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The impact of sleep on neurodevelopmental disorders and the contribution of ICT in improving sleep quality in adolescents and adults

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Abstract

Sleep is an essential process for the human body, contributing to the optimal functioning of the brain and the immune system, aiding in stress management, and overall enhancing quality of life. The relationship between sleep and neurodevelopmental disorders is bidirectional; sleep is influenced by specific disorders, while symptoms of these disorders are exacerbated by sleep problems. This article aims to explore the significance of sleep in the context of neurodevelopmental disorders such as Autism Spectrum Disorder (ASD), Attention Deficit Hyperactivity Disorder (ADHD), and Specific Learning Disorder through a literature review. Additionally, the research concludes that leveraging Information and Communication Technology (ICT), such as virtual reality, digital cognitive behavioural therapy for insomnia (DCBT-I), smartphone applications, and the Internet of Things (IoT), can contribute to improving sleep quality in adolescents and adults.

Keywords: Sleep; Neurodevelopmental disorders; Emerging ICTs; Digital Cognitive Behavioral Therapy for Insomnia (DCBT-I)

1. Introduction

During sleep, the brain processes all the information received throughout the day and prepares for the demands of the following day. Since sleep enhances memory and positively affects the acquisition of new knowledge, it is puzzling that its value is not recognized as it should be in modern society. The fast pace of life and the multitude of daily obligations often lead to the misconception that sleep is sometimes a waste of time. Therefore, it is essential to understand that sleep is a necessary ally for the optimal functioning of the human brain [21], the immune system, and the overall development of an individual. Sleep deprivation is associated with increased anxiety, poor quality of life, decreased academic performance in children and adolescents, and behavioural problems [1].

Neurodevelopmental disorders are mental health challenges caused by alterations or injuries during brain development. Although the identification of these specific disorders occurs in the early years of an individual's life, they continue to accompany the individual into adulthood, affecting their functionality [41]. Children with neurodevelopmental disorders face significant sleep problems compared to typically developing children [50, 51]. It is no coincidence that sleep disorders are one of the diagnostic criteria for many neurodevelopmental disorders. Sleep issues, such as insomnia, observed in neurodevelopmental disorders arise from genetic, neurobiological, and environmental factors [51].

Specifically, Autism Spectrum Disorder (ASD), which falls under neurodevelopmental disorders, is characterized by deficits in social interaction and stereotypical behaviours. In adults, ASD often coexists with other disorders, impacting sleep quality. The prevalence of sleep disorders in children with ASD can reach up to 86%, while the prevalence rate in

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adults has not been adequately documented. Additionally, Attention Deficit Hyperactivity Disorder (ADHD) is a psychiatric disorder marked by symptoms of impulsivity, inattention, and hyperactivity. Sleep disorders, such as insomnia and restless legs syndrome, are among the most common comorbidities in patients with ADHD. Approximately 85% of adults with ADHD report poor sleep quality, while children with ADHD are more likely to experience daytime sleepiness [41]. Moreover, sleep disorders in individuals with learning difficulties are linked to the manifestation of irritability and challenging behaviours. They also face an increased risk of sleep apnea, as they typically engage in less physical activity and maintain unhealthy dietary habits. Estimates suggest that the prevalence of sleep disorders among adults with learning difficulties can reach up to 34.1% [54].

Finally, the contribution of Information and Communication Technology (ICT) as an intervention tool for addressing sleep-related disorders has been highlighted in several recent studies. Monitoring sleep problems can be achieved through technology by utilizing specific devices. ICT-based interventions can be implemented across all age groups [36].

