

Digital Media Use and its Implication for Sleep Disruption in Patients with ASD: A Qualitative Review with a Focus on The COVID19 Pandemic

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Autism spectrum disorder is a complex neuropsychiatric disorder characterized by impaired social communication and repetitive and restricted behavioral patterns. Patients often have multiple systemic comorbidities, such as a high prevalence of sleep disturbance. Sleep is regulated by the highly complex interplay between environmental cues, internal hormonal state, as well as neuronal circuitry. In particular, exposure to blue light from electronic devices directly impacts sleep regulation. In patients with ASD, electronic devices are double-edged swords: while they may increase blue light exposure, they often have therapeutic roles that are unique to this patient population. Sleep disorders have detrimental emotional and physical consequences, such as exacerbating behavioral dysregulation and difficulty in social communication in patients with autism. During the COVID19 pandemic, screen time exposure for people of all ages and backgrounds, including patients with autism, increased dramatically. In this qualitative review, we first summarize the recent literature on the mechanisms of sleep regulation and the importance of adequate sleep in patients with ASD. Second, we discuss the pros and cons of electronic device use in patients with ASD. Next, we assess the extent of screen time exposure in patients with autism prior to and during the COVID19 pandemic, in comparison to the control cohorts. We evaluate evidence for altered sleep duration/quality, and behavioral consequences of sleep disturbances based on the recent literature, especially those emerging from the pandemic. Finally, we make recommendations, based on our clinical experience and literature evidence, regarding measures to limit screen time to only productive use for patients with autism.

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INTRODUCTION

The human sleep-wake cycle is regulated by complex mechanisms, among which the circadian rhythm is a key player. The circadian rhythm follows an internal clock mediated by the activities of the suprachiasmatic nucleus (SCN) in the anterior hypothalamus, which is a part of the central nervous system (CNS). This region of the brain controls important autonomic functions such as sleep, temperature regulation and satiation.^{1,2} Light sources act as the stimulator that synchronizes the SCN rhythm with the external environment. Following this cue, the SCN triggers the pineal gland to secrete melatonin (often called the sleep hormone, which increases with darkness and decreases with light exposure).³ Since the light-dark cycle creates a 24 hour

periodicity, melatonin production follows the same pattern and helps to generate a circadian rhythm and sleep cycle through complex mechanisms through binding to its receptors in the CNS and peripheral organs, such as the retina of the eye, the liver and gallbladder, the colon, the skin, the cardiovascular system, the kidneys, and many others.^{3,4}

The blue light, which is emitted in great amounts by light-emitting diodes, can disrupt the circadian rhythm.⁵ Exposure to blue light in inappropriate times such as right before sleep could delay and decelerate the release of the melatonin, promoting high alertness and reduced sleepiness.^{6,7} Uncontrolled exposure to blue light, such as through television and other electronic devices, which causes repeated insult to the circadian clock, can potentially lead to sleep disturbances and even some clinically significant sleep disorders.^{4,8}

Autism spectrum disorder (ASD) is a neurodevelopmental disorder characterized by deficits in social communication and

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restricted and repetitive behaviors. Approximately 40-80% of children with ASD frequently experience sleep disturbance.⁹ Compared to children diagnosed with ASD, only 20-40% of neurotypical children suffer from sleep difficulties.⁹ Hence, disordered sleep is considered one of the most prevalent comorbidities among children with ASD, which creates additional challenges for the overall management of this complex behavioral disorder.¹⁰⁻¹² Studies show that the peak onset of significant sleep problems is around the second year of life and persists onwards.¹³ Patients with sleep disturbances can have a diverse range of symptoms, such as bed-resistance, late onset sleep for more than an hour, reduced sleep duration and frequent night awakenings. Insomnia syndromes such as limit-setting disorder and sleep onset association disorder were also prevalent in children with ASD.¹⁴

