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Systematic Review

Assistive and Emerging Technologies to Detect and Reduce Neurophysiological Stress and Anxiety in Children and Adolescents with Autism and Sensory Processing Disorders: A Systematic Review

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Abstract: This systematic review aims to investigate the ways in which assistive and developing technologies can help children and adolescents with autism spectrum disorder (ASD) experience less stress and neurophysiological distress. According to recent CDC data, the prevalence of ASD in the United States has climbed to 1 in 36 children. The symptoms of ASD can manifest in a wide range of ways, and the illness itself exhibits significant variations. Furthermore, it has been closely linked to experiencing stress and worry in one's life, which many people refer to as sensory processing disorder (SPD). SPD is a disorder that describes how people behave when they are exposed to environmental stimuli that they may not normally process by feeling more intense than what is causing them to worry and distress. One of the most significant limiting factors that can prevent someone from engaging in what they need to do in their everyday lives is stress. Individuals with ASD deal with stress on a regular basis, which has a big impact on how they function. In order to address a significant research vacuum concerning the use of assistive and emerging technologies to reduce stress in individuals with ASD, this systematic review aims to investigate performance, measuring techniques, and interventions by gathering data from the past 10 years. In order to determine the research hypothesis, particular research questions, and the inclusion and exclusion criteria for the studies, the research process entails gathering studies through systematic review analysis in accordance with the PRISMA principles. Experimental and observational studies on the use of assistive and emerging technologies for stress and anxiety management in children and adolescents with ASD that were published only in English met the inclusion criteria. Research not directly related to stress and anxiety outcomes, articles published in languages other than English, and research conducted outside of the designated time frame were also excluded. The study's findings demonstrated that the technologies under examination had beneficial impacts on reducing stress; nonetheless, notable limitations were found that could compromise the replication and generalizability of legitimate and dependable applications in their utilization.

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1. Introduction

According to the most recent CDC estimates, approximately 1 in 36 children are diagnosed with autism spectrum disorder (ASD), with data pointing to a fourfold higher incidence in boys. The prevalence in Greece among children aged 10 to 11 years is 1.15% [1]. Although each person with the disorder is unique, ASD is characterized by key features, and abnormal early brain development and neuronal reorganization appear to be contributing factors to the cause of ASD. Social interactions are frequently quite challenging for people with ASD. These challenges could include trouble keeping eye contact and facial expressions, adjusting to social norms and expectations, and comprehending the intentions and feelings of others. People with ASD could find it difficult to make and keep friends, they might not comprehend that social interactions are two-way, or they might feel awkward sharing their hobbies and interests [2]. Avoiding eye contact, not responding to names, extreme fear, and a lack of interactive and pretend play are some of the symptoms of ASD, which differ from child to child. Children who receive early diagnosis and intervention have been shown to have better social outcomes and higher independence as adults, which ultimately saves healthcare expenses and lessens family stress. Long-term, substantial cost savings also decreased the demand for special education services and more intense treatments. It has also been demonstrated that an early diagnosis results in early enrollment in specialized educational programs that are designed to meet the particular requirements of children with ASD. For these children, these activities provide enhanced socialization opportunities and enhanced scholastic or educational results [3]. Many researchers have also studied the association between the diet of pregnant mothers and environmental factors that may also contribute to this phenomenon. However, because there are no reliable biomarkers, diagnosis is based solely on behavior [4]. ASD is a highly comorbid disorder that includes anxiety, ADHD, obsessive-compulsive disorder, mood disorders, and other behavioral disorders, which show considerable heterogeneity in the recent literature. A recent meta-analysis of 30 studies measuring the prevalence of anxiety and 29 studies measuring the prevalence of depression by [5] found that 46% of patients had a comorbid behavioral challenging disorder, 8% had mood disorders, and 66% of over 600 patients had more than one concurrent condition. Children with ADHD who sought therapy had a similar incidence of any anxiety illness (42%). Other prevalent health issues include selective eating, gastrointestinal diseases, sleep issues, seizures, obesity, and dietary limitations [6]. In terms of cognitive functioning, individuals with ASD demonstrate a wide range of abilities, from severe cognitive impairment to superior and high intelligence. Studies in people with ASD with and without cognitive impairment have found significant differences between groups in terms of symptom severity and subsequent outcomes. In addition, cognitive impairment may be more common in women, in individuals with known birth defects, and in individuals with dysmorphic features, suggesting that there may be subgroups with different etiologies or risk factors [7]. Since they are frequently the initial point of contact for parents, pediatricians are crucial to the early discovery of an individual with ASD. Because of widespread media coverage and the internet, parents are now much better equipped to identify the early indicators of autism spectrum disorder. If their child exhibits any of the symptoms above, they are more likely to voice their concerns to their child's pediatrician. Pediatricians need to be aware of the symptoms of autism spectrum disorder and have a plan in place for systematically evaluating them.

Additionally, pediatricians need to know about local services that can assist them in diagnosing and treating ASD [8]. Although ASD can be diagnosed as young as 18 months of age, recent research has shown that the average age of diagnosis of ASD is between 38 and 120 months. Early detection of ASD can lead to early treatment, which improves later cognitive and language skills and reduces the underlying symptoms. Although there has been some criticism of universal screening of children with ASD due to lack of evidence, it is widely recognized that identification and early intervention are critical to public health priorities. Close monitoring of changes in the age of diagnosis of ASD over time will help us assess whether efforts to improve access to early identification and intervention are successful [9].

Improving the quality of life for children with ASD requires an explanation of the neurological mechanisms underlying their stress and anxiety. Since traditional therapy interventions frequently fail to alleviate symptoms, innovative and creative alternatives are needed. New treatment instruments have lately been made possible by advancements in technology. Emerging and assistive technologies have the potential to offer adaptive support and real-time monitoring that can alleviate stress and address a range of specific requirements in the population with ASD.

A condition known as sensory processing disorder (SPD) affects people with ASD in terms of their ability to interpret information from their surroundings. Although [10] proposed a classification of sensory processing disorders, many therapists prefer to refer to children as having difficulties processing and integrating stimuli; therefore, this term is not widely accepted. Excessive or insufficient responsiveness to normal levels of input from the sensory organs is known as sensory modulation disorder (SMD) [11]. Finding possible sensory stimuli and modifying the nervous system's reaction to them are both parts of the neurological process of sensory control. Sensory regulation is the intricate process of interpreting sensory data and generating reactions that are suitably calibrated or consistent with the circumstances. This ability to regulate and organize reactions to sensory inputs, filtering out unimportant stimuli and concentrating on the crucial ones while preserving the optimal level of arousal, is referred to by this word. A person's general quality of life, ability to overcome obstacles in daily life, and ability to interact with their physical and social environment are all impacted by this basic human functioning skill. SMD offers a crucial dimension for connecting with other categorical diagnostic entities that were previously thought of separately, making it an essential component of stress response physiology. In 2020, according to [12] overprotective and avoidant behaviors, as well as inappropriate reactions to harmless sensory inputs, are common in people with SMD. These actions frequently do not align with the expectations and requirements of the surroundings. According to research conducted on children with SMD, exposing them to sensory stimuli in a lab setting has an impact on their sympathetic and parasympathetic nervous systems from a neurophysiological standpoint. Many unique behaviors, including active sensation seeking and/or extreme sensitivity to sensory inputs, can be displayed by people with SMD. Innocent sensory inputs that provide unpleasant, painful, or annoying feelings can cause defensive reflexes, withdrawal from everyday activities, or elevated stress levels. Other symptoms of SMD include tiredness, apathy, or passivity. It can also manifest as delayed reactions to environmental stimuli of normal intensity. As a result, it is evident that SMD can negatively affect functional and developmental abilities, which hinders effective participation [13,14].

The World Health Organization (WHO) defines assistive technology (AT) as a general term that encompasses all systems and services associated with the use of assistive devices and service delivery [15]. In general, it is defined as "any item, piece of equipment or system, whether acquired, modified or adapted for commercial purposes, that is commonly used to enhance, maintain or improve the functioning of an individual" in accordance with the United States' Assistive Technology Act of 1998 [16]. AT is separated into high-tech (programming-based) technologies, like computers, and low-tech (programming-free) technologies, like pencil grips and magnifying lenses [17]. Researchers such as [18] also classify AT into two types: low or simple technology and high and complex technology. Low or simple technology has been described as equipment that most often has a low cost and is easy to create or acquire. It is, therefore, devices that require a simplified process for their operation (pencils, calculators, paper and laminated communication boards, wheelchairs, etc.). Complex technology refers to equipment that has electronic technology (computers, electronic communication boards, electric wheelchairs, etc.). Thus far, assistive technology has shown to be a useful instrument for enhancing the quality of life for all individuals with disabilities. Through assistive technology, people with disabilities can lead successful, independent, and healthy lives while participating in civic life, the workforce, and education. People frequently experience poverty, loneliness, and marginalization in the absence of assistive technology, which exacerbates the effects of illness and disability on patients, their families, and society at large. Assistive technology tools have a significant impact on the well-being of children with ASD, providing new opportunities for therapeutic approaches to improve various skills that contribute to the social inclusion of these children [19].

Emerging technologies are technologies that are at an early stage of development. This means that certain aspects, such as the characteristics of technology and its context of use or the network configuration of actors and their relative roles, are still uncertain and undefined [20]. They are defined as technologies that have the potential to be relevant to society within the next 10 to 15 years. This means that they are currently in the early stages of their development, but at the same time, they have moved beyond the purely conceptual stage [21]. Emerging technologies can be summarized as the definition of five key elements. These are (1) full innovation, (2) relatively rapid development, (3) consistency, (4) significant impact, and (5) uncertainty and ambiguity. More specifically, we conceive of emerging technology as a completely new and relatively rapidly evolving technology that is characterized by a certain degree of consistency that is maintained over time and has the potential to have a significant impact on socio-economic sectors. Moreover, it is observed in terms of the composition of actors, institutions, and patterns of interaction between them, as well as related knowledge production processes [22]. Emerging technologies include a broad and wide variety of technological developments that include artificial intelligence (AI), computer vision (computer vision), cellular communications, virtual reality (VR) and augmented reality (AR), robotics, drones, exergames, and serious games. This research will examine and synthesize the prevailing knowledge about the importance of technology in the field of combating and managing anxiety and stress in autistic children and adolescents to provide feasible and more effective solutions. For the purpose of this study, emerging technologies will be placed in the category of high-tech AT aids.

2. Materials and Methods

2.1. Study Design

The study design of this research was derived from the application of a systematic review approach followed by the PRISMA statement of systematic reviews and meta-analyses, reassuring rigorous and robust delivery through identification, selection, assessment, and synthesis of the finalized included studies. The Open Science Framework was the platform that was used to register the systematic review protocol (https://osf.io/6fnbj/ accessed on 22 February 2025)

The research was driven by more than one hypothesis, which was derived by applying the following PICO framework:

P: Children and young people from birth to 21 years of age with ASD.

I: Assistive technologies (low-high) and emerging technologies.

C: ASD, with typical development and other neurodevelopmental disorders; other types of interventions.

O: Reduction in stress and anxiety, improvement in ASD behavioral traits, reduction in aggressive behavior, and better concentration and focus.

H1**:** *Assistive and emerging technologies can effectively reduce stress and anxiety in children with ASD.*

H2**:** *The application of assistive and emerging technologies in real-world settings will demonstrate significant improvements in the management of stress and anxiety for individuals with ASD.*

H3**:** *The use of assistive and emerging technologies will lead to improved behavioral outcomes for individuals with ASD.*

Throughout this systematic review, we attempted to answer the following research questions:

- RQ1. What assistive and emerging technologies are used to combat stress in people with ASD?
- RQ2. Can assistive and emerging technologies help people with ASD reduce stress?
- RQ3. What are the measurements used to detect the outcomes?
- RQ4. What are the effect sizes of the studies?

For the purpose of this systematic review, research of the literature was conducted to explore the last ten years, studying the changes that have occurred in the years before and after COVID-19 in conjunction with the development of the Industrial Revolution 4.0 in the daily lives of people with ASD and how new emerging and assistive technologies can be beneficial in combating neurophysiological stress and anxiety.

2.2. Inclusion/Exclusion Criteria

To produce results, principles were used that followed specific criteria for the inclusion and exclusion of specific categories of research and articles, which were included in the final analysis for the main part.

More specifically, the inclusion criteria for the main part include the following:

- IC1: Research conducted between January 2014 and 30 March 2024 will be included.
- IC2: Experimental studies, observational studies, and original research will be included.
- IC3: Research and studies that are published in English only will be included.
- IC4: The use of new, assistive, and emerging technologies exclusively for the management of neurophysiological stress and anxiety will be included.
- IC5: Populations that have research inclusion criteria that are relevant to ASD and may include comorbidities with other conditions will be included.
- IC6: Research samples of children and adolescents up to 21 years of age will be included.

The following were the exclusion criteria for the study:

- EC1: Studies conducted before 2014 and after March 2024 will not be included.

- EC2: Studies of literature, systematic reviews, and meta-analyses of other studies will not be included.
- EC3: Studies published in a language other than English will not be included.
- EC4: Studies that include the use of new technologies or assistive technologies that do not include at least stress and anxiety in the outcome measures will not be used.
- EC5: Studies that include other populations of neurodevelopmental disorders will not be used unless they involve a comorbidity with ASD or suggest a corresponding study in that population.
- EC6: Included studies will not contain a sample of subjects older than 21 years of age.

2.3. Databases Screened and Selection Process

To obtain the finalized sample for analysis, the following databases were processed systematically to analyze the literature, which included PubMed, Web of Science, and Scopus. Google Scholar was used as a supplementary database. Eligibility requirements formed the foundation of the selection process. A keyword list for the database was also generated using Boolean operators and various search algorithms to obtain the best results.

The methodology followed, as previously discussed, was based on PRISMA principles using the snowball method for article selection, and the keywords used were autism spectrum disorder (ASD); assistive technologies (AT); emerging technologies; stress; neurophysiological stress; anxiety and their combination (Table 1).

Table 1. Research data string.

"Autism Spectrum Disorder" OR "ASD" OR "Assistive Technologies" OR "AT" OR "Emerging Technologies" OR "Stress" OR "Neurophysiological Stress" OR "Anxiety"
AND
"Autism Spectrum Disorder" AND ("Assistive Technologies" OR "AT") AND ("Emerging Technologies") AND ("Stress" OR "Neurophysiological Stress") AND ("Anxiety")
AND
"ASD" AND ("Assistive Technologies" OR "AT") AND ("Emerging Technologies") AND ("Stress" OR "Neurophysiological Stress") AND ("Anxiety")
AND
"Autism Spectrum Disorder" AND ("Assistive Technologies" OR "AT") AND ("Emerging Technologies") AND ("Neurophysiological Stress" OR "Physiological Stress" OR "Cortisol Levels" OR "Heart Rate Variability") AND ("Anxiety" OR "Emotional Dysregulation" OR "Mental Health")

An advanced search was then conducted using Boolean operators and filters in the databases. As soon as the candidate studies were selected, we started further processing. During the abstract/title screening step, studies that included the predefined terms in both the abstract and the title were given priority. Duplicate papers were then removed, and references that did not meet the eligibility requirements were excluded. Redundant references were eliminated using Mendeley Desktop 1.19.8.

The remaining studies underwent further processing during the full-text screening phase. Following the next steps, the full-text documents were acquired, and the information was carefully reviewed. The selection process also took into account other factors, such as the methodological practices used in each study. Four reviewers, P.P. and V.B., A.D. (Aikaterini Doulou), and A.C., independently identified the studies that qualified. The reviewers could choose to accept, reject, or remain undecided. In the event that the other reviewers were unsure or disagreed, a discussion was held with the input of the fifth (C.S.), sixth (N.B.), and seventh A.D. (Athanasios Drigas) reviewers. After the research was evaluated, the reviewers collected the relevant data and organized it in tables. After that, the results were combined. The qualitative synthesis offered a critical overview, analysis, and evaluation of the body of evidence discussed in this review.

2.4. Data Extraction

Data collected from the included studies referred to participant demographics, information (authors, year, country), specifics related to the research questions formulated, and aspects of the studies' structure (type of study, aim, conditions, measures, key findings, effect sizes, and longitudinal effects).

2.5. Included Studies

Following processing, inclusion, and representative criteria for the main part ($n = 36$) in the final selection for additional study and analysis, a total of $n = 293$ articles were found and screened for the included studies. The literature review included the years 2014–2024. Establishing the eligibility criteria was an initial step in the selection process. A list of keywords was also created to start the database search, which made use of a variety of search filters and Boolean operators in order to optimize the quantity of results. Following the elimination of duplicate studies ($n = 73$), the selection procedure was conducted using title and abstract screening in compliance with the eligibility criteria ($n = 220$).