2. Sleep and Working Memory

Sleep is essential for cognitive processes, and its deprivation is linked to difficulties in maintaining attention and acquiring new knowledge. Lack of sleep or poor sleep quality leads to changes in the frontal and parietal regions of the brain, which are crucial for the functioning of working memory [23]. The prefrontal cortex, responsible for executive functions such as memory, attention, and learning, is negatively affected by poor sleep quality or sleep deprivation [13]. Research conducted on 237 children (of whom 82 were girls) in Western Australia found that sleep-related brain dysfunction may specifically concern certain areas of the prefrontal cortex. Additionally, it was shown that sleep deficiency primarily negatively impacts students' verbal memory [45]. Similarly, a study involving 1,749 primary school children in Melbourne, Australia, indicated that poor sleep quality adversely affects verbal working memory rather than visuospatial memory [10]. Overall, disrupted sleep affects cognitive ability, leads to behavioural problems, and hinders academic success [13]. However, a study conducted with 83 students at King Abdulaziz University in Jeddah, Saudi Arabia, found that sleep deprivation did not negatively affect working memory or academic performance. It appears that the students' commitment to their goal of academic success enabled them to overcome objective challenges such as poor sleep quality [3].

Poor sleep quality, especially during adolescence, negatively impacts a child's working memory [60]. A study on infants demonstrated that sleep is critical for their memory function [33], while research conducted on mice indicated that sleep deprivation adversely affects both memory and learning abilities [73]. It is established that NREM sleep contributes to the enhancement of declarative memory, while REM sleep enhances procedural memory [32]. A study conducted on a sample of 40 adolescents aged 10-14 in a California school found that sleep particularly benefits long-term memory [48]. Furthermore, research involving 60 students aged 6 to 13 demonstrated that both the quality and quantity of sleep significantly affect working memory function. Children who did not sleep well struggled to recall auditory and visual information [57]. Additionally, the research by del Angel et al. (2015) aimed to determine whether sleep deficiency affects both the phonological and visuospatial components of working memory. The participant sample consisted of 13 students (5 males and 8 females), and the hypothesis was that reduced sleep over five consecutive days would impact both aforementioned components of working memory. Questionnaires were used as research tools. The study concluded that a reduction in sleep hours over a five-day period negatively affects both the phonological system (related, for example, to decoding and understanding text) and the visuospatial system (responsible, for example, for problem-solving) of working memory [17]. Finally, Xie et al. (2019) investigated whether sleep deficiency negatively impacts working memory capacity. Two studies were conducted as part of this research. In the first study, 110 students (68 of whom were female) from the University of California participated. During the process, students were asked to perform computer-based tasks that assessed their working memory function and complete a questionnaire regarding sleep quality. Based on the results, poor sleep quality leads to consequences for working memory, as it can limit its capacity. Similar findings emerged from the second study, which involved 31 participants (17 of whom were female), aged 21-77, from the Ann Arbor community, with approval from the University of Michigan. The same procedure was followed as in the first study, and results indicated a correlation between disrupted sleep and reduced working memory capacity [65].

3. Sleep and Autism Spectrum Disorder (ASD)

Both children and adolescents with ASD experience more severe sleep problems compared to their typically developing peers, with a prevalence rate ranging from 40% to 80% [18]. Sleep disturbances in ASD are the result of multiple factors [18, 56]. The primary sleep issues faced by children with ASD include insomnia, difficulty initiating sleep, and remaining in bed until they fall asleep [56]. Children with ASD are more susceptible to external stimuli, which explains their

difficulties in falling asleep. Overall, they sleep fewer hours, wake up during the night, and experience daytime sleepiness. Consequently, sleep problems negatively impact attention and learning processes, exacerbate stereotypical behaviors, and cause stress within the individual's family environment. Furthermore, a study involving 101 children aged 4-18 years (of which 45 were diagnosed with ASD) found that, among other issues, children with ASD exhibited sleep-related breathing disorders [20]. It is well known that neurotransmitters such as melatonin, serotonin, and GABA are essential for proper sleep, and any dysfunction can lead to disturbances. Specifically, melatonin, responsible for the regulation of the circadian rhythm, appears to be below normal levels in individuals with autism [18]. The administration of melatonin supplements has proven particularly effective in improving the sleep quality of children with ASD. Controlled-release melatonin, in particular, has been shown to significantly reduce nighttime awakenings and increase sleep duration. Additionally, melatonin supplements positively impact the social behavior of children with ASD, as they reduce their distractibility, anxiety, and manifestation of stereotypical behaviors while improving communication abilities [28].

