCD.

4. Gamification

Gamification in education is a strategy to increase engagement by incorporating game elements into educational environments. The goal is to create a level of engagement comparable to what games can typically generate. The main goal of gamification is to improve certain abilities, set learning goals, engage students, optimize learning, and support behavior change and social integration (Smiderle et al., 2020).

One category of ICTs that can be integrated to combat the key symptoms of ADHD are «serious games". Serious games encompass many definitions and concepts and can be presented in various forms. At their core, they are characterized as digital games that not only serve as entertainment tools but also offer a rich multimedia experience with the main objective of providing knowledge and skills training by providing the user with an appropriate experience in an ideal, entertaining and motivating environment. Users interact with each other usually with an input/output device (keyboard, touch screens, and mouse). Their main features include three elements which are simulation training, computer games, and sports (Almurashi et al., 2022). The serious games environment to be considered successful must include an immersive experience, meaningful engagement, engagement of learning by doing, simulation of real environmental problems, autonomy in-game decisions, and the presence of a guide (Tan & Nurul-Asna, 2023).

According to related research by Janakiraman et al. (2021), it has been shown that their use and implementation in the classroom can broaden students' interests and present an alternative way of learning to students who show reduced engagement motivation from conventional modes of instruction. Concerning their use in populations that include ASD, the samples presented are encouraging and emergent about their effectiveness, but there appear to be limitations in several of the existing studies that make it difficult to generalize the results. Some of these include the fact that most of them are aimed at a high-functioning ASD population and that issues arise regarding the reliability of their clinical evidence as well as their compatibility. Another limitation presented is the common lack in their description (Grossard et al., 2017). In a related review by Zakari et al. (2014) where an analysis of 40 serious game-type games was conducted, several limitations were also identified regarding the doctrinal configuration and design regarding their sensory processing repetition of behaviors as well as the development of imaginative play. Similar findings were added by Hassan et al. (2021) in which the use of serious games in the years 2000 to 2019 was investigated, using the Connolly rating scale. The researchers assessed and analyzed the results of the study which focused on samples that included high-functioning ASD (Asperger's). Several limitations were observed in the results, as in previous studies, which were related to sample size, clinical validity and reliability, and regular re-examinations of the populations.

People with ADHD can benefit from computer-assisted learning, particularly game-based interventions, which can improve their behavior in daily life, academic performance, and self-control. Research has shown that gaming enhances the level of engagement and motivation in people with ADHD (Alabdulakareem and Jamjoom, 2020).

Castro et al. (2023) in their systematic review studied the effect of computer-based interventions by analyzing 20 studies on their effect on executive functions of children with ADHD. The results showed that this type of intervention was found to have significant effects on improving working memory and attention, inhibitory control, and planning.

Benzing and Schmidt (2019) studied the effect of exergaming using the Microsoft X-box Kinect on the executive, cognitive, and motor functions of children with ADHD. For the study in a randomized, parallel-group trial, 51 children 8 to 12 years old (M = 10.63, SD = 1.32) with a diagnosis of ADHD were assigned to an 8-week video game intervention group (three 30-minute guidance sessions per week) or a wait-list control group and assessed pre- and post-intervention on basic executive functions (inhibition, shifting, and revision). Results showed that this type of intervention can improve the skills of children with ADHD in their executive functions and motor skills.

Active video Games (AVGs) are a type of ICT that has been used extensively as a tool to improve and develop physical activity and motor skills. Their differentiation from conventional games is that they incorporate a plethora of output devices and sensors that require the use of gross and coordinated body movements. Their implementation typically occurs on game consoles including the Nintendo Wii, PlayStation, and X-box using their respective input or output devices which may include a handheld stick, dance mat, or camera (Howie et al., 2017). Regarding the use of game consoles to target deficits in fundamental skills that are presented in DCD using AVGs, one of the most prevalent consoles studied was the Nintendo Wii.

Ferguson et al., (2013) studied and compared the use of Wii training and Neuromotor Task Training in 19 children with DCD aged 6-10 years old finding multiple benefits in terms of improving mean motor performance scores.

Jelma et al. (2014) in their research study using the Wii compared two groups of typical children (n=20) and children with possible DCD (n=28) with difficulties in dynamic balance. Children with ADHD were given a 6-week intervention program in which post-intervention results showed gains in all testing categories (balance, running speed, and agility).