The next step in the process was full-text screening after 95 publications were excluded. The remaining studies ($n = 125$) were processed thoroughly. Unfortunately, retrieving $n = 12$ articles for full-text screening was not feasible. The final selection process involved five independent reviewers, as discussed previously, who debated whether the eligibility requirements were applicable while looking over the full texts of ($n = 113$) papers. The remaining ($n = 77$) were removed since they did not fit the eligibility criteria. Consequently, ($n = 36$ items) were included in the final selection (Figure 1).

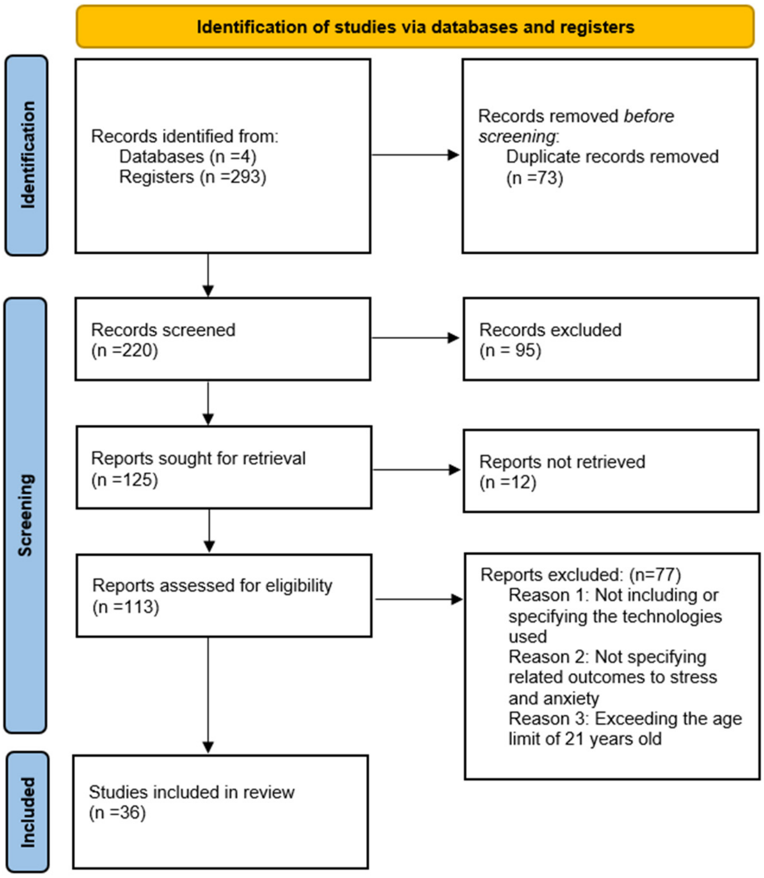

Figure 1. PRISMA 2020 flow diagram.

3. Theoretical Knowledge

3.1. Neurophysiological Stress and Anxiety

In the twenty-first century, stress is the main contributor to health issues. When managed, stress can be good for our physical and mental well-being, but if it persists for an extended period of time, it can cause a number of issues that can significantly affect a person's functioning and general health [23]. Stress might appear as a real or possible threat that necessitates a quick adjustment in behavior. Neural circuits and the brain are essential for the processes of stress response, adaption, and recuperation. More precisely, our nervous system is in charge of deciding what is dangerous and regulating the body's behavior and physiological changes in response to a stressor [24].

In response to stress and other experiences, the growing brain demonstrates notable neuroplasticity (structural and functional plasticity), including synaptic pruning, dendritic remodeling, and neuronal replacement. Stress can cause disruptions in the brain circuits supporting mood, anxiety, judgment, and cognition, which can alter how these behavioral states manifest. This imbalance also impacts systemic physiology through immunological, metabolic, autonomic, and neuroendocrine mediators [25]. To lessen the threat, the stress response triggers a number of defense systems, such as the hormonal messenger system [26].

More precisely, the catecholamines norepinephrine and epinephrine are significant peripheral stressors, while the hypothalamic–pituitary–adrenal (HPA) axis controls glucocorticoids (GCs). Both of these systems are regulated by the autonomic nervous system (ANS), which is composed of the parasympathetic nervous system, sympathetic nervous system, and sympathetic-adrenal cortex. The internal control nerve system's ANS and HPA axes are both intimately related to the autonomic nucleus centers. Following stressor exposure, the central ANS is swiftly activated, peripheral catecholamine production increases rapidly, and the HPA axis is activated immediately thereafter. The anterior pituitary creates and releases adrenocorticotropin hormones into the bloodstream following the first release of corticotropin-releasing hormone (CRH) in the portal pituitary circuit. This, in turn, triggers the pituitary's release of GCs like cortisol. A mostly negative stress response is produced when circulating GCs attach to GC receptors. Additionally, circulating GCs augment certain sympathetically mediated actions. Crucially, the adrenal cortex is directly regulated by the ANS, which could promote the release of GC [27].

3.2. Gut–Brain Axis

An interesting idea in the field of health and disease is that the gut microbiome has the ability to communicate with areas of the brain that can regulate behavior [28]. Examining the interaction between the gut and brain through neurobiological research has revealed a complex system of two-way communication that can maintain homeostasis and proper digestion and impact motivation and higher cognitive function. The brain–gut axis is a bidirectional communication system consisting of neural pathways, such as the enteric nervous system "ENS", vagus, sympathetic and spinal nerves, and chemical pathways, including cytokines, hormones, and neuropeptides as signaling molecules [29].

Emotion-related peripheral patterns, motor activity, excretion, and immunity in the gastrointestinal tract are controlled by both sympathetic and parasympathetic neurosis [30]. Current methods to identify the bacteria that make up the gut microbiota depend on omics analysis using advanced high-tech equipment [29].

Bacteria are essential for normal brain development as well as brain function in adulthood. Neuroplasticity in the adult brain is regulated by the microbiota, which is a critical process involved in neurogenesis and microglia activation. Such discoveries have contributed to a paradigm shift in neuroscience and psychiatry so that early development and subsequent brain function can be altered by targeting the microbiome [31].

The microbiome also affects the structure and function of the amygdala, another key brain region associated with stress. The amygdala is essential for emotional learning and social behavior, as well as for the activation of behavioral and physiological responses to stressful stimuli, particularly those that induce anxiety and/or fear [32]. Disrupted amygdaloid processes have been implicated in a variety of neuropsychiatric disorders, including the autism spectrum [31].

The microbiome contributes to the regulation of neurotransmitters by generating serotonin, dopamine, GABA, histamine, and acetylcholine, both directly and indirectly. The gut microbiota expresses a number of neurotransmitter receptors, which explains the direct influence of the CNS on gut microbiota. All these tasks are performed in coordination with the autonomic, enteric, and neuroendocrine systems, and the HPA axis also contributes [33,34].

3.3. Structural and Functional Differences Caused by Stress in Early Development

Psychosocial stressors, especially when present early in life, contribute to the development of anxiety and depressive disorders. In the cognitive domain, changes have also been observed in children exposed to chronic stress early in life.

Even after controlling for sociodemographic variables like maternal IQ, delivery complications, gender, ethnicity, and birth weight, these effects remained. Language, memory, attention, and executive function are the domains that are engaged. Furthermore, babies that experience stress at a young age frequently have more cognitive biases. For instance, they are less likely to notice positive facial expressions and more prone to perceive social cues as hostile than children who have never experienced psychological distress. Additionally, these children were twice as likely to repeat courses, had poorer work habits, and struggled to build them on their own. They also scored lower on intelligence and academic success assessments and had lower IQ scores. Furthermore, children who experience neglect are more likely to experience behavioral issues. Some of these behavioral issues can be brought on by a decrease in cognitive flexibility. Psychosocial functioning is still impacted. They displayed outcomes linked to decreased social skills and lower behavioral control when their professors evaluated them [35].

The study by [36] examined the relationship between early stress and mesial microstructural integrity in a sample of healthy controls aged 8 to 73 years. Participants were divided into four age groups (8–12, 13–18, 19–50, 51–73). For fractional anisotropy (FA) mesoclavium, a comparison was made between those with three or more morning stress events and those with fewer than three events. During separate analyses, both groups were tested for verbal memory, information processing speed, psychomotor speed, and cognitive flexibility. The results showed that both the younger and older groups of early stressed subjects had significantly lower gender-specific fractional anisotropy than those without early stress. However, no differences were observed between groups for any of the cognitive tasks. Through this research, it was found that early stress is associated with subtle changes in brain structure but not function.

The study by [37], through their systematic literature review, examined how developmental stress, particularly childhood maltreatment, may affect the HPA axis' function and hippocampal structure. In addition, they examined the relationship between HPA axis function and hippocampal volume in healthy states, depression, and other diseases. Evidence was observed that prenatal stress and childhood maltreatment are associated with abnormal development of the HPA system, as well as reduced hippocampal volume. Reduced hippocampal volume was also associated with increased daily cortisol secretion. The conclusions concluded that a model incorporating child maltreatment, cortisol abnormalities, and hippocampal volume may need to account for other factors such as temperament, genetics, or the presence of depression, providing a holistic explanation of all findings. Also, the role of early-life maltreatment in the impairment of the HPA axis remains unclear.

[38] study involved the collection of structural MRI scans (n = 61) (32 boys, 29 middle-aged girls, 142.35 +− 21.12 months), using well-validated executive function assessments and in-depth interviews that were conducted to assess stress exposure in humans. Smaller volumes in the prefrontal cortex, namely in the medial frontal gray and white matter and both frontal poles, are linked to cumulative life stress and spatial working memory, according to an analysis of the differences in brain anatomy. The relationship between cumulative life stress and spatial working memory can be explained by individual differences in prefrontal volume, according to mediation analyses. These findings imply that structural alterations in the prefrontal cortex might be a mechanism via which increased cumulative stress results in diminished cognitive function.

The current study's authors [39] looked at how teenagers' brain structures and functional activation to images evoking negative emotions, as well as the stress levels in mothers' self-reported items, affected their cortisol responses to stress. Data on maternal stress perception and salivary cortisol responses to a demanding task were gathered from 66 mothers and adolescents, ages 12 to 14. The teens' brain structure and function were then evaluated by MRI. Adolescent reactivity in the medial prefrontal cortex to negative emotional stress-inducing stimuli was predicted by higher levels of parental perceived stress but not cortisol reactivity, according to whole-brain functional studies. However, no statistically significant correlations were shown for structural analyses. Given the finding that maternal responses to stress are associated with adolescent medial prefrontal cortex function, parental stress may play a role in the development of the neuropsychiatric stress system in adolescence, with potential implications.

In the study by [40], through a systematic review of the literature on functional MRI, as well as a meta-analysis of research regarding structural MRI sensory imaging of brain tumors in pediatric patients with posttraumatic experiences, a possible association between early traumatic experiences and variant brain regions and functions was investigated. A meta-analysis assessing group differences was conducted using all amygdala, hippocampus, brain tumor, and intracranial tumor data that satisfied the inclusion criteria. According to the meta-analysis, PTSD patients had a reduced intracranial volume, total brain volume, and total cortical area. The gray matter volume of the frontal lobe and amygdala and the total gray matter volume of the hippocampus (left and right) were all decreased, although these differences were not statistically significant. Functional investigations showed that the PTSD/PTSD symptom group differed in how different parts of the brain were activated in response to stimuli.

In the study by [41], 27 young subjects with PTSD and 21 typically developing subjects without trauma were assessed at baseline and at a one-year follow-up. During each visit, the youth underwent structural MRI and functional resting MRI at each visit. Areas showing volumetric abnormalities on whole-brain structural analyses were identified and used as seeds in exploratory analyses of intrinsic connectivity. The results showed that young subjects with PTSD showed persistently reduced gray matter volume in the right dorsal prefrontal cortex and a bilateral ventrally arranged prefrontal cortex. Group analyses over time revealed abnormal longitudinal growth of the bilateral prefrontal cortex, with typically developing adolescents showing a normal decrease in the right dorsal prefrontal cortex from baseline to follow-up, whereas adolescents with PTSD showed an increase. Using these regions as seeds, PTSD patients showed atypical longitudinal decreases in intrinsic connectivity of the prefrontal cortex and amygdala as well as with the hippocampus, in contrast to increases in developing adolescents, specifically. Specifically, adolescents with PTSD showed increased ventricular connectivity of the prefrontal cortex and amygdala as well as with the hippocampus over time. Also, volumetric abnormalities of the interventricular PFC and extraventricular PFC were predictive of symptom severity.

3.4. ASD, Sensory Modulation Disorder (SMD), and Stress Due to Hyperreactivity to Stimuli

SMD has been widely recognized and linked in the literature as one of the primary sensory processing issues affecting people with ASD. In their research, [14]clearly identified sensory processing dysfunction in children with ASD and contrasted it with SMD as two distinct characteristics. Thirty-three generally developing children (4–12 years old), thirty-eight children with ASD (5–15 years old), and thirty-one children with ASD problems (5–13 years old) participated in the study. The respondents' arousal and reactivity were examined and quantified by the researchers in a lab setting. The results showed that the two clinical groups differed from one another. Children with ASD exhibited lower initial arousal and reduced reactions when shown a laboratory example of sensory problems. The ASD and SMD clinical groups exhibited considerably more abnormal sensory-related behaviors than children with usual development. In addition, there were three differences between the two groups: the ASD group showed more proprioceptive and vestibular behaviors, which were signs of sensory under-reactivity; the latter group showed more sensation-seeking behaviors; and the former group showed more signs of hyperreactivity to taste and smell.

By comparing sensory processing, social participation, and praxis in a group of 79 children aged 5 to 8 years (M = 6.09), 14 of whom were girls and 65 of whom were boys, [42] added more findings. The children were divided into two groups: the ASD group (n = 41) and the standard development comparison group (n = 38). The researchers assessed the children's sensory profiles using a sensory processing measure (SPM). Details on aspects of their home and classroom modifications were supplied by parents and teachers, respectively. The ASD group received scores suggesting higher levels of dysfunction on all the evaluated measures in both situations, with the biggest differences observed in the variables of the motor act and social involvement. The two senses most impacted in the ASD group were hearing and touch.

Others looked into food selectivity and oral sensitivity to SMD. [43] evaluated the oral sensory processing of children with SMD (n = 53) and those without SDM (n = 58) who were between the ages of 3 and 11. In addition, the researchers evaluated food in children with ASD according to their preferences, informal oral sensory processing, and fruit and vegetable consumption and how they all related to each other. They discovered that more children with ASD exhibited abnormal sensory processing than those without the disorder. Furthermore, the study revealed that children with ASD who had unusual oral sensory sensitivity ate fewer vegetables and rejected more items. More recent research has found associations between ASD and social difficulties. [44] study examined the connection between children with ASD's social and adaptive functioning and sensory challenges. The researchers looked at the connections between abnormal sensory processing responses and social skill deficiencies, impaired social cognition, and general adaptive functioning in a group of preschool-aged children with ASD. This study contrasted 36 peer children of similar ages who were generally developing and 64 children with ASD aged 3 to 6 years. Measures of general adaptive functioning, social problems, and sensory processing were gathered from the parents of each child. The results of the study showed that children with ASD who experienced more sensory problems were more likely to struggle in social situations and have lower levels of adaptive functioning. When [45] compared the play activities and sensory information processing of children with ASD (6–10 years old) to those of age and gender-matched (typically developing children), they added more data on social participation. A total of 95 parents of typically developing children and 93 parents of children with ASD were surveyed at daycare facilities, schools, and hospitals. Both the sensory profile (SP) and Participation in Childhood Occupation (PICO) metrics were employed. Boys made up 74% (n = 72) of the study's participants (with a 4:1 ratio of boys to girls) in the autistic group. The findings indicated that sensory processing issues are linked to certain childhood participation limits. Children with ASD engaged less frequently, at a lower level, and with less pleasure than typical children their age. Compared to the typical group (n = 95), which had sensory processing issues at 21.5% (p = 0.28), children with ASD had sensory processing issues at 68.8%. Another study emphasized symptom variability.

In order to ascertain whether cognitive capacity and reported sensory symptoms in the ASD sample explained the sensory processing measure (SPM-2) scores, [46] compared the sensory processing of school-aged children with ASD with that of their normally developing (TD) counterparts. Parents of the two groups—105 children with ASD and 70 children with TD—were given the exam, and the groups were subsequently split into high-functioning and low-functioning groups. The findings demonstrated that children with ASD had higher SPM-2 subscales and overall scores. The hearing, social participation, balance, and movement subscales of the SPM-2 showed a significant difference between children with high and low functioning in the context of ASD, although the total SPM-2 scores did not differ between the two groups of children. This research highlights that the variety of sensory patterns is associated with either high or low cognitive functioning.