Studies suggest that the disordered sleep in patients with ASD can be caused by complex pathophysiological mechanisms both in the melatonin pathway and other important sleep-regulatory pathways. One potential mechanism is a genetic defect leading to reduced function of the Acetylserotonin O-Methyltransferase (ASMT) enzymes, which are produced in the pineal gland and are responsible for the final step in the production of melatonin. A number of independent studies have demonstrated abnormal melatonin regulation in individuals with ASD compared with controls, including elevated daytime melatonin levels and significantly lower nocturnal melatonin levels.¹⁵ Alterations in hormone production have been implicated in patients with ASD, including not only melatonin but also serotonin, cortisol, and epinephrine/norepinephrine.^{16,17} These hormonal dysregulations in the hypothalamic-pituitary-adrenal axis can also contribute to sleep disturbances in patients with ASD.¹⁴ Other research studies suggest that the neurobiological abnormalities, such as excitation/inhibition imbalance could also play a role. Common causes of excitation/inhibition imbalance include dysregulation of ion channels (e.g. KCC2) and GABAergic pathways.^{18,19} Chromosome 15q, which is lost in a subset of patients with ASD, contains important GABA-regulatory genes. Abnormalities in GABAergic interneuron migration and maturation have also been observed in patients with ASD, and may contribute to sleep disturbance in addition to other neurological conditions.²⁰

Many studies suggested that multiple risk factors can aggravate symptoms of sleep disturbance. These biological, psychological and environmental factors work in complex interactions to affect sleep patterns and qualities.⁹ Comorbid anxiety is the strongest predictor of disturbed sleep among children with ASD, alongside communication abnormalities, gastrointestinal symptoms and night-waking.^{11,21,22} Sleep disturbance in children with ASD poses substantial challenges in clinical management because it may also exacerbate social interaction deficits, repetitive behaviors, affective problems, inattention and hyperactivity.²³ Furthermore, parents of children with ASD have high stress, poor sleep quality and shorter sleep duration.²⁴ This may even lead to poor parental mental health and poor parenting.²⁵ In addition, it is worth noting that there is substantial and complex interaction

between blue light exposure, ASD comorbidities, and sleep. Comorbid seizure disorders are highly prevalent in patients with ASD. Some patients can be exquisitely sensitive to light stimulation (through natural light, flashing light, or electronic devices), in a condition called "photosensitive epilepsy".²⁶ Especially for these individuals, poorly controlled seizure disorders could further exacerbate sleep quality, and studies have demonstrated insomnia in epilepsy is associated with continuing seizures and worse quality of life.²⁷

In this review, we will discuss recent literature on the extent of screen time exposure (as a surrogate for blue light exposure) in patients with ASD compared to their neurotypical peers, as well as the pros and cons of technology use in this patient population, with a focus on sleep disturbances. Next, we explore the evidence for the impact of screen use on sleep in these patients, with an emphasis on the global increase of screen time during pandemic that has been reported for all populations. Given the higher risk of sleep disturbance in patients with ASD, and the current understanding of its pathophysiology, we hypothesize that increased screentime exposure during the pandemic may have exacerbated existing neuropsychiatric symptoms, which is supported by our clinical experience and some literature findings. We also propose practical strategies to reduce screen time exposure and subsequent consequences on sleep and patient well-being, which hopefully serve as a general resource to parents, patients and clinicians during the pandemic.

METHODS

For the results and discussion sections, we included studies related to screen time exposure and sleep disturbance in patients with ASD, with a particular focus on screen time exposure during the COVID19 pandemic. We used the following terms for literature search on the PubMed database, including "screen", "television", "digital media", "ASD", "sleep" and "COVID19". All clinical research studies, including case control studies, cohort studies and prospective longitudinal studies are included. Case reports are excluded. We included research articles published up to September 2021. Titles and abstracts of the papers identified by this initial search strategy were evaluated by at least two independent reviewers. We obtained potentially relevant papers and conducted subsequent full text screening. We also conducted a recursive search of the literature based on the bibliographies of the relevant full text articles. Any disagreement between investigators was resolved by consensus.

RESULTS AND DISCUSSION

Screen Time Exposure for Children with ASD

Excessive screen time can negatively impact the circadian rhythm of individuals, with particularly detrimental effects on children with ASD.²⁸ Therefore, it is important to consider the quantity of screen time and how technological interventions may be harmful. Recent studies investigated screen time exposure for children with ASD, but they produced conflicting results.^{29,30} Specifically, a 2013 study found that, on average, children with ASD spend significantly more time playing video games and less time performing physical activity or with

their peers.³⁰ Furthermore, children with ASD tend to favor non-social media (television or video games) instead of social media (email, internet chatting), even compared to children with other disabilities/impairments.³¹ This implies that unstructured screen exposure may not enhance social skill development and potentially detracts from opportunities to develop prosocial behaviors. Contradictory to these results, a national representative study published in 2016 found children with ASD do not have a significantly greater amount of screen time compared to typically developing children.²⁹ However, this study also found that over 50% of all US children exceed the American Academy of Pediatrics recommendation of two hours or less of daily screen time. This widespread overuse is concerning because screen exposure is negatively associated with sleep quality for all children.^{32,33}