The poor sleep quality of children with ASD affects their daily lives, leading to difficulties in managing their emotions, increased aggression, lack of mood, and hyperactivity. Moreover, sleep disturbances negatively impact the social skills and academic performance of children with ASD [18]. Individuals suffering from insomnia struggle with concentration and memory problems [58]. A study conducted on children with ASD aged 9-16 years found that sleep, even if restless, contributed to the consolidation of their memory. Specifically, it was observed that memory loss during sleep was significantly less than in wakefulness. Undoubtedly, improving sleep quality in children with ASD can enhance their memory and cognitive functions [43]. Furthermore, poor sleep quality, sleep-related breathing problems, and restless legs syndrome impact children's ability to maintain attention. In their study, Taylor et al. (2012) found that children with ASD who slept less performed lower in terms of intelligence and verbal skills compared to those who slept more hours. Additionally, the same research indicated that disrupted sleep affects children's communication skills [58]. Sleep disturbances cause deficits in working memory, worsening the learning difficulties of adolescents with high-functioning autism [6]. Numerous studies indicate that addressing sleep issues contributes to enhancing the quality of life for individuals with ASD [20]. Moreover, adults with autism face sleep problems [35, 39], such as sleep apnea and insomnia, more frequently than their non-autistic peers, and it is established that poor sleep quality correlates with poor mental health functioning. Improving sleep quality and addressing depression, which often affects individuals with ASD, is crucial for enhancing their mental well-being [35]. A study conducted on 89 individuals with ASD (including 44 children and adolescents and 45 adults) revealed that sleep problems in these age groups serve as predictive factors for psychiatric symptoms such as anxiety and depression. In contrast, no significant correlation was found between sleep disturbances and executive functions [27]. Finally, Holingue et al. (2021) found that children with ASD and ADHD experience sleep disturbances compared to typically developing children. However, they noted a direct correlation between poor sleep quality and difficulties in executive functions in children with ASD, ADHD, and typically developing children [29].

4. Sleep, Attention Deficit Hyperactivity Disorder (ADHD), and Specific Learning Disorder

The majority of children with ADHD face sleep problems, which exacerbate the neurodevelopmental disorder, affecting their functionality and overall quality of life [53, 46]. ADHD is associated with deficits in executive functions, such as working memory [71]. Although further research is needed to establish the correlation between sleep, working memory, and ADHD, it appears that insufficient sleep affects the working memory function in children with ADHD [53]. Fatigue and the inability to control behavior resulting from insomnia have a negative impact on the executive functions of the prefrontal cortex, including working memory and attention [53, 46]. This was also confirmed in a study conducted on children with ADHD aged 5-13 years from 21 pediatric offices in Victoria, Australia, where those facing severe sleep problems exhibited weaknesses in working memory [53]. The manifestation of sleep disturbances in children aged 2 to 9 years serves as a predictive factor for the emergence of ADHD symptoms by the age of 9. Sleep problems create deficits not only in neurocognitive functions, such as attention and memory but also in emotional regulation, which also depends directly on the prefrontal cortex [7]. Lack of sleep negatively affects the prefrontal cortex and activates the amygdala, resulting in an inability to manage emotional responses [59]. Findings from research conducted on adults indicate that sleep deficits significantly affect the prefrontal cortex and amygdala. These brain regions are vital, and if they suffer damage during childhood due to sleep deprivation, it may negatively impact the child's behavioral functioning [44]. A study conducted on 32 children aged 9-12 years (of which 16 had ADHD) found that sleep is beneficial for addressing the procedural memory deficits present in children with ADHD [49]. Additionally, the research by Waldon et al. (2018), conducted on 50 children aged 6 to 12 years divided equally into two groups (ADHD and typically developing children), showed that poor sleep quality adversely affects the attention of children with ADHD [62]. In conclusion, lack of sleep affects attention maintenance and overall executive functions [44].