3.5. Stress Measurements

The common types of psychological stress commonly measured are major life events, traumatic events, exposure to early life stress, and chronic or current stress. The choice of appropriate stressor exposure to measure depends on the relevance of the population, the research objectives, and the assumption that certain types of stress are associated with relevant outcomes. Capturing a variety of stressors will reduce the likelihood of underestimating an individual's psychological and social stress [47]. Responses to stress can be measured with self-report measures, behavioral coding, or physiological measures. These responses include the emotional, cognitive, behavioral, and physiological responses elicited by stressful stimuli. One of the simplest ways of measuring stress response is a self-report of perceived stress associated with a particular stressor or life situation.

[48] distinguished three ways in which stress is investigated: (1) The epidemiological tradition focuses on identifying situations and experiences that are considered stressful based on the consensus that they pose a threat to social or physical health. (2) The psychological tradition focuses on individuals' perceptions of stress caused by life events based on their assessment of the threats posed and the availability of effective coping resources. (3) The biological tradition focuses on the brain disruption of physiological systems necessary to regulate homeostasis and normal metabolic control.

Outside of the laboratory, new technologies have improved our ability to record real-time responses to stress in everyday life using mobile phones and handheld devices that are increasingly being implemented by many researchers ([49–51]. Examining the impact of stressor exposure and stress responses on health can improve the prediction of health outcomes, as many stress models suggest that these responses also mediate the effects of stress exposure, which may influence health outcomes [47].

The most common ways of measuring and obtaining data on the neurophysiological changes observed are as follows:

- Through GSR (galvanic skin response) by using changes in skin conductance. When stress is present, skin resistance decreases due to increased sweat secretion.

- Electromyography (EMG) measures the electrical activity of muscles. Stress causes differences in muscle contraction, which can be used to determine stress levels.
- Skin temperature changes that correlate to an increase in stress levels.
- Measurement of heart rate and heart rate variability.
- Electrocardiogram (ECG), from which the heart rate and heart rate variability are measured. (Calculation of the variability of heart rate variability [52].

Many physiology-based stress-sensing systems use machine learning and rely on three main types of sensors: wearable sensors, external sensors, and software sensors, where sensor data collected by software do not necessarily require a dedicated hardware sensor [53].

3.6. Measurement of Stress in Individuals with ASD

Individuals with ASD appear to have increased levels of neurophysiological stress and anxiety disorders compared to the neurotypical population and can be categorized into three categories: (1) neurophysiological changes in the presence of a stressor, (2) questionnaires of individuals with ASD and parent caregivers, and (3) those of a mixed type (neurophysiological changes and questionnaires).

From studies conducted by various researchers who have aimed to measure these effects in populations with ASD, we identified a great diversity in the mode of taking; more specifically, [54] measured cortisol in children with ASD who were at rest compared to when faced with a stressor such as blood intake. In addition, the parent questionnaire was given to further the reliability of the child behavioral checklist measurements.

The findings of [55] suggest a distinct neuroendocrine response to social stress in high-functioning autistic children despite similar sympathetic and parasympathetic responses to stress compared to the neurotypical population. This preliminary study examined physiological arousal in children with high-functioning autism (HFA, n = 19) compared to a control group (n = 11) before, during, and after the Trier Social Stress test (Trier Social Stress). The HFA group was more likely to have decreased salivary cortisol after the stressor, whereas the comparison group was more likely to have increased cortisol (p = 0.02); however, no differences in electrodermal activity (a measure of sympathetic arousal) or vagal tone (a measure of parasympathetic activity) were identified between groups.

In their study of a population with ASD compared to a neurotypical sample, [56] measured the skin's temperature, heart rate, and electrodermal activity in a sample of children with ASD (n = 12) and those typically developing (n = 17) during a stress condition (Stroop task) and baseline condition (surveillance tape). With some regression model adjustments based on the internal period, the recovery period, the stress test, and the remainder of the main level, a comparison of saliva control, heart rate, and heart rate variability was conducted.

[57] collected behavioral and physiological measures of stress and anxiety during dental cleaning in order to examine the causes and consequences of behavioral and physiological discomfort experienced by children with ASD during normal dental visits. In the control group, which included 44 people aged 6–12 years, there were 22 individuals with ASD and 22 individuals with neurotypical traits. Based on physiological measurements and measures of overt behavioral anxiety, classified by the researchers and dentists, the results indicated that children with ASD were more anxious than the control group. Age was linked to behavioral discomfort in the typical group, while expressive communication and sensory processing issues were linked to behavioral distress in the ASD group. Physiological dysphoria was associated with parent-reported anxiety in the typical group and with sensory processing difficulties in the ASD group. The following assessment measurement tools were used to measure anxiety: Child and Adolescent

Symptom Inventory-Anxiety Scale (CASI), Children's Fear Survey Schedule-Dental Subscale (CFSS-DS), Anxiety and Cooperation Scale (A & C Scale), Short Sensory Profile (SSP), Frankl Scale, and the Children's Dental Behavioral Rating Scale (CDBRS) from the questionnaires used to measure neurophysiological changes, such as electrodermal activity (EDA).

The aim of [58] study was to determine if Zen Shiatsu can reduce short and long-term stress levels in children with ASD. The PEDS QL 4.0 Young Child Questionnaire was used to measure stress on the impact of intervention implementation by parents [59].

[60] conducted a preliminary investigation to evaluate the physiological stress (cortisol) and regulation (respiratory sinus arrhythmia, RSA) of children aged 10 to 12 who were either normally developing (TD) (n = 25) or who had ASD (n = 31) after they were subjected to two social stress protocols. The extent to which cognitive emotions (emotional knowledge) and stress (state and trait) mediate stress responses was also investigated. Depending on the type of stressor, the results displayed distinct stress response patterns. Both groups regularly displayed adaptive and synergistic cortisol and RSA responses during cordial social interactions. However, in response to social appraisal, the ASD group did not show any correlated responses across the physiological systems, which may be due to an attenuated stress response from the evaluative social stressor. The following instruments were used in the present study: the Trier Social Stress Test (TSST)-Child Version, the TSST-friendly pre-baseline, salivary cortisol test, respiratory sinus arrhythmia (RSA), and the Stress Inventory for Children (STAIC).

The study by [8] investigated the relationship between stress and symptoms of ASD in this population in n = 22 without ASD and n = 24 with ASD (with a mean age of 35.7 and 31.8 each), who were individuals with both sensory and cognitive disabilities. Physiological stress levels were determined using salivary cortisol according to the protocol of [61]. No additional self-report or parent and caregiver questionnaires were administered in this study. Participants with and without ASD showed no differences in cortisol levels, as well as differences between the OASIS test day and control day. In contrast, cortisol levels were positively associated with the presence of stereotypical and repetitive behaviors.

[62] gathered and categorized the scales used in their systematic review in order to create a framework for researching stress in people with OASIS using self-report measures. More precisely, two primary scale categories were reported: a moment-specific state-like questionnaire and general trait-like stress surveys. The following subcategories, which comprised the stress-specific questionnaires, were developed from these in the first category: (1) Chronic Stress Questionnaire for Children and Adolescents, (2) Perceived Stress Scale, (3) Stress in Children Questionnaire, and (4) Adjusted Stress Survey Schedule, and in the second group, these were self-made questionnaires and Depression Anxiety Stress Scale questionnaires. Lastly, the Subjective Units of Distress Survey, a compliance questionnaire, was likewise found in the second category. Only the SSS, which asks the subject to score the severity of their stress responses in eight scenarios, was created for use with individuals with ASD from the first category listed. (1)Threats and changes, (2) expectation and uncertainty, (3) unpleasant experiences, (4) enjoyable experiences (like birthday celebrations or presents), (5) sensory and interpersonal contact, (6) food-related activities, (7) social and environmental connections, and (8) stress associated to rituals were considered [63]. [64] used resting heart rate variability (HRV) in combination with the Emotional Dysregulation Inventory to measure resting heart rate variabilities in adolescents with ASD compared to neurotypical subjects.

4. Results

4.1. Studies Characteristics

The present study gathered results from a comprehensive summary of n = 36 studies that were finally pooled into this systematic review for further analysis. The included studies examined assistive and emerging technologies as mediators to detect and reduce neurophysiological stress and anxiety in children and adolescents with ASD and sensory processing disorders, which were published from 2015 to 2024 (Figure 2).

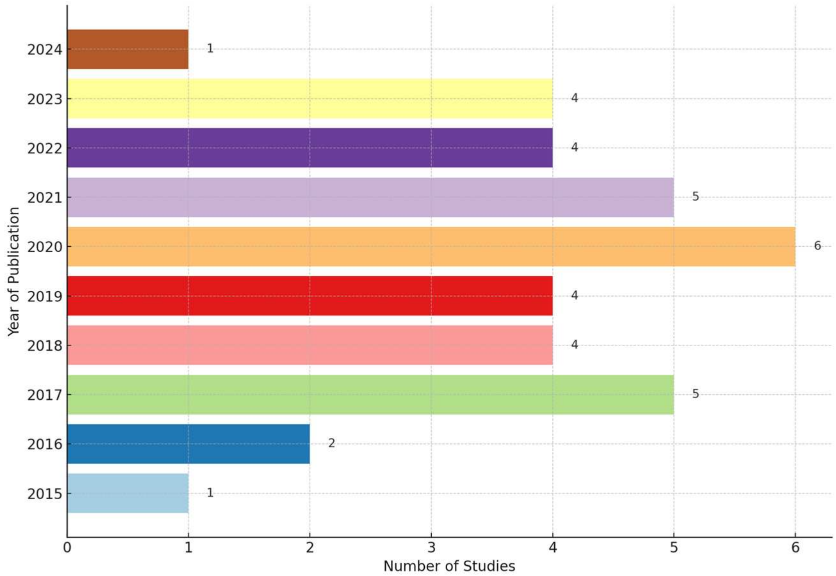

Figure 2. Distribution of studies by year of publication.

The included studies utilized a diverse set of research methodologies, including randomized control trials (RCTS) in n = 7 studies, employing a rigorous experimental design to evaluate intervention effectiveness ([65–71]). Further studies (n = 7) utilized comparative designs without full randomization (quasi-experimental studies) ([72–78]). n = 8 more studies (pilot and feasibility) focused on assessing the feasibility and preliminary effects of interventions [79–86]. Finally, in n = 5 studies (single-subject and case studies), the researchers presented detailed individual analyses of the interventions' impacts [87–91]. Moreover, in n = 9 (observational and exploratory), they tried to examine real-world interactions with these types of technologies [92–100] (Figure 3).

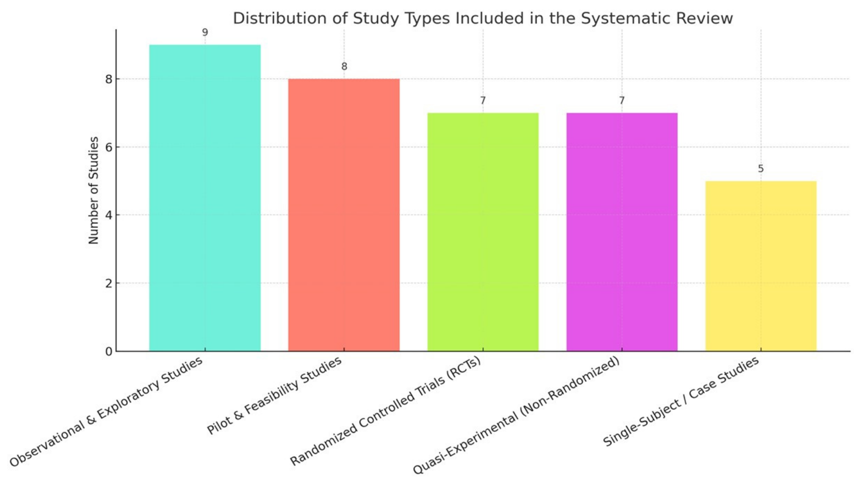

Figure 3. Distribution of study types in the systematic review.

According to the study populations, we observed a wide variety of data collected. More specifically, the sample size studies ranged from single-subject case studies up to 201 participants ([71,72,97]. The age range of the pool was primarily children and adolescents 3 years of age to 19 years, with some of them including young adults [65–67]. Regarding gender distribution, most of the studies reported more male samples (~80–90%), reflecting ASD prevalence trends [73,75,87].

Finally, the studies were performed across different countries (some uniquely, some co-organized, and some jointly), providing a wider approach to the interpretation of the data acquired. More specifically *n* = 7 were from the USA [75,79,80,85,87,90,100] ; ; , *n* = 3 were from Canada [66,71,76] , *n* = 3 were from China [65,72,77], *n* = 3 were from Indonesia [68,69,82], *n* = 3 were from Qatar [81,89,91], *n* = 3 were from UK [70,96,97], *n* = 2 were from India [86,98], *n* = 2 were from Italy [73,95], *n* = 2 were from Japan [84,99], *n* = 1 was from Australia [88], *n* = 1 was from Belgium [83], *n* = 1 was from Netherlands [92], *n* = 1 was from Sweden [74], *n* = 1 was from Israel [94] and *n*= 3 were studies that were performed in multiple countries, i.e., Israel, the UK, and Sweden [67], France and Italy [78], as well as Turkey, Macedonia, the UK, and Poland [93] (Figure 4).

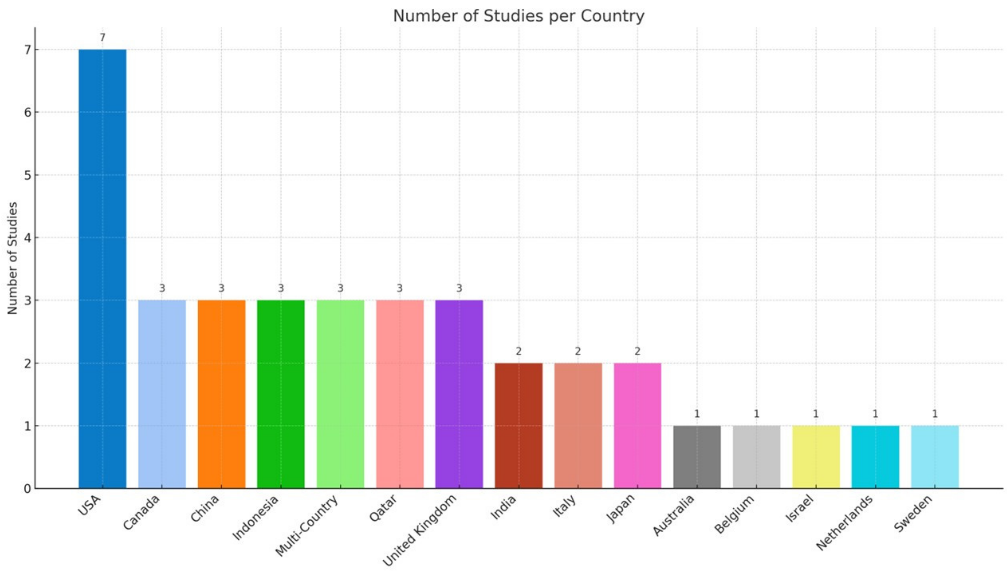

Figure 4. Studies distribution by countries.

4.2. Assistive and Emerging Technologies for Children and Adolescents with ASD on Stress Management (Low Technology)

4.2.1. Visual Programs/Schedules

Stress and anxiety are common among persons with ASD, and they are frequently brought on by the challenges they encounter on a daily basis. Visual programs are a type of low technology that has shown promise when used in any situation where people frequently encounter difficulties. A visual program is a set of pictures or words intended to motivate someone to carry out various duties. They provide abstract ideas like time and action in a concrete form by using words, pictures, and other visual elements to explain what will happen, when it will happen, and where it will happen. They have been effectively utilized to treat issues with sequential memory, time management, and language understanding, as well as to lower anxiety in a range of contexts (classrooms, homes, private gyms, dental offices, etc.) [101].

[76] conducted a pilot study to investigate whether a visual design system using pictorial communication symbols can help children with autism achieve daily oral hygiene. The study involved 14 boys with ASD, ages 3 to 8, who attended a dental clinic

for four consecutive weekly dental appointments. The patients were randomly assigned to either the experimental group, which received a visual program system in addition to standard care, or the control group, which received a "Tell-Show-DO" approach (standard care). The results showed that the combination of a visual teaching program and repeated weekly visits seemed to have helped children with autism reach more milestones by showing higher levels of reduced behavioral distress during dental exams and cleanings.