Neto et al. (2019) studied the effect of the Wii on the motor performance of children with DCD aged 7-10 years for 16 sessions of 60 minutes each. Following the intervention, they also found benefits concerning their manual dexterity, targeting and grasping, and balance, with greater benefits observed in manual dexterity.

Finally, Hashemi et al. (2022) found benefits in using the Wii to improve executive functions and visual perception in boys (n=50, M. A= 9.55) with DCD who were divided into two study groups (usual schedule and Wii training) for 8 weeks, 3 30-minute sessions. The results showed a positive effect in both groups in improving executive skills and visual perception.

Smitts-Engelsman et al. (2021) examined the effect of AVGs in a population of children with DCD and compared them to typically developing children aged 7-12 years (DCD, n=32 and TA, n=28) in the school setting. The results of the study showed a positive effect in both test groups on improving children's motor coordination, balance, and aerobic and anaerobic health, demonstrating that their use in school settings can improve and enhance motor performance.

Further findings were confirmed in the meta-analytic research by Li et al. (2022) to evaluate the effect of AVGs on the development of typical and non-typical gross motor skills in children. Results from the 21 included studies concluded that AVGSs had a significantly positive effect on gross motor skills [SMD = 0.59, 95% CI (0.40, 0.77)].

5. Wearables

Wearable technologies can be considered an important ICT tool because they help to transfer useful information on the detection of neurophysiological changes and increased activation of the HPA axis which is a phenomenon in ASD that often occurs when these individuals encounter environmental inputs that are not harmful to them and situations such as a social interaction that may cause them increased stress. These technologies involve a variety of user-wearable devices with specific user-friendly features. This category includes devices that can often be found on the market for widespread use such as smartwatches, smart clothes, and smart glasses. Through them, many functions related to neurophysiological changes such as heart rate, variability and responsiveness, respiration rate, skin and body temperature, electrodermal activity, cortisol levels, blood pressure, and blood oxygen are recorded, measured, and interpreted. Further uses include facial recognition for emotional recognition (Liu et al., 2017; Koo et al, 2018; Koumpouros and Kafazis, 2019).

According to Tavakoulnia et al. (2019), wearable technology may be particularly useful in combating symptoms related to executive functions in ADHD. The results of their research showed that the concerns of children with ADHD outweigh the benefits of using smartwatch technology and suggested that an app should mimic the current self-regulation methods taught in their school to be able to monitor self-reflection for mood and behavior. Furthermore, the results suggested that wearable devices could potentially be used as interventions to support executive function in children with ADHD.

6. Mobile and tablet apps

Fage and colleagues (2018) in their pilot study looked at 50 subjects of which 30 were children with ASD and 20 were children with intellectual disabilities in how mobile and tablet apps can help with their inclusion in the mainstream classroom. The intervention involved equipping these children with the specific apps in a three-month intervention at school and home. The main findings showed that students with ASD showed greater improvements in their social adaptive actions and reactions during the school day.

Stathopoulou et al. (2020) studied the effectiveness of digital social stories in children with ASD. For this study, three subjects diagnosed with high-functioning ASD were tested by following a one-year program through a tablet/android designed to solve social interaction problems. The results of the study showed that over a long period, social behavior in children with autism can become more integrated. Findings on the effectiveness of these tools are also confirmed in the study by Leung et al. (2021) to investigate the effectiveness of their use in combating cognitive and social difficulties, reviewing the literature since 2000 by incorporating only randomized trial research. The results revealed that handheld mobile devices may be a promising tool for providing interventions for people with ASD.

Regarding social communication for children with ASD, research by Parsons et al. (2019) examined the effectiveness of a tablet-based early intervention app that uses information and communication technology to complement existing treatments and improve visuomotor and mimicking skills in young children with ASD residing in the community. When all participants were collected and measured over time, results showed that receptive and practical language and social skills improved. These increases were sustained, indicating skill acquisition. This study included 59 participants who were randomly assigned to either the usual care group or the intervention group.

According to the use of mobile apps to reduce symptoms of ADHD Păsărelu et al. (2020) systematically examined iTunes/iOS (Apple App Store), Google Play, and the National Health Service Health App Library from May 2017 to September 2019. Apps were included designed for ADHD, aimed at goal assessment, treatment, or both that were in English and functional. The researchers in their final selection included 109 of the initial 355 that were identified. The results of this study revealed that very few apps contained information about their development, and none contained information about the evidence of its effectiveness.