There is a bidirectional relationship between ADHD symptoms and sleep disturbances [26]. Children with ADHD exhibit more difficulties sleeping (e.g., refusal to sleep, difficulty initiating sleep, restlessness during sleep, and morning wake-up difficulties) compared to typically developing children [42]. It seems that children with ADHD are more likely to develop sleep problems during both adolescence and adulthood [26]. According to findings from a study conducted on 192 children with ADHD, averaging 10 years of age, it was revealed that sleep disturbances affect both the functionality and quality of life of these children. Additionally, it was found that sleep quality shapes their life satisfaction level to a greater extent than the disorder itself [12]. Lack of sleep causes hyperactivity, inability to concentrate, social deficits, and academic failure. In a study conducted in Ankara on 77 boys (of which 46 had ADHD and 31 were typically developing) aged 7-13 years, it was determined that children with ADHD faced sleep problems at a rate of 84.8%, which negatively impacts their quality of life [71]. Furthermore, Carpena et al. (2022) found that sleep deficiency in children correlates with the exacerbation of inattention/hyperactivity symptoms, while persistent sleep disturbances indicate severe ADHD symptoms during adolescence. Additionally, persistent nightmares serve as a predictive factor for ADHD. Since individuals with this disorder struggle to manage their emotions, it appears that nightmares reflect the fear of failure in emotional regulation. Lack of sleep also leads to impulsivity, fatigue, poor mood, and reduced performance in daily activities. Studies indicate that children with sleep deficiency exhibit cognitive and behavioral deficits that mimic ADHD symptoms [7]. Conversely, based on studies, increased sleep duration is associated with higher emotional intelligence, as individuals can perceive others' emotions by decoding relevant information. Research indicates that youth with ADHD struggle to regulate their emotions and process information related to others' emotions. Additionally, youth with ADHD exhibit deficits in cognitive flexibility. Therefore, it is highly likely that these issues are directly related to sleep [59]. According to research, both children and adults with ADHD experience sleep disturbances such as insomnia, daytime sleepiness, restless legs syndrome, and even breathing disorders. The delay in melatonin onset in children with ADHD leads to difficulties in sleep initiation. Establishing a bedtime routine, such as limiting screen time from television or computer devices an hour before sleep, could be particularly helpful [67].

In the case of comorbid ADHD and Specific Learning Disorder, greater sleep problems are observed. Generally, the relationship between neurodevelopmental disorders and sleep is bidirectional: neurodevelopmental disorders affect sleep, while changes in sleep exacerbate symptoms of neurodevelopmental disorders. Poor sleep quality can negatively impact even the effectiveness of pharmacological treatment for ADHD [52]. Sleep disturbances affect cognitive functions and create learning deficits in children and adolescents. Both attention and memory, which are necessary for producing spoken and written language, are disrupted by poor sleep quality. Therefore, it is not surprising that good sleep quality is linked to academic success, according to research findings. In order to determine whether sleep is associated with Specific Learning Disorder and affects the behavior of individuals exhibiting this disorder, a study was conducted. The sample consisted of 58 students aged 8-13 years, divided equally into two groups: the Specific Learning Disorder group and the control group (comprising typically developing students). Based on the results, students with Specific Learning Disorder suffered from sleep disturbances at a higher rate (65.5%) compared to typically developing students (40%). In conclusion, children with Specific Learning Disorder exhibit problems with sleep, attention, and behavior [22].

5. The contribution of ICT in improving the quality of sleep in adolescents and adults

5.1. Virtual reality

Insomnia is a critical issue not only for adults but also for teenagers. Factors such as development or changes in the central nervous system and increased school obligations disrupt the sleep of teenagers, particularly girls, as this disorder is more prevalent among females [15]. Virtual reality is increasingly gaining ground as a therapeutic tool in the field of mental health. In the context of virtual reality, audiovisual three-dimensional interactive stimuli are presented through computers or independent head-mounted displays [15, 25]. Thus, virtual reality can be utilized as an intervention method to facilitate sleep for individuals experiencing this problem. Through virtual reality, individuals experience the simulation of a relaxing state that contributes to changing their mood and restoring the psycho-physiological levels necessary for sleep [16]. In the case of sleep, virtual reality can be utilized to transport individuals to another environment, away from their bedroom, that evokes calmness [15]. The representation of nature within the context of virtual reality contributes to the release of gamma-aminobutyric acid, which is essential for the onset of sleep. In general, the projection of a calming environment through virtual reality aids in the relaxation of individuals and consequently facilitates sleep [19]. As teenagers are familiar with digital media, virtual reality is particularly interesting as it creates motivation and keeps them engaged [15].