[69] compared the effectiveness of using a visual training module to reduce anxiety during dental treatment with that of video modeling in a population of children with ASD. Twenty children with ASD, ages 6 to 10, participated in this experimental clinical investigation. They were split into two groups: the PV-BDG module's visual intervention group (n = 10) and the video modeling group. To quantify salivary immunoglobulin A (sIgA) concentrations, patients' saliva was taken both before and after the intervention. The Shapiro–Wilk normality test and the independent t-test were used to analyze the data and compare how much stress was reduced in the two groups. The findings demonstrated that, as indicated by changes in the sIgA levels, video modeling and visual teaching modules might effectively lower the stress levels of children with ASD while receiving dental care.

[68] found similar results regarding the efficacy of visual methods when comparing the Berkunjung ke Dokter Gigi Visual Pedagogical Module intervention method (VPM-BDG) and the Berkunjung ke Dokter Gigi Video Modeling intervention method (VM-BDG) in lowering anxiety levels in children with ASD while receiving dental care. Twenty children with ADHD, ages six to ten, participated equally in this clinical study and experimental trial. Following that, they were split into two groups based on the type of intervention: VPM-BDG and VM-BDG. The children's saliva was taken both before and after the intervention, and the delta values of their salivary cortisol concentrations were measured in a lab. The Mann–Whitney test was used to analyze the effectiveness of the two interventions. The mean value in the two intervention groups was −0.006 and 0.0005. The delta values of the salivary cortisol concentrations showed that VM-BDG and VPM-BDG effectively reduced stress levels in the tested sample of subjects.

The study by [88] evaluated the use of visual schedules and task systems to help four students with ASD stay on task and work independently in a typical classroom environment. These strategies were implemented by teachers as inclusive practices and were evaluated by observation in physical classroom environments to test their feasibility in general contexts. All participants demonstrated improvement in their behavior during the task. The results for other secondary dependent variables were mixed, with some students demonstrating decreased off-task behavior and increased productivity.

4.2.2. Sensory Modalities and Wearables

Children and adults with ASD frequently struggle with sensory processing and modulation [102]. According to [14], [42], and [44], a person with ASD may have hyper-responsiveness (touch, hearing, smell, etc.) to the various stimuli they encounter in their surroundings. This can activate the ANS and, more specifically, the sympathetic system, which can lead to an increase in stress levels in the body. The term "wearables" refers to a wide range of items that users can wear to offer biometric information about their homeostatic condition or to normalize their level of arousal by using their features to provide input (biofeedback). The following is a list of topics that have been studied for their qualities as low- or medium-tech aids.

[99], in their pilot study, investigated the effectiveness of earplugs and noise-canceling (NC) earplugs in relation to behavioral control of problems caused by over-reactivity to auditory inputs in children with ASD. The results showed that the T-scores

on the Goal Attainment Scale (GAS) were significantly higher during the use of acoustic noise cancelation compared to baseline. During the baseline time frame, five children with DSA demonstrated improved behavior from those with normal headphone (NC) use; however, there were no differences in the GAS T-Goal scores between the headphone (NC) phase and the baseline phase or between the headphone and NC headphone phases. NC headphones were given to 21 children aged 4 to 16 years who had not used the sound isolator for two weeks and received normal earplugs as a sample after random selection. Participants' responses to auditory stimulation were assessed by their parents or teachers.

Six children with ASD, ages 8 to 16, were examined using a multi-item treatment method in a related study by [75]. As part of their treatment, participants were randomized to wear either over-ear (above the ears) or in-ear (within the ears) hearing aids for two periods. Every child underwent four stages of investigation. The reference week was the first week of data collection; then came the intervention week, the non-intervention week, and the alternative intervention week (as is customary). The Empatica E4 bracelet was used to gather data on electrodermal activity (EDA). Five measurements were taken throughout each of the 16–20 data collection periods that the participants underwent. The purpose of this study was to determine whether there is proof that therapies that lower children's sympathetic activity can effectively treat both hypersensitive and autistic children. The current study used skin conductance measurements to analyze these findings. Separate analyses for paired study periods revealed that the use of noise-isolating headphones led to statistically significant variations in skin conductance levels and the frequency of nonspecific conductance responses between baseline and post-study periods. The researchers came to the conclusion that in individuals with ASD and auditory hyper-responsiveness, noise-isolating auditory sensitivity may lessen sympathetic activity.

[77], in their study, took into account the heterogeneity of auditory perception in children with ASD and how it differs compared to conventional isolation hearing aids. For the purpose of this study, they designed appropriate noise control functions in hearing aids to meet the needs of children with ASD who have different auditory perceptions through a series of auditory perception and electroencephalogram tests, in which children with ASD and with auditory hypersensitivity listened to sounds of different frequencies and amplitudes which were analyzed through the subjects' responses. Appropriate noise reduction targets were determined based on acoustic perception curves constructed from mean acoustic perception values and noise levels using an appropriate power function. A hybrid active noise cancelation (ANC) system based on acoustic perception was then developed and validated. The results showed that frequencies of 250 Hz and 8 kHz were considered the most unpleasant by the majority of autistic children. Participants were divided into five groups using the K-means algorithm. It was found that each group had its own characteristic auditory perceptual response. Finally, improvements in auditory perceptual response were observed when children used this type of headphones, with their auditory perceptual characteristics consistent with different groups of children with autism.

[87] used an alternating treatment design that assessed the engagement of a 5-year-old child with ASD during math in a general education kindergarten classroom using a weighted blanket and structured work boxes as objects. The results showed that the weighted blanket did not lead to changes in therapeutic behavior, and it was observed that the student's engagement was lower than the baseline. More specifically, the subject sat on the mat more often when using the blanket compared to the baseline sessions but often engaged in behaviors that were not functional (touching the blanket) or were not consistent with engagement in an academic response (e.g., pulling the blanket over his head).

[85], through their research, examined children with ASD who exhibited behavioral symptoms of sensory processing deficits and whether weighted blankets improved sleep quality. A single-subject design study was conducted with two 4-year-old children who had been diagnosed with both ASD and sleep disorders. An 8-day baseline phase, a 14-day total intervention with weighted blankets, and a 7-day removal period were used to examine the objective sleep measurements and caregiver surveys. Visual analysis and the rate of non-overlap techniques were used to evaluate the caregivers' accounts and objective data. The weighted blanket intervention had little effect on sleep patterns, according to the results. However, by considerably shortening the time it took for participants to fall asleep, the usage of weighted blankets improved their morning mood and decreased stress after nighttime use.

The study by [74] sought to ascertain whether using weighted blankets improved sleep and day-to-day functioning in individuals with ASD and/or ADHD. A total of 85 participants with an ADHD or ASD diagnosis, 48 children (57%) and 37 adults (44%), who were at least 18 years old, were given a weighted blanket to utilize. The participants answered over the phone. The weighted blanket enhanced sleep-related skills, sleep quality throughout the night, and relaxation during the day, according to the results. In children and adults with ASD and/or ADHD, the use of a weighted blanket enhanced their daily morning/evening routines, including getting ready for bed and waking up early.

4.3. Assistive and Emerging Technologies for Children and Adolescents with ASD on Stress Management (High-Tech and Emerging Technologies)

4.3.1. High-Tech Wearables

[80], through their study, demonstrated a machine learning approach using data from wearable devices to discriminate physiological states associated with stressful and non-stressful conditions in children with ASD in a controlled laboratory setting, where the heart rate and resting rate interval measurements were collected during rest and during activities designed to simulate stress using a consumer (wearable) device. The analysis included 38 children (22 children with ASD and 16 children without ASD). After removing the outliers, 20 statistical features were explained from the data collected during the rest and stress periods of each subject. Using nested cross-validation across 76 sample periods (38 rest periods/38 stress periods), logistic regression (LR) and support vector machine (SVM) classifiers were trained and evaluated to classify each validation sample as a rest or stress period. The SVM and LR models achieved an accuracy of 93% and 87%, respectively. The results of the study showed that the machine learning model combined with mobile device data can support real-time health intervention applications, helping to detect and reduce stress.

In contrast to children with a language impairment (LD), the study by [95] assessed the heart rate (HR) as a possible indicator of stress reactivity in children with ASD. A total of 24 patients (mean age = 42.62 months; SD = 8.14 months) participated in the study; 12 children with ASD and 12 children with LD received physiological evaluations (HR monitoring) and clinical trials while donning HR measurement devices during five interaction activities. An increase in HR during the third activity (ADOS-2 bubble game) was significantly associated with autism symptoms ($r = 0.415$; $p = 0.044$), whereas the association between total ADOS-2 and HR during the first activity (ADOS-2 free play; $r = 0.368$; $p = 0.077$), the second activity (baseline subscale of the Leiter-R scheme; $r = 0.373$; $p = 0.073$), and the fifth dynamic (predicting ADOS-2 of an object procedure; $r = 0.368$; $p = 0.076$) did not quite reach statistical significance. Using a linear regression model, it was found that the total ADOS-2 score significantly influenced heart rate variability ($p = 0.023$). Heart rate monitoring may provide information about stressful situations in children with

ASD. In addition, it may help clinicians detect the impact of stress on the core of autism and develop treatment strategies.

The E4 wristband is a portable research tool that offers physiology data, analysis, and real-time imaging software. The E4 has four sensors installed to track and record the heart rate, heart rate variability, skin temperature, sympathetic nervous system activity, and blood volume pulses. Studies on the IBI and mean heart rate have demonstrated the validity and reliability of the E4, which has been used to quantify stress and anxiety in particular populations, including the IBI [75] . In comparison to the Mindwave mobile impedance cardiography device, the study by [103] looked at the instrument's suitability as a pure research tool. Its behavior was examined through naturalistic observation that included gestures and face-to-face interaction. Thirty participants were included in the sample collection; they were connected to both devices and split into pairs to rest and converse with one another. The HRV devices' correlations ranged from modest to high, with the resting values being greater than talking ones. The E4 is unable to deliver precise EDA data, nevertheless.

In order to capture and analyze data, the Hexoskin Shirt (HS), a smart shirt with sensors that assess changes in the body's physiology, including the heart rate, respiration rate, and blood oxygen level, is connected to a health platform. In terms of the validity of Hexoskin's findings, its application has primarily been assessed in groups that do not include individuals with ASD, and it is generally regarded as valid and trustworthy. Nevertheless, it poses challenges associated with connection issues that are seen during physical activity. In a recent study, [94] employed it as a research tool to measure physiological variations in a community of adults with ASD. Three stages of research were carried out. The HS was used in the first phase to measure the physiological differences between adults with high-functioning ADHD and those who were neurotypical. The creation of a particular machine learning algorithm to forecast challenging behavior (CB) in real time, in combination with a smartphone app that notifies users when CB is likely to occur, was the focus of the second phase. In the last phase, individuals with CB and their caretakers were asked to test the system's acceptability and efficacy. According to the sample size estimates, 20 high-functioning individuals with ASD, aged 20 to 40, who lived at home and were part of the observation group, and 20 additional neurotypical individuals of the same age who worked in the control group were part of the first phase of the study. Ten persons with ASD, ages 20 to 40, who displayed extremely violent or disruptive conduct, as well as their caregivers, were recruited for the second phase. One individual with ASD who was between the ages of 20 and 40 and had disruptive or aggressive traits was included in the final phase. Participants with ASD accepted the usage of the SWS and did not find it bothersome.

Users can learn basic social and emotional skills using Empower Me Brain Power (EMBP), available for Google Glass Explorer Edition and other smart glasses. BPS smart glasses are social communication training devices that use augmented reality. Studies on the feasibility, acceptability, safety, and clinical impact of BPS have been conducted. In particular, EMBP glasses were used in a two-week study of a 13-year-old high school student with ASD in Massachusetts in order to develop an intervention targeting attention issues and social learning factors that can cause anxiety in children with ASD in school educational settings [90]. Twice daily, the intervention was given. Participating in the intervention's implementation were student health professionals, special education teachers, and general education teachers. Teachers' opinions, the value of technology, and its effects on students and classrooms were recorded through a series of one-on-one interviews and digital journals. Both teachers and students found the use of smart glasses to be practical and easy to use, needing little time for implementation or learning. Teachers also reported that pupils improved their verbal and nonverbal communication abilities and loved the experience. Furthermore, there was no indication that the technology was distracting or had a detrimental effect on the classroom or other students. According to these findings, social skills therapies that are given via smart glasses may be beneficial, realistic, and effective in enhancing social communication abilities and lowering anxiety. [104] conducted a second investigation on a single individual to examine the efficacy of a particular device employing EMBP. Over the course of four weeks, a technician used Brain Power glasses to conduct fifteen intervention sessions in a private office. The subject worked with a technician who wore Google Glasses supplemented with artificial intelligence for 15 min in each session. Measures of efficacy included behavioral rating scales with a pre-test design, qEEG analysis, and a few neuropsychological tests. The results of the neuropsychological tests revealed that social cognition and face memory had significantly improved by at least one standard deviation. Changes in particular regions of interest that may be connected to the brain areas involved in the particular neuropsychological functions assessed were found by a Z-Builder analysis. On the other hand, the instructor said that he did not notice any appreciable behavioral changes in the student.

[91] examined the feasibility of wrist-worn sensors for detecting challenging behaviors in autistic children prior to overt signs by monitoring children's heart rates, electrodermal activity, and movement, as well as the feasibility of using such sensors on the ankle instead of the wrist to reduce manual impact damage and improve object portability through two pilot trials. The first trial involved a wearable sensor on the wrist of a child with autism. The second experiment studied sensors that could be worn on the wrist and ankle of a child with ASD. The results of both pilots showed that the readings from the body-worn sensors correlated with the children's behavior obtained from videos recorded during the experiment. The results showed that wearable sensors can provide additional information that can be transmitted to social robots or caregivers to mitigate self-injurious behaviors.

4.3.2. AI Machine Learning Predictors

[89] examined a session in which a child with ASD interacted with various stimuli, such as a social robot that was programmed to exhibit the problematic behaviors they had noticed. A wearable gadget that could record different actions and physiological indications was worn by the youngster. To identify the best combination, various characteristics, and machine learning setups were examined. The study's findings demonstrated that, in addition to conventional kinematic measurements, physiological signals also result in more precise predictions. 97% accuracy was attained using the optimal feature and learning model combination. The findings of this study contribute to the development of early detection techniques for problematic behaviors, which may enable prompt intervention by social robots and caregivers.

In their most recent study, [81], the same research team, also investigated the impact of sensors using a variety of machine learning techniques and data methods obtained from children with ASD wearable sensors during their interactions with social games and robots that could identify challenging behavior. Every child wore a wearable gadget that gathered information. The occurrence of problematic behaviors was identified through the use of video comments of the sessions. To identify problematic behavior, four machine learning algorithms were applied in conjunction with extracted temporal data (mean, standard deviation, minimum, and maximum). This study also looked into variations in heart rate variability (HRV). The XGBoost algorithm achieved the best performance, with 99% accuracy. Furthermore, the physiological features outperformed the kinematic features, with the heart rate being the main feature contributing to prediction performance. This study highlights the importance of developing tools and methods to detect challenging behaviors in autistic children during social robot support sessions.

4.3.3. Mobile Apps

A data recording system based on mobileHCI, which employs self-assessment and physiological signal collecting, was presented by [79]. In order to achieve this, the EasyConnect mobile app was created to make it simple for parents of children with ASD to document stressful situations through an online survey. A portable physiology sensor was used concurrently to gather electrodermal activity (EDA) and photoplethysmography (PPG) data. In order to determine whether physiological patterns and self-reported stress were related, these signals were synced with self-reports. The findings gathered from eight families demonstrated that the suggested framework effectively facilitated data collection. In addition, EDA-based stress markers were identified and found to be connected with self-reported stress. Ten families participated, and eight of them completed the data collection. Seven females and one male (mean age (years): 44.5, SD = 3.16) were among the caregivers. The mean age (years) of the eight boys with ASD was 9.92, with a standard deviation of 1.28. The severity of ASD symptoms in children was assessed using the Social Responsiveness Scale (SRS-2).

In order to determine whether Anxiety Monitor, a wearable, real-time anxiety detection device, can help children with ASD become more conscious of their anxiety symptoms and begin practicing anxiety relaxation strategies, [66] carried out a randomized controlled trial. Over the course of three sessions, twenty-eight children with ASD received instruction on how to use the Anxiety Monitor and relaxation methods for diaphragmatic breathing. On the fourth visit, participants were advised to practice deep breathing when they felt uncomfortable and were randomly assigned to either obtain feedback on their anxiety level or no feedback at all from the stress meter while completing a difficult task (speaking in front of an audience). An increased propensity to commence deep breathing in response to stress was linked to the responses from the stress meter.