Given their underlying neuropsychiatric pathophysiology, children with ASD may be more susceptible to changes in sleep patterns as a result of screen exposure. In a recent survey of 101 children with ASD, those who incorporated screens into their bedtime routines often experienced delayed sleep onset and shorter sleep durations.³⁴ In fact, the sleep latency for children who used screens before bedtime was more than double that of the control group. Another study found that the age at which children with neurodevelopmental disorders (NDDs) (which includes ASD) are exposed to screens is associated with sleep disturbances and emotional/behavioral difficulties.³⁵ Specifically, Lin et al. found that children with NDDs who were exposed to screens before reaching 18 months of age, along with children who had devices in their bedrooms, were more likely to experience sleep and behavioral dysregulation. These findings are particularly alarming when considering caretakers' increasing reliance on technological interventions and that children with ASD are often exposed to screens at an early age.³⁶

Regardless of the substantial evidence, it is important to note that no causal relationship between screen use and sleep difficulties can be drawn from either Mazurek et al. or Lin et al.'s observational studies. However, the effects of blue light on circadian rhythm and the abnormal neurological mechanisms in children with NDDs offers a plausible explanation for the observed sleep difficulties that affect children with ASD in association with screen exposure. **Table 1** summarizes recent literature on the extent of digital media exposure in patients with autism. Main conclusions, cohort description, and study methodologies are provided for ASD-focused studies.

Potential Benefits of the Use of Electronic Devices and Screen Time Exposure in ASD

Despite the risks of screen exposure, electronic devices are double-edged swords that can offer a variety of potential benefits for individuals with ASD. Specifically, there are commonly used interventions which aid children with ASD in behavioral training and communication.³⁷⁻³⁹ Computer-assisted learning platforms, such as mobile device applications, are frequently employed to support academic learning, social skill development and life skill development,

while also mitigating challenging behaviors.³⁷ Modern advances in technology have also been adapted to benefit children with ASD. For example, virtual reality has emerged as a promising platform to construct collaborative virtual environments for children with ASD.³⁸ This form of intervention is particularly advantageous because it accurately simulates real-world social interactions in a controlled environment and allows for training to be personalized and measured.⁴⁰ Filmmaking and video therapy is another form of technological intervention that demonstrated success in improving social skills of children with ASD. In a recent study, two pairs of children with high-functioning autism were enrolled in a therapeutic filmmaking and cinematherapy project where each group developed personal short-films, both members acting as directors and main characters.³⁹ Cinematherapy requires further research given this study's small sample size, but researchers noted that the filmmaking project decreased all participants' core symptoms of ASD and promoted prosocial behaviors.

Technology also offers more advanced forms of intervention, specifically in the realm of communication. For children diagnosed with severe ASD and little to no functional speech capabilities, Speech-Generating Devices (SGD), often integrated with common tablets or smartphones, allow them to effectively communicate with the world.^{41,42} Furthermore, tablet-integrated applications such as *Open Book* help improve reading comprehension by simplifying complex texts and semantics.⁴³ Given that individuals with ASD, including those diagnosed as high-functioning, often struggle to decode social and pragmatic uses of language, apps that can clarify meaning and context are particularly valuable.^{44,45}

These findings highlight the complexity in technology and screen use for patients with ASD. Technological interventions are often necessary to improve a child's wellbeing, yet excessive use carries significant risk regarding sleep and behavioral regularity. As screen-based interventions continue to develop, it is critical to consider how the electronic devices are used and a cost-benefit analysis of increased screen time.