A study conducted on 29 girls aged 16-18 years demonstrated that the use of virtual reality combined with diaphragmatic breathing, which occurs at slow rates, contributes both to relaxation before sleep and to the improvement of sleep quality among teenagers [70]. Additionally, research conducted on 16 women with sleep issues found that immersion in a simulated relaxing environment combined with slow diaphragmatic breathing led to an

improvement in sleep quality [16]. In another study involving 52 students aged 16-20 years, participants received guidance for slow diaphragmatic breathing while simultaneously experiencing the atmosphere of a natural environment through virtual reality, accompanied by recorded guided meditation. Although further research is necessary, this study provides insights into addressing hyperarousal in adolescent insomnia and may lay the groundwork for creating new therapies through virtual reality [15]. Furthermore, Eremita & Chitra (2024) conducted research on 32 individuals aged 18-20 years to determine whether virtual reality therapy contributes to the improvement of sleep quality. Participants were provided with virtual reality headsets and a program consisting of three meditation videos. The intervention took place three times a week for 15 minutes. The conclusion drawn is that the intervention through virtual reality improves the sleep quality of individuals with insomnia [19].

Similarly, a study involving 28 students aged 18-30 years was conducted to assess the impact of virtual reality on sleep quality. The intervention showcased a combination of three relaxation videos that depicted nature, while music was simultaneously played through the headphones provided to participants. The intervention lasted for 2 weeks, specifically implemented by the students 20 minutes before bedtime, twice a week. Based on the findings, the utilization of virtual reality contributes to the improvement of sleep quality for individuals facing difficulties in this area [9]. Additionally, in research conducted among 90 participants aged 24-53 years, it was found that the use of 3D virtual reality contributes to facilitating sleep [30]. In a study involving 63 patients with chronic insomnia symptoms, it was determined that the intervention through virtual reality once daily for a duration of 6 weeks contributed to the improvement of sleep quality [63]. Finally, Kim et al. (2024) conducted research to determine whether meditation therapy through virtual reality contributes to improving sleep quality. The sample of participants consisted of 60 nursing students divided into three groups of 20 individuals (experimental group for meditation through virtual reality, experimental group for meditation, and control group). During the intervention involving meditation through virtual reality, traditional meditation techniques were employed in artificial environments that simulated reality. After placing a head-mounted display on each participant, the presentation of realistic virtual reality was achieved through the processing of visual and auditory information via video projection. For the purposes of the study, four types of videos were created (ocean, night sky, walking in the woods in autumn, and walking in a dense forest), and participants had to select one video based on their preference for meditation. This specific intervention was applied for 5 days, lasting 30 minutes and taking place between 10 PM and midnight. The results of the research indicated that meditation through virtual reality positively contributed to the improvement of sleep quality [34].