4.3.4. Social Robots

A social robot is a machine designed to interact and communicate with humans in any compatible way. Social robots are usually relatively simple in appearance, provide specialized verbal and nonverbal communication capabilities, and are commonly used in a variety of application areas. Robots can use speech, eye contact, body language, gestures, head positions, and social media to communicate with humans in situations where they exhibit predictable and unacceptable behavior, providing humans with accountability, positive feedback, and emotional release from anxiety and stress. In the literature, many social robots have been used with people with ASD. Some of those found in the literature that have been used with children with ASD to reduce anxiety include KASPAR, Kiliro, and Paro ([105,106].

Kiliro is a robotic parrot with 270-degree vision that is equipped with two wireless AI sphere cameras and a USB connector. It includes seven touch sensors to identify touch interactions by children and can use QR codes to distinguish letters and numbers. Additionally, Kiliro is able to navigate, comprehend, and react to sounds. Regarding its application in children with anxiety and ASD, [86] employed it to provide data on decreases in anxiety symptoms in autistic populations. For 49 days, seven children between the ages of 6 and 16 participated in this study. One method of measuring stress was to measure the biological changes in physiology by taking samples of saliva and urine. The results following interactions with the Kiliro robot demonstrated effectiveness and utility. Specifically, the findings of saliva and urine testing suggested that research participants' stress levels had decreased.

Blow and colleagues developed the KASPAR robot in 2005 with the goal of using it as a study platform for human–robot interaction [107]. Because of its basic human form, KASPAR was used to evaluate whether it could be utilized as a therapy aid for children with ASD. It serves as a social mediator, assisting children in growing and interacting with both adults and other children. It also helps children build their foundational emotional intelligence. It makes use of basic gestures, body language, and facial expressions. Additionally, without the need for outside stimulation, sensors on the face, hands, body, and feet react to touch, assisting children in learning about tactile contact and promoting socializing.

To find out how well the KASPAR robot interacted with children with ASD, [92] carried out pilot research in a special school. Nine children between the ages of eight and twelve participated in a mixed-methods study using an ABAB design for this reason. A total of 36 sessions were recorded, including two sessions with the teacher (normal care) and four sessions with the KASPAR. The primary findings were the teacher's responses, which were captured on videotape, and the children's small activities during the lesson. The findings indicated that during the KASPAR sessions, as opposed to teacher sessions, the children touched the robot more frequently than the teacher (p-value = 0.028), replicated nonverbally more frequently (p-value = 0.012), focused more (p-value = 0.011), and were less distracted (p-value = 0.021). Children gave teachers more positive verbal replies than they did for KASPAR (p-value = 0.028). Children's spontaneous speech usage and the quantity of nonverbal behavior seen both exhibited clinically significant differences favoring the KASPAR condition. According to the findings, KASPAR is better at connecting with children, holding their attention for longer, and providing more targeted guidance than teachers. In addition to lowering fear and fostering an ideal environment for deeper learning, the children appeared at ease and enthusiastic when interacting with the robot.

Using KASPAR, [93] investigated responses to anxiety when engaging with the technology. The current study set out to create a blood volume pulse (BVP) signal-based anxiety detection system for children with ASD. In order to analyze heart rate variability for stress detection, the researchers in this study extracted the HRV features from the raw BVP signals obtained from the E4 wristband while conducting interactive research with the social robot KASPAR. Children with HRV had their facial emotions examined in order to validate the study of low- and high-frequency power features and the results. The study included twenty-one children from three different nations. The study's primary discovery was that the children's interactions with the KASPAR robot appeared to lessen their anxiety-related emotions.

Japan's AIST created a robotic seal pup known as PARO. Similar to reinforcement mechanisms, autonomous mechanisms can pick up new behaviors from user feedback. With its touch, sound, vision, motion, and temperature sensors, PARO can identify what we are holding and use head, flap, and eye movements to convey emotions. In order to assess the efficacy of assistive therapy, [84] looked at a population of individuals with ASD. To assess their mood, anxiety, and impulsivity, nine inpatient psychiatric patients, ages 8 to 19, were watched. The inpatients were allowed to engage with the robot for two months. The findings were not entirely consistent. It is anticipated that this research will assist individuals with ASD in improving their communication abilities or lowering obsessive or nervous behaviors. However, some individuals find it unfavorable due to specific features, like big eyes and high-frequency navigation noise. It has been demonstrated to be successful in reducing stress and anxiety symptoms in those without ASD [108,109]).

4.3.5. Serious Games

Concerning people with ASD and stress management, [83], in their research, examined the impact of the New Horizon game and the SpaceControl app, which were developed in collaboration with therapists and followed the empowerment principles of eHealth. The game combined two short games with relaxation techniques. The performance of the game was analyzed, and usability studies were conducted with three families. Parents and children were asked to complete the Spence Children's Anxiety Scale (SCAS) and the Spence Children's Anxiety Scale-Parents (SCAS-P). The results showed that this game had the potential to reduce anxiety and stress in children with ASD.

By mapping the imitation and joint attention (JA) subset of age-appropriate stimuli from the Early Start Denver Model (ESDM) intervention, [78] created GOLIAH, an automated platform of 11 serious home intervention games, to address the need for hours of intensive intervention to treat children with this condition. A total of 14 children (ages 5 to 8) with ASD and 10 controls (matched for gender, age, region, and normal care) participated in a survey in two specialized clinics, which yielded the results of 6-month matched exploratory controlled research. For six months, participants in the experimental group had four 30 min GOLIAH sessions per week at home and one session in the hospital, in addition to their regular treatment. Linear mixed models were used for statistics. Parents and their children participated in 40% of the planned sessions and had access to all 11 games. In addition to experiencing an increase in the imitation scores on the majority of imitation games, the participants who received GOLIAH training saw improvements in their task completion times on the majority of JA games. Parental anxiety index ratings were unaffected by the GOLIAH intervention. Lastly, there were notable improvements in both groups' Vineland socialization scores, autism diagnostic observation program scores, total parental stress index scores, and issues on the child's internal, external, and overall behavior checklists.

[67], through their study, investigated Emotiplay, a serious game, by conducting a cross-cultural evaluation (in the UK, Israel, and Sweden). Emotiplay aims to teach emotion recognition to children with ASD in a fun way and to create internal motivation. Children with high IQs and ASD, ages 6 to 9, participated in the game for 8 to 12 weeks. Parent-reported levels of autistic symptoms and adaptive socializing were measured, along with emotional recognition (ER) activities, including face, voice, body, and integrative socialization. Fifteen children in the UK were placed through tests, both before and after using serious play. Children were randomly assigned to either the waitlist or control group in Sweden (n = 36) and Israel (n = 38). The results from the UK indicated that 8 weeks of game use greatly enhanced participants' performance on integration, SA, and body language tests. Additionally, parents indicated that their children were less stressed and had better adaptive socialization.

The research team of [73] developed and validated a 3D serious game through virtual training that can be played to help ASD patients practice their shopping while reducing stress. Due to the need for individualized training, many aspects of this game have been adapted to enhance engagement and improve the overall effectiveness. To evaluate the validity of the game, ten subjects (11.9 ± 2.7 males, 20 years old) with ADHD played ten sessions of serious games once a week. Participants had practical experience before and after training in a real supermarket. Changes in the participants' daily living skills were assessed using specific tools, including a form based on the International Classification of Functioning, Disability, and Health in Children and Adolescents and the Vineland II Adaptive Behavior Scale. Significant improvements ($p < 0.05$) were found in basic skills acquired through serious game play, particularly in understanding the purchase process, attention direction, and problem-solving skills. These results suggest that personalized serious games may be an important tool for improving daily living skills.

According to [71], 201 families—parents and children—participated in the study. Three steps were incorporated in the mixed research design employed in this investigation. Depending on their diagnoses (ASD, ADHD, or neurotypical), participants were randomized to one of three intervention groups: serious play, parental support, or a combination of serious play and parental support. Following that, routine scores, obtained at three time intervals (baseline, mean, and endurance) throughout an 8-week period, were analyzed using latent growth modeling and repeated ANOVAs. The findings indicated that a diagnosis had a moderate impact on the children's daily routine. Two interventions (parental support alone and a combination of serious play and parental support) showed very large clinical effects for participants with ADHD, while only one treatment (a combination of serious play and parental support) showed this effect for children with ASD.

4.3.6. Virtual Reality

VR technology provides digital installations that promote virtual immersion through electronic visual simulation, immersing users in an engaging 3D world full of sensory cues and emotions. As virtual reality becomes increasingly popular as an educational tool in learning environments, there are growing expectations about its effectiveness with people with disabilities. Virtual reality provides a fun, safe, controlled, and motivating educational environment and can be an engaging intervention for people with ASD. Virtual reality educational applications have shown promising results in this regard [110].

Concerning their use to combat stress in children and adolescents with ASD, their use seems to be increasingly explored by researchers. More specifically, in the study by [111], the researchers used a sample of nine boys aged 7 to 13 years old who were verbal and diagnosed with ASD but without learning difficulties to create and evaluate a novel treatment using cognitive behavioral therapy (CBT) and gradual exposure to a virtual reality environment (VRE). Every child was interested in a particular subject. In addition to increasing the child's exposure to the phobia or phobic stimulus as necessary, the VRE participants received behavioral and cognitive therapy from a psychologist, such as breathing exercises. For each child, four sessions lasting 20 to 30 min each were planned. Four participants fully conquered their fear, while eight of the nine children in the study were eventually able to regulate their phobias. The treatment's effects persisted after a year. These findings demonstrated that CBT, in conjunction with AER, can be a highly successful treatment for phobias, anxiety, or a specific type of fear in certain young people with ASD.

In a dentistry clinic, [98] study sought to determine how well VR distraction worked to lower anxiety and behavior in children with ASD. A total of 68 children between the ages of 8 and 15 who needed routine, non-invasive dental care and had an ASD diagnosis were enrolled in this study. During two appointments spaced three months apart, these children received routine, painless dental care. At each visit, the children were given the Frankel Behavioral Rating Scale and the Venham imaging test to gauge their dental and behavioral anxiety following treatment. Forty children received dental treatment, and data collection and an analysis of the results were subsequently completed. When using VR distraction, patients' reported anxiety scores significantly decreased, and their dental behavior improved equally significantly ($p = 0.042$ and $p = 0.0001$, respectively). The results showed that VR distraction can help children with ASD who receive routine dental care.

An interactive virtual reality game called SoundFields was used by [70] in their research, using exposure-based therapeutic techniques targeting auditory stimulation through binaural spatial sounds. In order to assess the efficacy of SoundFields in lowering anxiety related to the chosen distracting noises, an experiment was carried out on six children and adolescents with ASD, ages 16 to 19, who showed hyper-responsiveness to particular sounds. Throughout the four weeks of the trial, every participant engaged in active VR game play. Significant decreases in anxiety levels related to the targeted auditory stimuli were found when pre- and post-survey data were compared. According to the study's findings, SoundFields could help individuals with ASD manage their aural hypersensitivity.

The City University of Hong Kong's Centre for Applied Innovation in Internet and Multimedia Technology (AIMTech Center) created six virtual reality training scenarios that mirrored the everyday lives of typical Hong Kong children in order to test the efficacy of a VR-based educational program on emotional and social skills. Ninety-four students with ASD from Hong Kong's general primary schools took part in the study, and 72 of them were included for analysis. The children in the training group were more engaged in social issues, had better adjustment after training (M = 21.8, SD = 2. 99) than before training (M = 20.2, SD = 3.43, t (35) = −3.987, $p < 0.0005$), and had higher emotional expression and regulation (M = 20.2, SD = 3.00) than before training (M = 18.9, SD = 3.57, t (35) = −2.174, $p = 0.037$). Additionally, for emotional expressions (F (1, 70) = 5.223, $p = 0.025$, partial η2 = 0.069) and social reciprocity (F (1, 70) = 7.769, $p = 0.007$, partial η2 = 0.100), there was a statistically significant interaction between the group and time. Children were able to participate in virtual reality training despite initial difficulties associated with the glasses. Some children declined to participate for programming reasons, which could have been minimized by using a head-mounted monitor as a portable and cost-effective device. The results summarized that virtual reality appears to be a promising addition to traditional education and therapy by aiding emotional regulation by reducing stress in children with ASD [72]. These six scenarios were put to the test by the same team of researchers [65] in a similar experimental study that used virtual reality to address emotional control in children with ASD. With corresponding psychoeducational procedures and protocols, six distinct learning scenarios were created, including one that facilitated reinforcement and conceptual generalization, four that simulated different social situations, and one that focused on relaxation and emotional control techniques. Children were shown the learning scenarios in a four-view interactive virtual reality environment with non-intrusive motion tracking, also known as half-CAVE. The 14-week, 28-session program involved 94 children with a clinical diagnosis of ASD, ages 6 to 12. When comparing the tests conducted before and after training, the study found that children's emotional expression and regulation, as well as the emotional reciprocity of social emotions, had significantly improved.

The preliminary experimental study by [100] examined the application of virtual reality-based functional communication in five children diagnosed with ASD using an iPhone X and a Google Cardboard device, conducting a VR intervention at a frequency of once a week for 3 weeks for each participant. In these interventions, the researchers measured the ability to perform an activity on a four-point scale. During the fourth week, all children participated in a realistic flight rehearsal at San Diego International Airport. Parents were asked to rate their child's ability to travel by airplane before the first week and after the fourth week. All children improved their airport travel skills from pre- to post-intervention, according to the researchers' and parents' observations. All children were able to move independently at the airport, showing reduced stress in the process.

[96] examined VR use in a classroom of 31 children with ASD aged 6–16 years by examining the subjects' perceptions of their use through mixed methodological approaches. The results showed that costly and technologically advanced VRs were preferred, more specifically, the HTC Vive; also, users described them as enjoyable, physically and visually comfortable, easy to use, and exciting, wanting to use them again. They also highlighted the beneficial effects of VR, including relaxation/feeling calm, the ability to virtually explore a place before visiting it in the real world, and the development

of learning opportunities at school. Figure 5 summarizes all the findings of the technologies used.

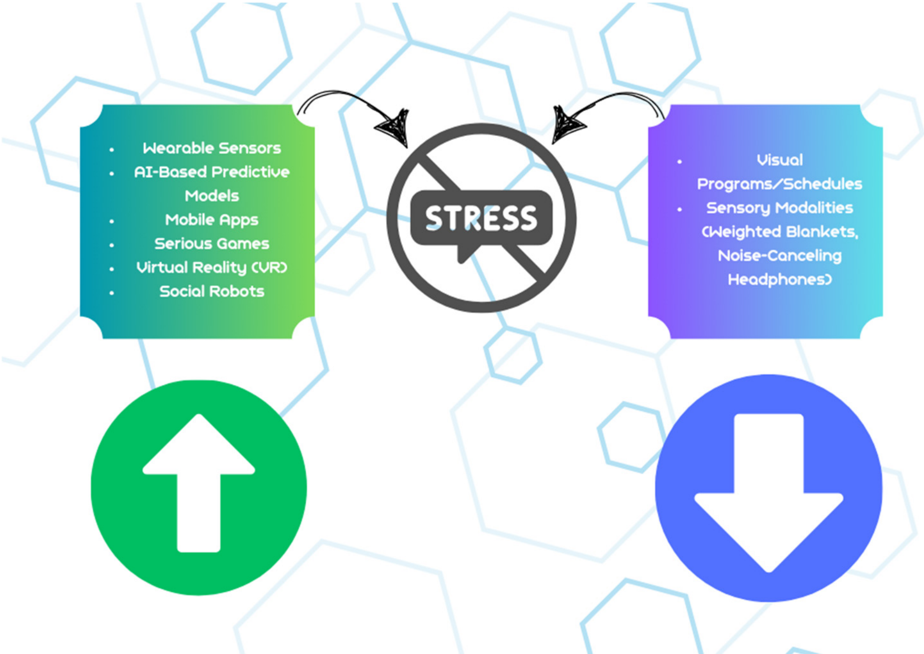

Figure 5. Low and high technologies combating stress.

4.4. Measurement Tools Used

Studies employed a wide range of measurement tools to evaluate stress and anxiety in children and adolescents with ASD. All these measurement tools can be categorized in six key areas, including physiological biomarkers, behavioral observations, psychological and self-reported measures, cognitive and emotional performance metrics, sensory processing assessments, as well as machine learning-based prediction metrics.