Screen Time Exposure during COVID19 with a Focus on The ASD Population

For most people, the onset of the COVID-19 pandemic quickly interrupted daily habits and behavioral patterns. Unsurprisingly, the pandemic corresponded with decreased physical or social activity and increased screen time. Multiple US studies reported significant increases in screen time over the past year for the general population, with some estimates reaching a 40% increase in daily screen time.⁴⁶⁻⁴⁸ Overall, the most common platforms for increased screen use were television and streaming services, social media, smartphones and video games.⁴⁶ Notably, countries around the world experienced similar effects from the pandemic. Studies in Germany, Turkey, Japan, Canada and Chile all observed increased screen time during the pandemic.⁴⁹⁻⁵³ Children with ASD exhibited similar behavioral changes to the rest of the population. While their pre-pandemic screen time was found to be greater than their typically-developing peers, the daily

screen time for Japanese children with ASD increased by an average of 1.25 hours.⁵⁴ A US study found similar results, which showed a significant increase in weekday and weekend screen time for children with ASD.⁵⁵ Furthermore, this study reported that the increase in screen time corresponded with a decrease in days of physical activity by an average of 46%.

It is important to note that most studies on screen exposure for children with ASD during the COVID-19 pandemic are preliminary and contain limitations, such as small sample sizes, short durations of follow-up, and inadequate controls. However, there is a clear trend in both the ASD and general population which indicates a global increase in screen exposure. More research on large, nationally representative samples is required before absolute conclusions should be drawn, but the current evidence raises the concern for potential health effects and necessary interventions. The observed behavioral changes are associated with adverse health effects for all adolescents,⁵⁶ but children with ASD may be more likely to experience sleep-related disturbances given their unique vulnerability, especially those who were already experiencing sleep difficulties at baseline, and therefore face even greater risks from the increased screen exposure associated with the pandemic. **Table 2** summarizes research articles on digital media exposure during the COVID19 pandemic, including ASD focused studies, and studies on the general population which did not exclude patients with ASD. Main conclusions, cohort description, and study methodologies are provided for ASD-focused studies.

Practical Recommendations to Mitigate Excessive Screen Time Use and Improve Sleep Quality in Children with ASD

In order to mitigate sleep disturbance due to excessive screen time, caregivers can try out a series of self-implemented strategies to limit and control the technology used by children with ASD. By creating daily schedules, children will better understand and cooperate with the consistent TV usage time. These schedules should be designed so that at times when social activity is possible, especially in an outdoor setting, technology could be limited. Replacing technology use before bed with alternative calming activities, such as reading a book or taking a bath can be an option as well. Parents may consider involving children's behavioral therapists in helping to implement changes to patients' routine, as patients with ASD have a particularly hard time adjusting to new routines.

If excessive screen exposure cannot be promptly addressed, and parents suspect worsening of sleep quality as a consequence, we recommend seeking professional help including behavioral therapy and pharmacologic interventions to address problematic sleep disturbance while working on setting a healthier routine. A study showed that cognitive

behavioral therapy for insomnia is effective in reducing sleep problems among children with ASD.^{57,58} Gaining an accurate assessment of the sleep disturbances will help reach effective treatments that can be used separately or in conjunction with the aforementioned treatments.

In regards to medication, parents and clinicians should exercise caution because some children with ASD can have paradoxical reactions to medications traditionally thought to have anxiolytic or calming effects such as benzodiazepines as demonstrated by a case report.⁵⁹ Another case series reported diminished response to melatonin in patients with intellectual disability, despite initial good response, which may be linked to abnormalities in drug metabolism.⁶⁰ However, for many children, the severity of the sleep problems can be mitigated to an extent by medications and some parents have seen a significant increase in the quality of life.⁶¹ In addition, there are many simple tactics to reduce everyday blue light exposure from electronic devices. For example, most of the commercial smartphones, monitors and computers now have a "night-shift" setting so that the users can change the screen color tone to a warmer, orange color, which is associated with reduced blue light emission through the screen. One can also purchase additional blue light filter film to be placed on the screen, if the change of screen color is bothersome and if one wants bluelight reduction throughout the day.

CONCLUSION

Autism spectrum disorder is a complex neuropsychiatric disorder characterised by impaired social communication and repetitive and restricted behavioral patterns. Patients often have multiple systemic comorbidities, such as a high prevalence of sleep disturbance. Sleep onset, duration and quality are regulated by highly complex mechanisms and are exquisitely sensitive to exposure to blue light emitted from electronic devices. Nowadays, the use of electronic devices is common for patients with ASD, and can potentially exacerbate or trigger sleep disturbances in this population. In this review, we summarize the known pathophysiology of sleep disturbance in patients with ASD, and critically evaluate the recent literature on the extent of screen time exposure as well as its consequences, with an emphasis on sleep disorders. In light of COVID19 pandemic, the screen time exposure for people of all ages and backgrounds, including patients with autism, increased dramatically. In the final part of the review, we assess the extent of screen time exposure in patients with autism during the COVID19 pandemic, and evaluate evidence for altered sleep duration/quality, and behavioral consequences of sleep disturbances based on the emerging literature. Finally, we make recommendations, based on our clinical experience and literature evidence, regarding measures to limit screen time for only productive use and to improve sleep quality for patients with autism.