5.2. Digital cognitive behavioural therapy for insomnia (DCBT-I)

In 1993, Charles Morin proposed Cognitive Behavioural Therapy for Insomnia (CBT-I), an intervention aimed at addressing sleep issues without the use of medications. However, as CBT-I is not widely available and is financially inaccessible, the contribution of technology has led to the creation of digital CBT-I (DCBT-I). DCBT-I is available in various forms, such as educational video programs, but the most widespread and effective form is as a smartphone application. Based on recent studies, DCBT-I can both reduce insomnia symptoms and improve the quality of life of individuals suffering from sleep disorders. In the context of research, DCBT-I was utilized as a smartphone application for insomnia (SleepUp®). The treatment program in this application was based on the conventional form of the CBT-I program, which was adapted for suitable use via the application. Based on the results, DCBT-I reduced insomnia symptoms and significantly improved sleep quality [14]. Additionally, in a study involving 6,002 patients with sleep disorders, anxiety disorders, or comorbidity of insomnia or depression with anxiety disorders, aged 18 years and older, a mobile application was used to implement the DCBT-I intervention. The findings showed that DCBT-I is effective for patients experiencing insomnia problems, while it is also indicated for reducing insomnia symptoms in patients with anxiety disorders, provided that the intervention has a longer duration [38]. In another study involving 39 adolescents aged 14 to 17 years with comorbidity of insomnia and psychological disorders, the DCBT-I Sleepio application was utilized. Sleepio is an intervention that has already been tested in the adult population, is automated, available for free, and consists of 6 sessions, each lasting 20 minutes. Participants could access the program online using their computer, tablet, or smartphone. Although this program is highly interactive, there was also the option for weekly phone calls to provide support from a specialized Sleepio assistant. This option was created with the idea that phone calls could maintain the motivation and engagement of participants, especially as they belonged to a younger age group. Based on the findings, it was determined that DCBT-I Sleepio contributed to the reduction of insomnia, anxiety, and depression symptoms, as well as the improvement of sleep quality among adolescents [11]. Similarly, in a study conducted among 371 adults, the digital application Refresh was utilized, an automated, unguided program also based on the principles of Cognitive Behavioural Therapy for Insomnia (CBT-I). The Refresh intervention was implemented through a commercially available e-health platform. This intervention lasted 8 weeks and consisted of 8 modules lasting 10 minutes each, according to the CBT-I elements proposed by the German Sleep Society. The findings indicated significant improvement in insomnia symptoms [61].

It has been noted that girls face greater difficulty in sleeping compared to boys. One possible explanation may be the hormonal changes observed during adolescence or the anxiety that girls experience regarding sleep. In any case, this issue requires further investigation. Thus, Li et al. (2021) conducted a study to determine whether the use of a specific CBT-I smartphone application contributes equally to reducing insomnia symptoms in boys and girls. The sample of participants consisted of 49 adolescents (33 girls and 16 boys) aged 12-16 years with at least mild insomnia symptoms, and the intervention was carried out through the Sleep Ninja application. Sleep Ninja is an automated smartphone application derived from CBT-I, consisting of 6 lessons lasting up to 10 minutes each. Furthermore, in the context of the intervention, sleep is monitored, and advice is given regarding it, specific sleep times are suggested, and reminders for the evening routine are provided. The delivery of lessons takes place via a chatbot feature where Sleep Ninja acts as a sleep coach. After completing a lesson and three nights during which sleep was monitored, users of the application move on to the next "zone." Based on the findings, a reduction in insomnia symptoms was observed in both boys and girls [37]. It is worth noting that Sleep Ninja is designed based on the needs of young people, making it more appealing to teenagers compared to similar digital programs, such as Sleepio, which is primarily aimed at adults. Specifically, young users were excited by the idea that in Sleep Ninja, users advance levels, and there are "zones." Thus, the white zone corresponds to the beginner level, while the black zone indicates the attainment of advanced sleep level. To advance levels, users must first achieve a series of goals. In this way, the entire process maintains the interest of teenagers and keeps them engaged with the application [64]. Finally, in a randomized sampling study conducted at the First University Hospital of Beijing, it was found that a DCBT-I application adapted to Chinese culture and based on a smartphone contributed to reducing the severity of insomnia and improving the sleep quality of individuals in China. The sample of participants consisted of 77 adults, of whom 38 were assigned to the experimental group and were provided with self-guided DCBT-I through the resleep smartphone application. This intervention lasted 6 weeks and included, among other things, training in sleep hygiene, relaxation therapy, and cognitive therapy. The chatbot communication interface utilized a user-friendly question-and-answer format, and users accessed the application daily for 10 to 15 minutes. In conclusion, the DCBT-I adapted to the cultural context of China, may be suitable for the large number of patients facing insomnia issues [72].

5.3. Applications for smartphones

Thanks to the evolution of technology, portable devices have multiplied, and consequently, mobile applications have become a widespread means of treating various disorders, including sleep disorders [2]. Specifically, mobile applications serve as a useful and particularly convenient tool for improving sleep quality and addressing insomnia, as they are easily accessible to users at any time and in any place they find themselves [31]. In general, health applications for mobile devices (mHealth) used as an intervention for sleep have proven effective in this regard, with no reports of side effects [4]. According to the systematic review conducted by Shin et al. (2017), the utilisation of mobile phones as intervention tools for sleep disorders significantly contributes to improving the symptoms of these disorders and sleep quality [55].