Physiological biomarkers were found to be used to evaluate autonomic stress responses. HR and HRV were tracked via wearable devices to determine stress-related changes in ANS. [80] and [66], in their studies used HR monitoring as a primary physiological measure, and [81] integrated HR tracking with interbeat interval analysis for stress prediction. EDA and skin conductance in several studies were utilized as key factors to measure sympathetic nervous system activation [75,79]). EDA was also useful in identifying elevated stress responses in real-time settings. Furthermore, cortisol and salivary biomarkers were employed in studies like [68] and [69] to identify endocrine stress responses pre- and post-intervention.

Regarding behavioral observations, they were utilized to capture an understanding of the engagement and social interaction of individuals related to stressors. More specifically [87] and [88] applied naturalistic observations to assess engagement in classroom and structure work systems' effectiveness. Others, like [92] and [81], performed more in-depth micro-behavioral analysis using video tracking and motion data in their studies. These approaches are used to analyze verbal social behaviors, attention shifts, and motor patterns in robot -assisted and interactive interventions.

Psychological and self-reported measures were utilized to capture subjective experiences of stress and anxiety. Studies like [74] and [79] gathered parent and caregiver reports using structured logs to track stress levels, mostly in natural settings. Similarly, [97] and [73] evaluated parental perceptions of intervention effectiveness in improving emotional regulation and adaptive behaviors. Self-reported anxiety measures, just like SCAS used in [83], gathered data on a child's perceived anxiety changes.

Related to cognitive and emotional performance, studies focusing on social and emotional learning interventions basically evaluated emotion recognition and social adaption via validated cognitive measures. More specifically, [67] utilized face, body, and voice emotion recognition tasks, while [72] examined measuring affective expressions and social reciprocity using PEP-3 assessments. Others, like [78] and [88], examined executive functions and cognitive load by integrating them into their interventions involving visual schedules and serious games. More specifically, they analyzed the reaction times in imitation tasks as well as cognitive load reduction in classroom settings.

According to sensory processing and adaptation measures, most of the researchers used sensory profiles and physiological responses to stimuli. Specifically, [97] used SPQ 2 to examine fidget toys' effectiveness in reducing anxiety, and [99] measured auditory sensitivity reduction through the GAS T-scores. [77] used EEG-based neural monitoring to evaluate adaptive auditory processing responses to stress that was related to adaptive behavior RAAT, and VABS-II was utilized by [71] and [73], accordingly, to evaluate functional skills and real-life behavioral improvements.

Finally, several studies employed AI and machine learning models to predict stress and challenging behaviors. [80], as well as [94], utilized classification models to detect physiological stress patterns, presenting high accuracy (AUC > 0.70). Also, [89] used an XGBoost model, achieving 99% accuracy in stress prediction. Aside from the strong demonstration of predictive power, further validation in real-life scenarios is required to confirm their long-term application (Figure 6).

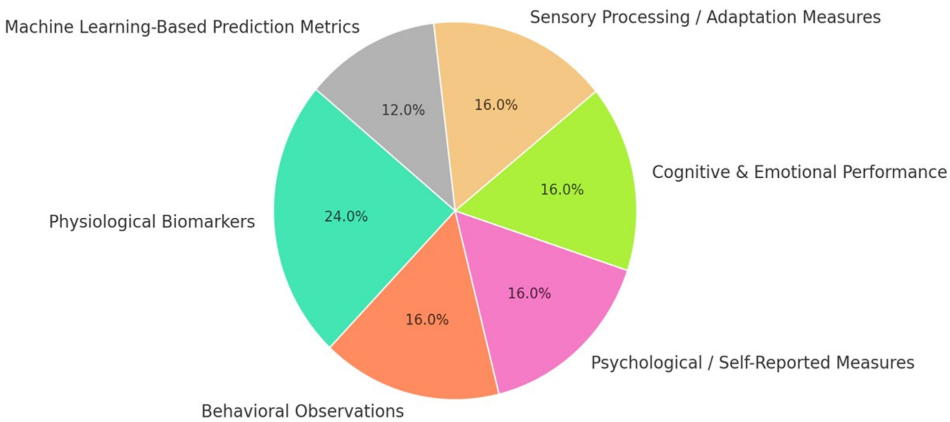

Figure 6. Stress-related measurement tools used across studies.

4.5. Effect Sizes Among Technologies

The present systematic review of n = 36 studies revealed important findings regarding the effectiveness of stress and anxiety reduction among children and adolescents with ASD. The results produced a broad spectrum of effect sizes, with some interventions demonstrating strong and significant improvements while others reported modes or inconsistent effects. There was also a significant number of studies that did not explicitly report the effect sizes, creating a critical gap in methodological standardization.

According to the studies analyzed, the most effective were those that provided wearable biofeedback and AI-driven stress detection technologies, demonstrating strong statistically significant effects [66,79,81]. VR interventions produced shared similar findings and presented strong effects, mostly in improving emotional regulation and stress resilience [71,79]. Moderate to large effect sizes were also found in social robotics interventions, supporting their potential for improving social engagement and emotional regulation [67,92]. On the contrary, low-tech assistive technology solutions demonstrated moderate effect sizes, as they were less consistent across different populations and settings in using interventions like weighted blankets [74,87], visual schedules [88], and VR-based distraction techniques [98]. Nonetheless, several studies did not provide explicit effect size calculations and were based on qualitative evaluations, descriptive statistics, as well significance testing without standardized measures of impact magnitude [69,70,84,85,91,93,94,97,99].

Another issue noticed in most of the studies was the limited diversity surrounding the pool of participants. Many studies demonstrated an overreliance on male participants, presenting an imbalance between male and female subjects. [77] used $n = 75$ boys and only $n = 8$ girls, showcasing unclear results if the effect of auditory interventions was similar across genders.

5. Discussion

The results of this study bring together and demonstrate the benefits and potential of emerging and assistive technologies to reduce neurophysiological stress and anxiety in children and adolescents with ASD and SMD by highlighting both the effectiveness and limitations of these technological interventions. The present research identifies several assistive and emerging technologies that have shown positive effects in reducing anxiety in children with ASD, also offering a unique insight by analysis of various efficacies across different types of technologies (low and high). To the best of our knowledge, this is the first study that collected data and analyzed the whole scope of technologies used (low and high), specifically for targeting stress and anxiety in children and adolescents with ASD, providing valuable pieces of information that can be utilized by researchers for future studies, as well as specialists and educators who work with children and adolescents with ASD and their caregivers. Table 2 summarizes all the data from the studies included.

Table 2. Summary of the included studies for analysis.

Name	Type of Study	Subjects (Age, Gender, Diagnosis)	Intervention	Type of Technology	Measure	Results	Limitations	Effect Sizes	Longitudinal Effects	Country
[99]	Preliminary Study	21 children with ASD, aged 4–16 years (16 boys, 5 girls)	Use of earmuffs and noise-canceling (NC) headphones	Earmuffs, NC headphones	Goal Attainment Scaling (GAS) T-scores	Earmuffs significantly improved Goal Attainment Scaling (GAS) T-scores compared to baseline. NC headphones showed improvement in some children but not significantly overall. Earmuffs were effective in reducing behavioral problems related to hyperreactivity to auditory stimuli. NC	Small sample size; refusal of some participants to wear earmuffs or noise-canceling headphones; limited behavioral data for noise-canceling headphones; lack of control over variables like age, sex, general intelligence, functional level, and frequency of intervention; no examination of adverse or long-term	Effect size was calculated with an alpha value of 0.05 and power of 80% for the Goal Attainment Scaling T-score; improvement was set to 1 for the sample size estimation.	No longitudinal effects were assessed; the study primarily focused on immediate behavioral changes using earmuffs and noise-canceling headphones.	Japan

						headphones were effective for some children but less consistent.	effects; and exclusion of other sound isolation devices like earplugs.			
[76]	Pilot Study	14 boys, 3–8 years old, autism spectrum disorder (ASD)	Tell-show-do method + Visual Schedule System (test group) vs. Tell-show-do method (control group)	Visual Schedule System using picture communication symbols	Number of dental steps attempted, completion time per step, behavioral distress levels, physiological arousal (EDA)	Test group completed 1.38 more steps, 35.52 s faster per step, and 18.7% lower distress than the control group.	Small sample size (14 boys). Lack of statistical power to detect significant differences; intervention limited to a single method (visual pedagogy); potential rater bias, as intervention was clearly noticeable; children were not informed about upcoming appointments, which might have influenced anxiety levels.	Patients in the visual pedagogy group completed 1.38 more steps on average, completed steps 35.52 s faster per step, and displayed 18.7% lower levels of behavioral distress. Cohen's d is not explicitly provided, but results indicate a notable clinical effect.	Limited by short study duration. No follow-up to assess long-term retention of improvements. Future research aims to explore more sensitive physiological stress indicators and broader participant demographics.	Canada
[88]	Multiple-Baseline, Single-Case Design	4 students, aged 8–11 years, diagnosed with ASD	Use of visual schedules and work systems to increase on-task behavior in mainstream classrooms	low	Observations within a natural classroom environment	Visual schedules and work systems increased on-task behavior in all four students. Mixed results for secondary variables, with some showing reduced off-task behavior and increased productivity. On-task behavior increased from a baseline mean of 20–61% to 53–86% during intervention. Off-task behaviors showed moderate improvement but were not statistically significant.	Small sample size (4 students); individual variability in teacher implementation of visual schedules and work systems; variability in baseline behaviors due to external classroom factors; limited generalizability due to specific participant demographics; fidelity of implementation was not consistent across all sessions; no follow-up sessions to confirm maintenance of behavior	Statistically significant improvements in on-task behaviors for three of the four students (Tau-U values ranging from 0.6458 to 1.25; $p < 0.05$); moderate improvements in productivity for two students (Tau-U = 0.7857, $p = 0.0184$ and Tau-U = 1.5, $p = 0.0015$).	A single maintenance probe was conducted for one student, showing decreased on-task behavior after intervention cessation. No broader longitudinal effects were assessed.	Australia

						Productivity increased significantly in some students.	improvements.			
[87]	Alternating Treatments Single Case Research Design	5-year-old male diagnosed with ASD	Weighted blanket and structured work boxes	low	Percentage of 10 s intervals of engagement	SWB resulted in consistently higher levels of engagement. Weighted blanket resulted in lower engagement, often similar to or less than baseline levels.	Single-subject design limits generalizability; short intervention duration (10 min sessions); possible novelty effect of weighted blanket intervention; lack of comparison to other evidence-based sensory interventions; limited reliability of teacher-reported engagement data; and no formal assessment of potential long-term benefits or harms of using weighted blankets.	No effect size was explicitly reported; visual analysis indicates structured work boxes (SWB) showed significant improvements in engagement, while the weighted blanket intervention demonstrated levels of engagement similar to or lower than the baseline.	No longitudinal effects were assessed; outcomes were limited to immediate responses during and after the short intervention period.	USA
[85]	Single-Subject Design	Two 4-year-old participants were diagnosed with autism	Weighted blanket intervention for 14 days	Weighted blankets	Objective sleep measures; caregiver surveys	Minimal changes in sleep patterns as a result of the weighted blanket intervention. Enhanced morning mood and significantly decreased time to fall asleep for participants. Findings suggest minimal changes in sleep patterns, enhanced morning mood, and decreased time to fall asleep. Not strong enough to recommend	Very small sample size (2 participants); convenience sampling from a medically underserved region; lack of blinding for caregivers; limited reliability of the Hello Sense Sleep app; potential for caregiver bias in self-reported measures; short intervention duration (14 days); and inability to generalize findings due to the single-	Effectiveness evaluated using Percentage of Non-Overlapping Data (PND). For participant 1 (John), PND for morning mood was 84% (effective); for participant 2 (Katie), PND for time to fall asleep and night wakings was 84% and 100%, respectively (effective).	No longitudinal effects were assessed; the study focused solely on immediate sleep behavior outcomes during the intervention period.	USA

						for clinical use.	subject design.			
[75]	Single-Subject Multi-Treatment Design	6 children, aged 8–16 years, diagnosed with ASD	Use of in-ear (IE) and over-ear (OE) noise-attenuating headphones	In-ear (IE) and over-ear (OE) noise-attenuating headphones, Empatica E4 wristbands	Skin conductance levels (SCL), nonspecific skin conductance responses (NS-SCRs)	Noise-attenuating headphones led to a significant decrease in skin conductance levels (SCL) and frequency of nonspecific skin conductance responses (NS-SCRs). SCL and NS-SCR frequency significantly decreased between baseline and the first intervention phase. The intervention provided protection against the negative effects of environmental noise.	Small sample size (6 children); high dropout rate (50%); individual variability in electrodermal activity (EDA) responses; no tracking of 'aware mode' use in in-ear headphones; inability to generalize findings due to single-subject design; and limited data on broader environmental variables like specific noise types or frequencies.	Effect size not directly calculated; intervention showed significant reductions in skin conductance level (SCL) and nonspecific skin conductance responses (NS-SCR) frequency in the intervention phases compared to baseline ($p < 0.05$).	No longitudinal effects were assessed; the study focused on short-term outcomes during and immediately after the intervention.	USA
[68]	Clinical and Laboratory Experimental Study	20 children, 6–10 years old, autism spectrum disorder (ASD)	Video Modeling Berkunjungke Dokter Gigi (VM-BDG) vs. Visual Pedagogy Module Berkunjungke Dokter Gigi (VPM-BDG)	Video Modeling (VM-BDG), Visual Pedagogy Module (VPM-BDG)	Delta salivary cortisol levels before and after intervention	Both VM-BDG and VPM-BDG effectively reduced stress levels; no significant difference between the interventions.	Small sample size (20 children); no control group without intervention; limited generalizability due to strict inclusion criteria; salivary cortisol measurement may be influenced by external factors; short duration between pre- and post-intervention saliva collection.	Delta salivary cortisol values showed a reduction in stress for both interventions; no statistically significant differences between VM-BDG and VPM-BDG. Both interventions were equally effective in reducing stress but lacked a control comparison for baseline reference.	Short study duration with no long-term follow-up. No assessment of sustained stress reduction over multiple visits. Future research should explore broader demographics and extended data collection periods.	Indonesia
[69]	Clinical Experimental Study	20 children, 6–10 years old, Autism Spectrum	Video Modeling vs. Visual	Video Modeling, Visual Pedagogical	Salivary Immunoglobulin A (sIgA) levels before	Both methods reduced stress levels as measured by	Small sample size (20 children); no significant	sIgA levels increased after video modeling	Short study duration with no long-term follow-up;	Indonesia