Table 1. Summary of recent literature on digital media exposure in patients with autism. Main conclusions, cohort description, and study methodologies are provided for ASD-focused studies.

Author	Year	Title	Main conclusion	Cohort Description	Methodology
Montes, Guillermo	2016	Children with Autism Disorder and Screen Time: Results from a Large, Nationally Representative Study	Children with ASD between 6-17 years old do not have a significantly greater amount of daily screen time than children without ASD. However, over 50% of all US children exceed the recommended amount of daily screen time from the AAP.	Age: 6-17. Gender: Male and female. Sample Size: ASD = 1393, TD = 64163. Country: US Study	Survey. Parents/caregivers reported child's average daily media usage
Mazurek & Wenstrup	2013	Television, video game and social media use among children with ASD and typically developing siblings	Children with ASD spent more time watching TV and playing video games than typically-developing siblings and were more likely to have problematic video game usage	Age: 8-18. Gender: Male and female. Sample Size: ASD = 202, TD = 179. Country: US Study	Survey. Parents/caregivers assessed and reported results. Unclear whether propensity matching was used.
Mazurek et al.	2012	Prevalence and correlates of screen-based media use among youths with autism spectrum disorders	Majority of children with ASD spend time on non-social media (TV, video games) instead of social media, even compared to groups of children with other disabilities (speech impairments, learning disabilities, intellectual disabilities).	Age: 13-17. Gender: Male and female. Sample Size: ASD = 920, SI = 860, LD = 880, ID = 850. Country: US Study.	Survey. Parents/caregivers reported categorical answers to questions regarding screen use. Demographic variables of interest were age, gender, ethnicity, race, household income, single-parent household, home access to computer/internet.
Hale & Guan	2015	Screen Time and Sleep among School-Aged Children and Adolescents: A Systematic Literature Review.	Screen time is adversely related to sleep outcomes among children and adolescents, especially when used before or during bedtime hours.	Systematic Review. Inclusion criteria required that study participants were between 5 - 17 years old.	Systematic Review. Methods varied by study.
Carter et al.	2016	Association Between Portable Screen-Based Media Device Access or Use and Sleep Outcomes: A Systematic Review and Meta-Analysis	Bedtime access and use of portable media devices were associated with decreased sleep quantity, poor sleep quality, and excessive daytime sleepiness.	Systematic Review. Inclusion criteria required that study participants were between 6 - 19 years old.	Systematic Review. Methods varied by study. Data that was sufficiently clinically homogeneous was pooled in a random effects meta-analysis.
Mazurek et al.	2016	Bedtime Electronic Media Use and Sleep in Children with Autism Spectrum Disorder.	Children with ASD who used digital media before bedtime, especially violent media, experienced greater sleep onset latency and shorter sleep duration	Age: NA. Gender: NA. Sample Size: 101. Country: US Study.	Survey. Parents/caregivers reported children's behavioral & sleep patterns
Lin et al.	2019	The Relationship Among Screen Use, Sleep, and Emotional/Behavioral Difficulties in Preschool Children with Neurodevelopmental Disorders	Sleep problems fully mediated the relationship between the number of screen devices in the bedroom and EBDs in children with ASD. Also, children exposed to screens before reaching 18 months old were more likely to have sleep problems and EBDs.	Age: 2-5. Gender: NA. Sample Size: 367 (39.5% ASD). Country: US Study	Survey. Parents/caregivers reported the child's behavior/results.
Krishnan et al.	2021	Early Social Experience and Digital-Media Exposure in Children with Autism Spectrum Disorder	Children with ASD tend to be exposed to digital media at an earlier age and spend significantly more time with digital media and less time with their mothers/caretakers.	Age: 3-8. Gender: 72.2% male, 27.8% female. Sample Size: ASD = 74. TD = 74. Country: Indian study	Survey. Available medical records were verified and ASD was diagnosed using INCLIN diagnostic tool. Parents were asked to report all information regarding screen time and social behavior.