The Nenne Navi application for smartphones was created by experts in child sleep at Osaka University Hospital [68, 69], with the aim of improving the sleep habits of children in Japan through the creation of interaction between caregivers (most often mothers) and specialists. This specific application provides personalised advice according to each family's needs, enabling small behavioural changes related to children's sleep routines. In the research conducted to determine the effectiveness of this intervention, 85 mothers from Japan participated along with their children, who were divided into two groups (intervention and control). During the process, mothers had to answer 36 questions related to the sleep routine for 8 days via smartphone. Based on their responses, personalised advice was sent to caregivers from the application, as well as feedback messages. Additionally, the application provided all caregivers with videos and suggestions for daily activities that contribute to good sleep. At the end of the intervention, mothers were asked to complete a questionnaire assessing the specific application. According to the findings, the Nenne Navi application played a decisive role in improving children's sleep habits [68].

KANOPEE is another smartphone application that helps alleviate insomnia symptoms. It is a free application available through the Google Play Store and Apple Store, although it is only accessible in France. To assess the effectiveness of the KANOPEE application, a study was conducted involving 535 adults. During the 17-day intervention, users interacted through three consecutive interviews with a virtual companion, Louise. The virtual companion provided a sleep diary as a monitoring tool, and personalised recommendations for each user concerning their sleep routine, stimulus management, sleep schedule improvement, and physical activity. According to the results, the self-guided digital intervention offered through the KANOPEE application significantly reduced the severity of insomnia symptoms and improved sleep quality [47]. Another behavioural intervention programme supported by the use of technology is the Sleep Bunny application. The purpose of this application was to increase the duration of sleep. As part of the intervention, participants were provided with a mobile application and a portable sleep monitoring programme (Fitbit).

Additionally, participants attended short weekly guidance sessions conducted over the phone. The results of the study showed significant improvements in both the duration of participants' sleep and their daytime sleepiness [5].

Furthermore, Low et al. (2020) conducted a pilot study with a sample of 23 adults to assess the effectiveness of a mindfulness application for smartphones in improving insomnia symptoms. Participants were randomly divided into two groups. In the experimental group, the mindfulness application Headspace was used as an intervention tool, which included 60 exercises (each lasting 10 minutes) for guided mindfulness meditation. Participants were required to use this application for 60 days, of which 30 days would involve the "Foundation Pack" (covering basic mindfulness skills), and the remaining 30 days would involve the "Sleep Pack" (containing mindfulness skills specifically tailored for sleep disorders). However, due to time constraints, some participants were asked to use the mindfulness application for only 40 days, of which 30 days would be dedicated to the "Foundation Pack" and the remaining 10 days to the "Sleep Pack." In the control group, a progressive muscle relaxation application for smartphones provided by Headspace was used as an intervention tool. This specific application contained 60 exercises for progressive muscle relaxation (each lasting 10 minutes). During the exercises, participants were required to reduce their breathing rate and gradually relax their body muscles. Since there was no time frame, some participants were asked to use the progressive muscle relaxation application for 40 days instead of the initially planned 60 days. Finally, participants in both groups were asked to complete one exercise daily and avoid using the smartphone application at least two hours before sleeping. According to the results, both the mindfulness application for smartphones and the progressive muscle relaxation application for smartphones appeared effective in improving insomnia symptoms. Additionally, the mindfulness application seemed to facilitate the onset of sleep slightly more. In conclusion, as digital therapies are gaining widespread popularity, further research is needed on the effectiveness of smartphone applications as an intervention tool for addressing insomnia [40].