		Disorder (ASD)	Pedagogical Module	Module (PV-BDG)	and after intervention	sIgA; no significant difference between the groups.	difference in stress reduction between the two interventions; limited generalizability due to specific participant criteria; no control group without intervention; external factors influencing saliva IgA levels were not controlled.	but decreased with the PV-BDG module; no significant difference in ΔsIgA levels between the two groups; clinical effectiveness was observed but lacks strong statistical significance.	further research is needed to assess sustained stress reduction effects. Future studies should include broader demographics and additional physiological stress markers.	
[74]	Retrospective Follow-up Study	85 individuals: 48 children aged ≤17 (57%), 37 adults ≥18 years (44%), diagnosed with ADHD and/or ASD	Use of weighted blankets	Weighted blankets (chain-weighted and ball-weighted)	Self-reports via telephone interviews	Weighted blankets improved falling asleep, sleeping through the night, and relaxing during the day. They also improved morning and evening routines, including preparing/going to sleep and waking up. Also, 59% reported improved ability to fall asleep, 81% reported improved sleeping through the night, and 45.8% reported improved daily routines.	Small sample size (8 families); non-randomized design; data collection interruptions due to technological issues; limited diversity in family demographics; inability to capture nuanced stress triggers beyond predefined survey options; and no assessment of real-world generalizability of findings.	Medium to large effect sizes were observed for SCR features (Cohen's d ranging from 0.59 to 2.67) during stress episodes, indicating strong associations between physiological signals and self-reported stress.	No longitudinal effects were assessed; the study focused solely on immediate stress patterns during a short data collection period.	Sweden
[77]	Experimental Study	83 children (75 males; 8 females), 7–12 years old, autism spectrum disorder (ASD)	Development and validation of noise-canceling headphones with aural perception tuning	Hybrid Active Noise Cancelation (ANC) system with EEG-based sound perception tuning	Subjective aural perception ratings, EEG signals for neural responses	Headset effectively reduced auditory hyperreactivity; unpleasant frequencies (250 Hz, 8 kHz) were identified, and noise cancelation	Small sample size (83 ASD and 50 TD children); subjective aural perception ratings may introduce bias; external noise factors could impact	Significant reduction in unpleasant sound perception with ANC headset; frequencies of 250 Hz and 8 kHz were rated as most	No long-term follow-up on adaptation and behavioral impact; ANC effectiveness in daily settings remains uncertain. Future	China

						improved participants' aural comfort.	ANC effectiveness; study limited to specific frequencies (250 Hz–8 kHz); lack of long-term usability testing in real-world environments.	unpleasant; aural perception ratings significantly correlated with EEG neural responses; different ASD clusters exhibited unique auditory response profiles.	studies should assess sustained benefits and individual long-term auditory adaptation.	
[84]	Observational Study	9 patients with ASD (4 boys; 5 girls), aged 8–19 years	Interaction with PARO, a baby harp seal-type therapeutic robot	PARO, baby harp seal-type therapeutic robot	Observation of patient interactions with PARO	Effective for some patients in developing good communication and reducing impulsive behaviors or anxiety. Some patients did not like PARO due to its features, like big eyes or drive noise. Some patients treated PARO like a real animal, which helped in communication and reducing anxiety. Other patients disliked PARO for its features.	Small sample size (9 patients); lack of objective indices for measuring effectiveness; potential influence of other concurrent treatments; results may be due to temporary changes in emotional state rather than PARO itself; limited generalizability due to narrow demographic diversity.	Effect size not calculated; observational data indicated some positive changes but lacked quantitative analysis.	No longitudinal effects were assessed; the study focused on short-term behavioral and emotional changes observed during interaction with PARO.	Japan
[86]	Pilot Study with Mixed Methods (Quantitative-Qualitative)	9 children, aged 6–16 years, diagnosed with ASD	Interaction with semi-autonomous parrot-inspired robot KiliRo using the Adapted Model-Rival Method (AMRM) Semi-autonomous parrot-inspired robot	Semi-autonomous parrot-inspired robot (KiliRo)	Facial expressions (Oxford emotion API), informal and semi-formal interviews, closed-format questionnaire	Children appeared attracted and happy to interact with KiliRo. AMRM may help improve learning and social interaction abilities. Participants showed increased happiness and engagement over the study period. Positive feedback from	Small sample size (9 children); short duration of intervention (5 days); simulated autonomy of the robot limits ecological validity; potential bias in qualitative interviews due to group settings; limited diversity in participant	Effect size was not explicitly calculated; qualitative and descriptive analyses provided positive indications of emotional engagement and social interaction.	No longitudinal effects were assessed; the focus was on immediate responses and interaction patterns during the short intervention period.	India

						parents, pediatricians, and psychologists on robot's potential.	demographics; absence of control group for comparison.			
[67]	Cross-cultural Evaluation with Randomized Controlled Trial	89 children with high-functioning ASC, aged 6–9 years (Israel: 38, Sweden: 36, UK: 15)	Use of Emotiplay serious game for emotion recognition training	Internet-based serious game (Emotiplay)	Emotion recognition tasks (face, voice, body, integrative), SRS-2, VABS-II Socialization scale	Significant improvements in emotion recognition across face, voice, body, and integrative tasks. Parents reported reduced autism symptoms and improved socialization in Israel and Sweden. Children using Emotiplay showed significant improvements in emotion recognition and social skills compared to controls. Parents in Israel reported reduced autism symptoms.	Variation in intervention protocols across countries (UK, Israel, Sweden); inconsistent parental involvement; dropout rates due to lack of motivation and technical issues; potential cultural biases in emotion recognition tasks; short duration of intervention (8 weeks); reliance on parental reporting for generalization and socialization outcomes; and lack of active control groups in certain study sites.	Significant effect sizes were reported for emotion recognition improvements in the intervention group: η^2 = 0.20 for body tasks, 0.40 for integrative tasks, and 0.30 for country-level differences (MANOVA results).	No longitudinal effects were assessed; improvements were only measured immediately post-intervention with no follow-up period.	UK, Israel, Sweden
[78]	Matched Controlled Exploratory Study	24 children (14 experimental group, 10 control group), 5–8 years old, autism spectrum disorder (ASD), IQ ≥ 60	GOLIAH (Gaming Open Library for Intervention in Autism at Home) platform combined with Treatment As Usual(TAU) for 6 months	Automated serious gaming platform (GOLIAH) targeting joint attention and imitation tasks	Performance metrics in imitation and joint attention games; ADOS scores, Vineland socialization, Parenting Stress Index (PSI), Child Behavior Checklist (CBCL)	Improvement in imitation and joint attention performance within GOLIAH games; no significant differences in core ASD symptoms compared to the control group (TAU alone); no increase in parental stress.	Small sample size (14 experimental, 10 control); no randomization due to parental motivation selection; observance rate lower than expected; limited generalizability due to strict inclusion criteria; no web-based version of GOLIAH available at the time of the study.	Significant improvement in 4 out of 6 imitation games; 3 out of 4 joint attention games showed reduced reaction times; no significant group × time interaction for clinical measures; improvements in Vineland socialization, CBCL scores, and parental stress	No long-term follow-up conducted; study suggests potential for larger randomized controlled trials; future research to focus on younger children and web-based implementation of GOLIAH.	France, Italy

								observed in both groups.		
[91]	Pilot Study	10-year-old boy with mild autism, 6-year-old neurotypical boy	Use of wearable sensors and social robots for detecting and mitigating meltdowns	Wearable sensors (Empatica E4 wristband), social robots (PARO, toy train)	Physiological signals (HR, EDA, movement), video observations	Wearable sensors effectively detected physiological changes correlating with meltdowns. Sensors on the wrist and ankle showed similar responses. Social robots helped in calming the child. Effective detection of physiological changes during meltdowns. Social robots were effective in calming the child.	Small sample size; pilot study design limits generalizability; sensor placement (wrist vs. ankle) needs further investigation; no long-term data on effectiveness; limited diversity in participant demographics; challenges in controlling for external variables like environmental stimuli.	Effect size not directly calculated; study focused on the correlation of physiological signals (EDA, BVP, accelerometer) with challenging behaviors.	No longitudinal effects were assessed; the focus was on real-time detection of challenging behaviors and immediate intervention possibilities.	Qatar
[65]	Controlled Trial	94 children, 6–12 years old (86 males; 8 females), autism spectrum disorder (ASD) with IQ ≥ 60	28-session virtual reality-enabled program using an immersive half-CAVE system to train emotional regulation and social adaptation	Immersive virtual reality (CAVE environment with non-intrusive motion tracking)	Emotion regulation (PEP-3 Affective Expressions), social interaction (PEP-3 Social Reciprocity), emotion recognition (Faces and Eyes Tests), adaptive skills (ABAS-II)	Significant improvement in emotion expression ($p = 0.037$) and social reciprocity ($p = 0.007$); no significant changes in emotion recognition or adaptive skills.	Small sample size (94 children); lack of randomization due to parental selection; no follow-up assessments beyond training period; limited generalizability to diverse ASD populations; no comparison with other VR-based training programs.	Significant improvements in emotion expression and regulation ($p = 0.037$); social reciprocity scores increased significantly ($p = 0.007$); no significant changes in emotion recognition ($p = 0.666$); mixed findings on adaptive skills improvements.	No long-term follow-up was conducted; future studies recommended to assess sustained behavioral improvements; need for broader participant demographics and comparisons with alternative training methods.	China
[90]	Single-Subject Study	One 13-year-old male student diagnosed with autism	Smartglasses-based socio-emotional learning intervention using the Empowered Brain system	Smartglasses (Google Glass), Empowered Brain system	Educator logs, video interviews	Educators found the intervention practical and easy to implement. The student demonstrated improved verbal and nonverbal	Single-subject design; limited to one 13-year-old male participant with autism; absence of quantitative validated outcome	Effect size was not calculated; qualitative teacher-reported improvements in social interaction, eye contact, and	No longitudinal effects were assessed; the study focused on immediate teacher-reported outcomes during the	USA

						communication skills. No adverse effects on the classroom environment. Positive impact on student's social communication skills. Educators found the technology practical and usable without causing distractions in the classroom.	measures; short intervention period (2 weeks, 16 sessions); findings cannot be generalized due to the specificity of the sample; teacher-reported improvements lack independent verification.	classroom participation were observed.	two-week intervention.	
[72]	Waitlist Control Design	94 children, mean age 106.3 months (88.9% boys, 11.1% girls), all diagnosed with ASD	VR-based social skills training	Virtual Reality	PEP-3 Affective Expressions and Social Reciprocity	Children showed improved emotional expression, regulation, social interaction, and adaptation post-training, indicating VR training's effectiveness.	Large dropout rate (approximately 20%); limited diversity in demographics (primarily from Hong Kong); difficulty with logistics and scheduling due to reliance on a large, stationary CAVE VR system; some children refused initial participation due to discomfort with VR goggles; absence of long-term data to assess the sustainability of improvements.	Significant effect sizes for improvement in emotional expression and regulation (partial η^2 = 0.069, p = 0.025) and social reciprocity (partial η^2 = 0.100, p = 0.007).	No longitudinal effects were assessed; outcomes were measured immediately post-intervention with no follow-up.	China
[80]	Experimental Study	38 children (22 with ASD, 16 without ASD), ages not specified	Machine learning models (SVM, logistic regression) trained on wearables data to differentiate	Consumer-grade wearable device with machine learning algorithms	Heart rate (HR) and RR interval data; accuracy of machine learning models	SVM achieved 93% accuracy; logistic regression achieved 87% accuracy in differentiating stress vs. rest states; similar performance for both ASD	Balanced dataset (equal rest and stress samples) may not reflect real-world class imbalance; small sample size (38 participants);	The SVM model achieved 93% accuracy; the logistic regression model achieved 87% accuracy;	No long-term follow-up to assess real-world applicability. Further research is needed to test effectiveness in social settings.	USA

			stress and rest states			and non-ASD groups.	study conducted in a controlled setting, limiting generalizability; movement-induced physiological changes that are not fully accounted for.	high F1 scores (above 0.84) for stress detection in the ASD group; model performance was stable across ASD and non-ASD groups.	Future studies should address class imbalance in real-world stress exposure scenarios.	
[96]	Mixed-Methods Exploratory Study	31 autistic children, 6–16 years old, with autism spectrum disorder (ASD)	Exploration of preferences and usability of three VR head-mounted displays (HTC Vive, ClassVR, Google Cardboard) in school settings	Virtual reality head-mounted displays (HMDs): HTC Vive, ClassVR, Google Cardboard	Questionnaire responses on device preference, enjoyment, physical comfort, and potential uses of VR in classrooms	HTC Vive was most preferred due to the immersive experience, while ClassVR was least preferred; children reported high enjoyment, comfort, and interest in VR for calming, preparing for real-world events, and learning.	Small sample size; limited diversity in participants; narrow age range (6–16 years old); diverse devices with varying functionalities potentially skewed results; lack of longitudinal assessment; only partial utilization of device capabilities; limited software comparability across devices; and subjective preference data.	Effect size not explicitly calculated; results highlighted high preference rates for interactive VR devices (e.g., HTC Vive) over lower-tech options.	No longitudinal effects were assessed; the study focused on the immediate usability and preferences of VR devices.	United Kingdom
[98]	Experimental Study	40 children, 8–15 years old, with autism spectrum disorder (ASD)	Virtual reality distraction (VR) during routine non-invasive dental treatments compared to conventional behavior management	Virtual reality (VR) eyeglasses with visual and auditory stimuli	Venham's Picture Test (anxiety), Frankel's Behavior Rating Scale (behavior)	Significant reduction in anxiety (p = 0.037) and improvement in dental behavior (p = 0.0001) when VR distraction was used.	Small sample size (40 children completed both visits); high dropout rate (58.8%); no randomization due to practical constraints; anxiety and behavior scores may be influenced by prior exposure to dental teams; no physiological stress biomarkers were measured.	Statistically significant reduction in anxiety scores (p = 0.037); significant improvement in behavior rating (p = 0.0001); negative correlation between anxiety and behavior scores (p < 0.001), indicating VR distraction had a positive impact.	No long-term follow-up beyond the second dental visit; future studies should explore extended intervention effects; larger randomized trials are needed to validate VR distraction as a sustained behavior management tool.	India

[83]	Feasibility and Usability Study	3 families, children aged 6–10 years old, autism spectrum disorder (ASD)	New Horizon Serious Game designed for stress and anxiety reduction with relaxation mini-games; parent app SpaceControl for monitoring gaming behavior	Serious Game (mobile-based), relaxation techniques (guided imagery and focused breathing), supporting parent app	Children's mood (Likert scale), SCAS (Spence Children Anxiety Scale), SCAS-P (Parent version), gaming behavior logs	Positive feedback from parents and children. The game showed potential for reducing stress and anxiety, but the results were preliminary due to the small sample size.	Small sample size (3 families); imited generalizability due to pilot study nature; no objective stress biomarkers measured; game impact on actual stress reduction remains unclear; short testing period restricts behavioral adaptation assessment.	Preliminary positive trends were observed in SCAS and SCAS-P scores; no statistically significant effect sizes due to a small sample; parental feedback suggested potential improvements in relaxation effects; engagement levels varied among children.	No long-term follow-up was conducted; future studies aim to assess sustained use over extended periods; need for larger sample size to evaluate longitudinal effectiveness in stress management.	Belgium
[95]	Comparative Study	24 children (mean age = 42.62 months; 12 with ASD, 12 with LD)	Use of a wearable heart rate measurement device during interactive activities	Wearable heart rate measurement device (thoracic belt with ECG sensors)	Heart rate (HR) monitoring	HR was significantly higher in children with ASD compared to those with LD during interactive activities. Increased HR correlated with autism severity.	Small sample size (24 children) with a high dropout rate (55.6%); potential biases in interpretation due to unbalanced gender representation; short duration of interactive activities limiting comprehensive HR analysis; reliance on ADOS-2 for stress correlation may miss nuanced non-social stressors; and technical limitations of the wearable device leading to signal inconsistencies in certain activities.	Significant effect sizes were observed for HR differences during stress-inducing activities (ADOS-2 bubble play: Cohen's d = 0.93, *p* = 0.026; anticipation of routine: Cohen's d = 1.06, *p* = 0.012), indicating strong stress responses in children with ASD.	No longitudinal effects were assessed; the study focused solely on short-term physiological responses to structured activities.	Italy
[70]	Pilot Study	6 participants diagnosed with ASD,	Use of SoundFields, a virtual reality game with	Virtual reality game (SoundFields) with binaural-	Self-reported anxiety scores, tracked voluntary	Significant decrease in anxiety linked to target auditory	Small sample size (6 participants); lack of a control group	The effect size was not explicitly calculated; the Wilcoxon	No longitudinal effects were assessed; focus was	UK

		aged 16–19 years	binaural-based spatial audio	based spatial audio	interaction time	stimuli after four weeks of intervention. Participants actively engaged and enjoyed the VR environment. Decreased anxiety towards target stimuli, increased voluntary interactions with target auditory stimuli, and positive engagement with the VR environment.	to compare results; short intervention duration (4 weeks); potential biases in self-reported anxiety scores; no measures of generalization to real-world auditory hypersensitivity; and reliance on subjective outcome measures rather than physiological or objective behavioral data.	signed-rank test indicated a significant decrease in self-reported anxiety scores (p = 0.026).	limited to immediate post-intervention outcomes without follow-up evaluations.	
[100]	Preliminary Controlled Trial	5 children, 4–8 years old (4 males; 1 female), autism spectrum disorder (ASD)	Virtual reality-based air travel training (VR-ATT) with social stories and real-world air travel rehearsal	Google Cardboard VR with iPhone X and narrative-based functional communication activities	Parent-rated air travel ability questionnaire (Likert scale) and clinical activity rubric during intervention	4 out of 5 participants improved by at least 2 points in air travel ability; no significant statistical changes due to the small sample size.	Small sample size (5 children); no control group for comparison; short intervention period (3 weeks); individual differences in VR engagement levels; parent-reported improvements lack objective physiological validation.	Improvement in air travel skills reported by parents; activity completion rubric showed increases in task performance; no statistically significant differences in pre- and post-training scores (p = 0.0625).	No long-term follow-up conducted; future studies are recommended to evaluate real-world transferability; need for a larger sample size and an extended intervention period.	USA
[89]	Feasibility Study	One 10-year-old male child diagnosed with ASD	Use of wearable sensors and social robots to detect challenging behaviors	Wearable sensors (Empatica E4) and social robots (Nao, PARO)	Physiological signals (HR, EDA, IBI, TEMP, BVP), acceleration	Physiological signals combined with kinetic measures led to more accurate predictions of challenging behaviors. Best machine learning model achieved 97% accuracy. Heart rate and interbeat interval were significant predictors of challenging	Single-subject design (10-year-old male); limited generalizability to other populations; reliance on manually annotated challenging behaviors; absence of long-term or repeated sessions; wearable discomfort or potential harm to the child not	High accuracy reported for combined physiological and kinetic data (97%) using an MLP classifier; effect size not explicitly calculated, but performance metrics indicated strong model reliability.	No longitudinal effects were assessed; the study was limited to single-session outcomes in a controlled lab environment.	Qatar