Table 2. Summary of papers regarding changes in digital media exposure during the COVID19 pandemic. Main conclusions, cohort description, and study methodologies are provided for ASD-focused studies.

Author	Year	Title	Main conclusion	Cohort Description	Methodology
Wagner et al.	2021	Recreational Screen Time Behaviors during the COVID-19 Pandemic in the U.S.: A Mixed-Methods Study among a Diverse Population-Based Sample of Emerging Adults	On average, weekly recreational screen time for emerging adults increased by 2.6hrs during the COVID-19 pandemic.	Non-ASD Focus, but did not exclude patients with ASD.	Non-ASD Focus, but did not exclude patients with ASD.
King et al.	2020	Problematic online gaming and the COVID-19 pandemic	The increase in online gaming during the COVID-19 pandemic may solidify unhealthy lifestyle patterns in vulnerable individuals.	Systematic Review	Systematic Review
Meyer et al.	2020	Changes in Physical Activity and Sedentary Behavior in Response to COVID-19 and Their Associations with Mental Health in 3052 US Adults	During the COVID-19 pandemic, previously active individuals reported, on average, significant decreases in physical activity and increases in sedentary behaviors. These behavioral changes were associated with increased reports of negative mental health.	Non-ASD Focus, but did not exclude patients with ASD.	Non-ASD Focus, but did not exclude patients with ASD.
Schmidt et al.	2020	Physical activity and screen time of children and adolescents before and during the COVID-19 lockdown in Germany: a natural experiment	On average, sports activity declined by 10.8min/day and screen time increased by 61.2 min/day for German children and adolescents during the COVID-19 pandemic.	Non-ASD Focus, but did not exclude patients with ASD.	Non-ASD Focus, but did not exclude patients with ASD.
Eyimaya & Irmak	2021	Relationship Between Parenting Practices and Children's Screen Time During the COVID-19 Pandemic in Turkey	71.7% of Turkish parents/caregivers reported an increase in their child's screen time during the COVID-19 pandemic, reaching an average of 6.42hrs/day.	Non-ASD Focus, but did not exclude patients with ASD.	Non-ASD Focus, but did not exclude patients with ASD.
Xiang et al.	2020	Impact of COVID-19 pandemic on children and adolescents' lifestyle behavior larger than expected	The median time of physical activity for Chinese youth decreased by 105min/week and total weekly screen time increased to 1730min/week.	Non-ASD Focus, but did not exclude patients with ASD.	Non-ASD Focus, but did not exclude patients with ASD.
Guerrero et al.	2020	Canadian children's and youth's adherence to the 24-h movement guidelines during the COVID-19 pandemic: A decision tree analysis	During the COVID-19 pandemic, only 2.6% of Canadian children met physical activity, screen time and sleep recommendations.	Non-ASD Focus, but did not exclude patients with ASD.	Non-ASD Focus, but did not exclude patients with ASD.
Aguilar-Farias et al.	2020	Sociodemographic Predictors of Changes in Physical Activity, Screen Time, and Sleep among Toddlers and Preschoolers in Chile during the COVID-19 Pandemic	During the COVID-19 pandemic, children ages 1-5 years old showed decreases in physical activity and sleep quality and increases in recreational screen time and sleep duration.	Non-ASD Focus, but did not exclude patients with ASD.	Non-ASD Focus, but did not exclude patients with ASD.
Wong et al.	2021	Digital Screen Time During the COVID-19 Pandemic: Risk for a Further Myopia Boom?	Increased screen time and limited outdoor activities are significantly associated with the onset of myopia, which may be amplified by behavioral changes caused by the COVID-19 pandemic.	Non-ASD Focus, but did not exclude patients with ASD.	Non-ASD Focus, but did not exclude patients with ASD.
Kawabe et al.	2020	Excessive and Problematic Internet Use During the Coronavirus Disease 2019 School Closure: Comparison Between Japanese Youth With and Without Autism Spectrum Disorder	This study found that digital media use was significantly longer for children with ASD during the COVID-19 pandemic. Furthermore, children with ASD and their typically developing peers both exhibited excessive internet use.	Age: 6-18. Gender: 75% male, 25% female. Sample Size: 84 children w/ ASD, 361 controls. Country: Japanese study	Survey. Parents/caregivers reported survey on child's screen use during the pandemic. Controls were matched by age and gender.
Garcia et al.	2021	Brief report: The impact of the COVID-19 pandemic on health behaviors in adolescents with Autism Spectrum Disorder	This study found a significant decrease in physical activity and a significant increase in screen time for children with ASD during the pandemic.	Age: Adolescents. Gender: NA. Sample Size: 9 Country: US Study	Survey: Children reported on physical activity, screen and sleep behaviors during the pandemic.