The aim of the random sampling research conducted by Huberty et al. (2021) was to determine whether the Calm mobile application contributes, among other things, to reducing daytime sleepiness and improving sleep quality in adults. The sample consisted of 263 adults with insomnia symptoms, averaging 44.5 years of age, who were divided into two groups. The intervention was conducted using the Calm application. Calm is a mindfulness meditation application for mobile devices available to the general public. It includes a series of guided meditations based on mindfulness-based stress reduction (MBSR) as well as Vipassana meditation and Sleep Stories that rely on sensory immersion and present moment awareness. During the process, participants downloaded the Calm application from the Google Play or Apple App Store onto their phones, and after being granted free access to the application for eight weeks, they were asked to meditate daily for 10 minutes and generally use the application as often as they wanted during the intervention. According to the results, the use of the Calm application reduced daytime sleepiness and contributed to improving sleep quality. Specifically, individuals in the experimental group reported that their sleep quality improved significantly during the intervention, and notably, the more they used the Calm application, the better their sleep quality became. In summary, the Calm application, which is affordable and easily accessible worldwide, can be utilised for addressing insomnia issues in adults [31].

5.4. Internet of things (IoT)

The Internet of Things (IoT) enables the interconnection of a wide range of smart objects with detection, networking, and processing capabilities via the internet, facilitating access to information sharing[66]. SleepSmart is an intelligent sleep improvement application that relies on the use of the Internet of Things (IoT) and continuous learning through bio-signals. Specifically, SleepSmart collects physiological data during sleep through wearable biosensors, which are then processed and analysed by an IoT platform to provide personalised recommendations for improving sleep. The use of continuous learning techniques contributes to improving the accuracy of the application's recommendations over time. According to a study conducted with 30 individuals to evaluate the application's performance, it was found that SleepSmart has the potential to significantly improve sleep quality and reduce sleep disturbances. In general, the proposed smart system for sleep improvement is a method that promises a lot, not only in terms of sleep quality but also concerning the health consequences related to poor sleep. Therefore, the SleepSmart algorithm can contribute to improving the quality of life of individuals experiencing sleep problems [24].

Last but not least, we emphasize the significance of all digital technologies in the field of education, mind training and sleep habits which is very effective and productive and facilitates and improves the assessment, the intervention, and the educational procedures via mobile devices that bring educational activities anywhere [74-77], various ICTs applications that are the main supporters of education [78-93], and AI, STEM, Games and ROBOTICS that raise educational procedures to new performance levers [94-102]. Additionally, the improvement and blending of ICTs with theories and models of metacognition, mindfulness, meditation, and emotional intelligence cultivation [103-131], accelerates and improves more the educational practices and results, especially in education, mind training and sleep habits,

6. Conclusions

Sleep is a necessary process for the human body that contributes to enhancing memory, the proper functioning of the immune system, achieving academic performance, and generally improving individuals' quality of life. Sleep problems, such as insomnia, short sleep duration, sleep apnea, and restless legs syndrome, are particularly common in cases of neurodevelopmental disorders. As a result, poor sleep quality exacerbates these specific disorders negatively affecting individuals' functionality. Specifically, lack of sleep-in individuals with ASD intensifies anxiety and stereotypical behaviours, as well as leading to mood swings and an inability to manage their emotions. Furthermore, sleep disorders are responsible for social deficits and memory problems that negatively affect the academic success of individuals with ASD. Additionally, in individuals with ADHD, sleep deficiency adversely affects executive functions, exacerbates hyperactivity, and causes difficulties in concentration, while intensifying feelings of fatigue leading to decreased performance. Finally, poor sleep quality negatively impacts attention and behaviour in individuals with Specific Learning Disorder.

However, the contribution of ICT is crucial in improving sleep quality for both adolescents and adults. In particular, adolescents frequently face sleep problems due to either hormonal changes or demanding school obligations they are required to meet. Similarly, adults exhibit symptoms of insomnia, which negatively affects their quality of life. Therefore, the utilisation of technological means, such as virtual reality, digital cognitive-behavioural therapy for insomnia (DCBT-I), smartphone applications, and the Internet of Things (IoT), can serve as a valuable support in sleep matters. After all, digital therapies are particularly widespread for addressing various disorders, including sleep disorders. This is because individuals of all ages are now familiar with technological means, while digital applications are easily accessible, affordable, and maintain a high level of participant motivation.

Compliance with ethical standards

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Disclosure of conflict of interest

The Authors proclaim no conflict of interest.

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