Based on the studies of several researchers who have used tablets, the results that have been collected and presented for the DCD population show quite encouraging evidence of their effectiveness in a variety of environments including the classroom. More specifically, in the experimental study of Coutinho et al. (2016), we observed that significant improvements were noted regarding the participants' visuomotor integration.

In the pilot study by John and Renumol (2018) in a population of children with DCD and dysgraphia, aged 5-10 years, the Dexteria app was used, and the study sample consisted of 9 children who were tested for speed and legibility of their handwriting. The results showed that such type of program which aims to improve their visuomotor skills and readiness benefited the study participants more.

The same researchers also tested a prototype application (HanDex) which they tested on a sample of children who exhibited deficits related to fundamental skills surrounding writing. The results of the study showed significant improvement in letter formation, spacing, and speed (John & Renumol, 2022).

7. Digital Technologies overview

In this paragraph we underline the importance of all digital technologies in education domain. ICTs support education for everyone, give new methods for efficient teachers training, improve the knowledge retention, encourage collaboration, improve transparency, create learner-centered approaches, invent new teaching methods, and accelerate the knowledge acquisition. Moreover provide new tools for knowledge representation and endorse the education activities and methods via virtualization, mobilization, artificial intelligence, and through new learning environments-worlds. More specifically

in autism training ICTs are very productive and successful, facilitate and improve the assessment, the intervention and the educational procedures via Mobiles which brings educational activities everywhere [57-59] and through various ICTs applications which are the core supporters of education [60-66]. The exploitation of AI, STEM & ROBOTICS raise educational procedures into new levers of adaptability, innovation and performance [67-70], while games transform the education in a multisensory, very friendly and enjoyable interaction [71-72]. Additionally, the adoption, enhancement and combination of ICTs with theories and models of metacognition, mindfulness, meditation and emotional intelligence cultivation [73-81] brings the mental abilities to the core of the education procedures and policies, and as a result accelerate and improve even more the educational practices and results, especially in minority children with autism, treating domain and its practices like assessment and intervention.

8. Results

The integration of Information and Communication Technologies (ICT) in the educational process contributes to the inclusion of students with special educational needs (SEN) and disabilities, allowing them to express their ideas in various ways, either verbally or non-verbally, while encouraging their imagination. In addition, teachers adopt a positive attitude towards the integration of ICT and recognize its important role in the learning process, promoting equal participation of all students, including those with SEN/disabilities.

By using technology in the educational process, students take a more active role and do not remain passive observers, enhancing their sense of autonomy and responsibility for their learning progress. Active learning allows them to develop their skills in a more adapted environment, considering their needs and potential. Finally, the use of ICT is not just a tool

for acquiring knowledge but enhances students' motivation to learn and their interaction in the learning environment, promoting a sense of self-esteem and success.

The prevalent symptoms of children with NDDs appear to have a significant impact on their integration into their school environment. From the results of this study, it appears that the use of new technologies as ICTs may have a positive impact on the participation and engagement of the populations studied in the school setting.

9. Conclusion

More specifically regarding ASD by analyzing the most important difficulties related to social communication, anxiety, and repetitive behaviors, we observed that wearable devices can have positive effects concerning the detection of neurophysiological changes in different situations that may occur in children's daily lives (including school), thus acting as a preventive mechanism. The use of tablets, mobile devices, and VR can be found effective regarding the inclusion of targeted applications, social interaction, social adaptive responses, and anxiety of children creating motivation and new learning opportunities. Finally, serious games also seemed to be a useful tool in their involvement in the educational process but presented several limitations in their research designs for analysis and implementation and are mainly targeted at children with high-functioning ASD.

For the population of children with ADHD with the predominant difficulties related to executive functions, the research results showed positive effects regarding the use of game-based interventions which seemed to improve working memory, inhibitory control, planning, and programming.

In DCD most interventions mainly targeted deficits related to motor skills, academic difficulties, and physical fitness showing encouraging evidence regarding the use of tablets, applications, VR, and AVGs. From the results of the research on these populations, we observed that many of these technologies have been used and measured in school settings as well, showing positive effects on student participation.

Through this literature review, future research is suggested through the use of these technologies as complementary ICT tools in the school environment. The use of larger test samples, design analysis, and software description, longer intervention times, and study of long-term effects for generalizability of future results targeted to application in a personalized intervention context are suggested.

Compliance with ethical standards

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Disclosure of conflict of interest

The Authors proclaim no conflict of interest.

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