Supplemental Table. Summary of recent studies, systematic review and meta-analysis on the possible benefits of digital media exposure in patients with ASD. Main conclusions, cohort description, and study methodologies are provided for ASD-focused studies.

Author	Year	Title	Main conclusion	Cohort Description	Methodology
McIntyre et al.	2020	Growth in narrative retelling and inference abilities and relations with reading comprehension in children and adolescents with autism spectrum disorder	Reading inference skills in children with ASD were below average and declined over time relative to age-normed standard scores	Age: 8-16. Gender: NA. Sample Size: 93. Country: US Study	Observational Study. Reading inference and other skills were measured as time passed and compared to age-normed scores.
Saladino et al.	2020	Filmmaking and video as therapeutic tools: Case studies on autism spectrum disorder	Study finds evidence that film-making and video therapy can effectively treat children with ASD	Age: 10-13. Gender: 2 males, 2 females. Sample Size: 4. Country: Italian Study	Experiment: Researchers applied treatment via video therapy and measured behavioral changes
Cerga-Pashoja et al.	2019	Improving Reading in Adolescents and Adults With High-Functioning Autism Through an Assistive Technology Tool: A Cross-Over Multinational Study	Study found significant evidence that OpenBook improved reading comprehension for individuals with high-functioning ASD	Age: 12-70. 12-17 in Bulgaria & Spain Branch, over 18 in UK branch. Gender: 71% male, 29% female. Sample Size: 243 Country: Multi-national study. UK, Bulgaria, Spain.	Experiment. Subjects were randomly assigned to treatment or control groups and reading comprehension was measured and self-reported. Participants were considered to be high-functioning.
Wendt et al.	2019	Effects of an iPad-based Speech-Generating Device Infused into Instruction with the Picture Exchange Communication System for Adolescents and Young Adults with Severe Autism Spectrum Disorder	Use of Speech-Generating Device paired with Picture Exchange Communication System on an iPad resulted in improved communication and requesting behaviors in children with severe ASD	Age: 14-23. Gender: 100% Male Sample Size: 3. Country: US Study	Experiment: Subjects were treated and behavioral changes were measured. All participants had severe ASD with limited or non-verbal capacities
Gilroy et al.	2018	A pilot community-based randomized comparison of speech generating devices and the picture exchange communication system for children diagnosed with autism spectrum disorder	High-tech and low-tech augmentative and alternative communication approaches significantly improved communication skills in children with ASD	Age: School age (6-18?) Gender: NA. Sample Size: 35. Country: US Study	Experiment: Subjects were randomly treated with either high-tech or low-tech ACC and communication skills were measured
Mesa-Gresa et al.	2018	Effectiveness of Virtual Reality for Children and Adolescents with Autism Spectrum Disorder: An Evidence-Based Systematic Review	Systematic review found that there is moderate evidence that VR technology can effectively treat ASD	Systematic Review	Systematic Review
Didehbani et al.	2016	Virtual Reality Social Cognition Training for children with high functioning autism	VR social cognition training improved emotion recognition, social attribution, and executive function of analogical reasoning for children with ASD	Age: 7-16. Gender: 26 males, 4 females. Sample Size: 30. Country: US Study	Experiment. Researchers recorded benchmark results before applying VR treatment. After 5 weeks of treatment, results were measured again.
Brown et al.	2013	A meta-analysis of the reading comprehension skills of individuals on the autism spectrum	This study found that individuals with ASD struggled to comprehend highly social texts and identified several predictors to determine if individuals with ASD will struggle with reading comprehension	Meta-Analysis	Meta-Analysis

AUTHOR CONTRIBUTION

Yuna Um and Nicholas Iskenderian jointly wrote the first draft, with inputs from Jun Liu. Nicholas Iskenderian and Jun Liu created the tables. All authors contributed to manuscript revision.

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