						behaviors. Physiological features outperformed kinetic features in prediction accuracy.	thoroughly explored; and the model's dependency on lab settings for data collection.			
[92]	Mixed Methods (Quantitative-Qualitative) ABAB Design	9 children, aged 8–12 years, diagnosed with ASD	Interaction with robot KASPAR and usual care with teacher	Semi-autonomous humanoid robot (KASPAR)	Micro behaviors, attention metrics, video recall interviews	Children showed significantly more nonverbal imitation, touched the robot more often, maintained attention longer, and were less distracted during KASPAR sessions compared to teacher sessions. KASPAR was able to make contact with children, hold their attention longer, and engage them in more nonverbal interactions compared to teachers.	Small sample size (9 children); limited generalizability due to the controlled and artificial study setting; absence of long-term follow-up; potential novelty effect of KASPAR; variation in teacher engagement approaches; and limited individual customization of KASPAR for each child's specific needs.	Significant effect sizes were reported for specific micro-behaviors: non-verbal imitation (r = 0.589), touching KASPAR (r = 0.405), and maintaining attention (r = 0.545), demonstrating moderate to large effects.	No longitudinal effects were assessed; the study was limited to immediate outcomes over four weeks with no follow-up evaluations.	Netherlands
[66]	Pilot Randomized Controlled Trial	38 children with ASD, aged 8–18 years, IQ > 50	Use of Anxiety Meter (wearable, real-time anxiety detection technology) with diaphragmatic breathing training	Wearable sensors (Shimmer2) and a tablet display	Proportion of participants initiating deep breathing, heart rate, respiration rate and amplitude, self-reported anxiety	Participants using the Anxiety Meter were more likely to initiate deep breathing and reported feeling calmer. Feedback from the Anxiety Meter increased the likelihood of initiating deep breathing in response to anxiety.	Relatively small sample size (28 children); short intervention period (4 visits); imbalances in IQ and sex between treatment and control groups; controlled-laboratory setting limits real-world generalizability; potential confounding factors such as participant familiarity with stress-eliciting tasks;	Significant group differences in initiating relaxation techniques: Odds Ratio (OR) = 2.00 (95% CI = [0.340, 1.046], *p* = 0.001). The effect size for physiological signal improvements was not explicitly calculated.	No longitudinal effects were assessed; study outcomes were limited to immediate responses during and after the intervention sessions.	Canada

							and reliance on self-reported measures of anxiety reduction and relaxation initiation.			
[82]	Pilot Study	20 children with ASD, aged 7–13 years (14 boys; 6 girls)	Use of autism hug machine portable seat (AHMPS) with inflatable wrap and manual pull	Autism hug machine portable seat (AHMPS) with inflatable wrap and manual pull	Conners' Parent Rating Scale-48 (CPRS-48), Galvanic Skin Response (GSR)	Conduct problems significantly decreased in the inflatable group (p = 0.007) compared to the manual pull group. Significant reduction in sympathetic response (p = 0.01) only in the inflatable group. AHMPS with inflatable wrap effectively reduced emotional arousal and neurobiological stress in children with ASD. Conduct problems decreased more in the inflatable wrap group compared to the manual pull group.	Small sample size (20 children); short duration of intervention (3 weeks); limited demographic diversity (Javanese children only); results potentially influenced by parents' subjective ratings; no evaluation of long-term sustainability of behavioral changes; and absence of data on the broader applicability of the portable hug machine in different environments.	Medium effect size was observed for stress reduction in the inflatable wrap group (ηp^2 = 0.396), indicating moderate effectiveness; a small effect size for the manual pull group (ηp^2 = 0.09).	No longitudinal effects were assessed; the study focused on immediate outcomes within the 3-week intervention period.	Indonesia
[93]	Experimental Study	21 children, 2–12 years old, ASD	Robot-based intervention using the Kaspar robot combined with physiological monitoring (BVP signals) and facial emotion analysis	Empatica E4 wristband (physiological monitoring), OpenFace toolkit (facial emotion detection)	Blood volume pulse (BVP), HRV (LF and HF power), facial emotion annotations as stress verification	Overall, children were not stressed during Kaspar robot interactions; stress declined during sessions for some children, as verified by facial emotion analysis.	Small sample size (21 children); lack of real-time data processing; reliance on lab-based settings limits ecological validity; contradictory results between LF and HF stress metrics in certain sessions; no data on individual differences in stress	Effect size not explicitly calculated; descriptive and session-wise analyses showed reduced stress levels during robot-based interactions, as indicated by decreasing LF and increasing HF values in many cases.	No longitudinal effects were assessed; results were based on session-specific outcomes without follow-up evaluations or broader assessments.	Turkey, Macedonia, United Kingdom, Poland

							sensitivity; and limited diversity in demographics (participants mostly from specific regions).			
[73]	Pilot Study	10 children and teenagers, 8–16 years old, with autism spectrum disorder (ASD)	ShopAut 2.0, a 3D personalized serious game for training shopping activities with pre- and post-real-life supermarket assessments	3D Serious Game (ShopAut 2.0) with personalized training and individualized features for ASD severity levels	ICF-CY form scores (real-life shopping tasks), Vineland Adaptive Behavior Scale II (VABS-II)	Significant improvements in daily living skills, particularly in shopping procedures, attention, self-control, and problem-solving; VABS-II scores improved in communication, daily living skills, and socialization.	Small sample size (10 ASD participants); no control group for comparison; short intervention period (10 sessions); real-world shopping environment not tested beyond one location; no assessment of long-term retention of skills.	Significant improvements ($p < 0.05$) in shopping procedure, attention, and problem-solving skills; VABS-II scores showed enhanced daily living skills; statistically significant differences in pre- and post-training ICF-CY scores.	Short-term follow-up (6 months) showed sustained improvements; no data on long-term generalization beyond training period; future studies to explore extended intervention and broader sample sizes.	Italy
[94]	Mixed-Methods Design	Phase 1: 40 adults (20 with ASD, 20 without ASD); Phase 2: 10 adults with ASD presenting CB; Phase 3: 1 adult with ASD exhibiting CB	Development and validation of smart wearable shirt (SWS) for real-time prediction of challenging behaviors (CBs)	Smart wearable shirt (Hexoskin SWS)	Physiological parameters (HR, HRV, respiratory rate), behavioral diary	Higher stress levels anticipated in adults with ASD when exposed to stressors. The system was expected to predict CBs with high accuracy using physiological parameters. Higher stress levels were detected in adults with ASD compared to typically developed peers. The system was anticipated to predict CBs with an AUC value above 0.70.	Very small sample size for proof-of-concept phase (1 participant); limited generalizability due to lab-based controlled settings; lack of validated stimuli to elicit consistent stress responses; short duration of study phases (7 days for Phase 2 and proof-of-concept); and the technology's reliance on stable Bluetooth and internet connections may not suit all environments.	Effect size for prediction accuracy not explicitly calculated; expected AUC > 0.70 (fair sensitivity) for predicting challenging behaviors using machine learning models.	No longitudinal effects were assessed; the study focused on short-term proof-of-concept outcomes and immediate data-driven predictions of challenging behaviors.	Israel
[81]	Experimental Study	5 male children,	Use of wearable	Wearable sensors	Heart rate, HRV	The XGBoost algorithm	Very small sample size (5	High accuracy	No longitudinal	Qatar

		aged 7–10 years, diagnosed with ASD	sensors to monitor physiological and kinetic data during interactions	(Empatica E4), social robots (Nao, PARP)	(RMSSD), acceleration, electrodermal activity, temperature, blood volume pulse	achieved the best performance, with 99% accuracy in detecting challenging behaviors. Heart rate was the main contributing feature. RMSSD correlated with challenging behaviors. Heart rate (HR) was the most significant feature for detecting challenging behaviors. Physiological features outperformed kinetic features in prediction accuracy.	male children); limited generalizability due to controlled lab environment; manual annotation of challenging behaviors introduces potential human error; no consideration of gender differences; limited long-term data; and reliance on a single wearable sensor, which might miss multi-modal behavioral cues.	(99%) was achieved using the XGBoost algorithm for predicting challenging behaviors based on physiological data; effect size was not explicitly reported, but high-performance metrics indicate strong model reliability.	effects were assessed; the study focused on immediate data-driven predictions without long-term monitoring or evaluations.	
[71]	Combined 3 (intervention) × 3 (diagnosis) × 3 (time) research design with repeated measures	201 families (parents and children), children aged 6–12 years (neurotypical, ADHD, ASD)	Serious game (Kairos) and parental support	Serious game (Kairos) on electronic tablets	Routine Achievement Assessment Tool	For ADHD participants, a significant clinical effect was observed for parental support and a combination of Serious Game and parental support. For ASD children, an effect was observed for a combination of Serious Game and parental support. For neurotypical children, a significant effect was observed for Serious Game alone. Serious Game can improve children's routines. For ADHD and ASD children, adding	Significant COVID-19-related methodological adjustments (e.g., allowing parents to choose routines, inconsistent study conditions); lack of standardization in parental support implementation; sample attrition due to pandemic (10%); and variability in reported results due to differences in routines chosen by parents.	For autistic children, significant improvements in routine achievement when using combined intervention (Serious Game and parental support): huge clinical effect (Cohen's d = 2.81) over 8 weeks. For ADHD children, parental support alone yielded a large clinical effect (Cohen's d > 1.2) in the first 4 weeks.	Moderate persistence of effects in neurotypical children but decline observed in ADHD and ASD groups after initial improvement. No formal follow-up data to assess longer-term	Canada

						parental support produces greater clinical improvements.			
[79]	Feasibility Study	8 families, 8 autistic boys (mean age: 9.92 years), caregivers (mean age: 44.5 years)	Self-report stress logging and physiological signal measurement using a mobile app and wearable sensors	Mobile app (EasyConnect) and wearable physiological sensors (Empatica E4)	Self-reports, PPG, and EDA signals	Caregivers and children were able to use the mobile app and sensors effectively to report and measure stress in daily life. Stress indicators from EDA were aligned with self-reports.	Small sample size (8 families); Some families did not use the app despite training; wearable device discomfort, particularly for autistic children; limited options in the stress-reporting questionnaire; external validity concerns due to natural settings.	Medium and large effect sizes were observed in EDA SCR features; higher and wider SCR peaks were found in both autistic children and caregivers during stress-reporting periods; Cohen's d values for stress detection in caregivers were notably high (up to 2.67).	Limited due to the short study duration; no extended follow-up was conducted; future research aims to recruit more families and expand data collection for longitudinal analysis.	USA
[97]	Comparative Survey Study	129 children (53 autistic, 76 neurotypical) aged 3–16 years	Use of fidget toys and fidget spinners	Fidget toys and fidget spinners	Parental survey, Sensory Profile Questionnaire 2 (SPQ 2)	Parents of autistic children perceived fidget toys and spinners as more beneficial compared to NT parents. Higher sensory-seeking scores were associated with greater perceived benefits and reduced anxiety. Autistic children with higher sensory-seeking scores were seen to benefit more from fidget toys in terms of reduced anxiety and increased concentration. NT children	Limited generalizability due to parent-reported data; cultural biases in sensory perception and educational environments; inconsistent frequency and type of fidget toy use between autistic and NT children; small sample sizes for certain subgroup analyses; absence of longitudinal data on sustained outcomes; and potential biases influenced by school policies or media portrayals.	Significant group differences in perceived benefits of fidget toys for anxiety reduction and concentration improvement: χ^2 (4) = 17.478, p = 0.002 and χ^2 (4) = 16.148, p = 0.003, respectively.	No longitudinal effects were assessed; the study focused on cross-sectional parental perceptions without follow-up data.	UK

		with higher sensory-seeking scores also showed similar benefits.		

More specifically, low-tech interventions showed moderate effects in reducing anxiety-related behaviors by supporting individuals with sensory regulation and predictability [76,88]. Aside from the cost-effectiveness as well as availability and usability, their findings were related to several inconsistencies found in several studies [74,87]. On the contrary, high and emerging technology interventions showcased more potential and accuracy in the real-time detection of stress by identifying high-accuracy physiological markers, thus providing feedback for real-time interventions [66,80,94]. AI-based technologies [112], including machine learning models trained on physiological data, have proven to be highly effective in predicting stress-related behaviors in ASD individuals [81,89], showing their growing potential in preventing anxiety episodes and meltdowns. VR-based interventions showcased (in most of the studies) positive effects in improving social skills and emotional regulation [72] while decreasing anxiety levels [70]. Mobile apps were found helpful, providing users with accessible and friendly environments to reduce stress levels and help them to self-report and monitor their state by themselves or their caregivers [66,79]. Similar findings were also identified by the use of Serious Games, which reported a positive impact on emotional regulation and daily routines, especially when they were used in combination with parental support, showcasing a reduction in stress-related behaviors [71]. In addition, parents reported positive effects on autism symptoms in social reciprocity and adaptability while improving their emotion recognition and socializing skills [67]. Finally, social robots were found to be effective in improving social interaction by reducing stress levels in children with ASD [86,92].

Despite the positive effects presented in most of the studies about stress and anxiety reduction as well as detection, several limitations were identified. More specifically, these limitations are related to methodological, technological, participant-related, and longitudinal factors. One of the main limitations reported in a number of studies was the small sample sizes, having a negative impact on statistical power as well as the generalizability of the results. For instance, [87] had one participant, and [81] had only a sample of five children. Furthermore, in several studies [74,95], high dropout rates were identified, reaching 55,6%. In addition, other studies lacked randomized controlled designs, relying only on single-subject feasibility or pilot studies [66,79]. Last but not least, the short duration of many interventions made it difficult to evaluate their true effectiveness [85,86,98].

According to emerging technologies, many of the studies showcased promising results but also presented several limitations due to technical issues, user discomfort, device limitations, as well as data accuracy. More specifically, wearable sensors, VR interventions, and smart wearable shirts presented discomfort [66,79], difficulty with wearing the equipment [72], as well as technical inconsistencies like Bluetooth and internet connectivity, affecting real-time data collection. Furthermore, data accuracy and algorithm issues were other factors limiting the results, apart from succeeding in high-accuracy levels in stress prediction (up to 99%). Regarding [80] and [81], their studies were performed only in control lab settings. [93] also presented findings that made it unclear how biometric stress markers were presented in various sessions. Furthermore, another phenomenon observed in many studies was the overreliance on male subjects, showcasing results that cannot be interpreted without creating gender imbalance issues.

[77] included n = 75 boys and only n = 8 girls in their samples, making it unclear whether auditory interventions have the same effects across genders. Meanwhile, [66] presented similar findings between experimental groups regarding IQ and gender. No follow-up measurements were also another factor, thus limiting the sustainability of the intervention effects. Most of the studies only measured outcomes immediately post-intervention without measuring the long-term effects [66,71,72,88],.

6. Conclusions

Although the findings of this present study are quite encouraging for the application of these technologies in the daily lives of individuals, several limitations were identified that hinder the reliability, validity, and generalizability of the results. Moreover, high diversity was identified concerning the samples tested. ASD, as it is known, presents a wide range, and the samples tested showed high heterogeneity (ranging from low, average, and high functionality, as well as different sensory processing profiles of stimuli), making it difficult to generalize the results.

Regarding the use of these aids in settings such as schools and communities, issues concerning the acceptance and appropriate training of a teacher, therapist, as well as the community itself must be ensured. Cost is another factor that should be considered and is not mentioned in most of the included studies. Also, the majority of the technological tools used in these studies (especially those that are high-tech tools) are not accessible nor available to the general public, assuming that not every socio-economic group can afford to purchase them because they are not provided by the state. Furthermore, the majority of the reported technological devices require specialization and considerable time in training caregivers and users themselves to become familiar with their use. Regarding the methodological elements of the included studies, several limitations were identified regarding the small sample size, which may lead to a type two methodological error, where real effects are not detected, thus preventing the generalizability of the results to the wider population. In addition, most of the studies did not include a control sample and were short in duration (from a few weeks to months), hindering access to long-term changes and making the task of creating specific forms of intervention more difficult. Also, shortcomings were identified in terms of reviewing the data to be able to see if the benefits observed are long-lasting. Finally, an emerging field on gut–microbiome interactions was not identified in any type of study related to the use of any type of technology yet.

Based on the findings of this study, the following observations are noted for future research to improve the methodological factors and to create universal intervention plans in the physical environments of people with ASD experiencing stress.

Initially, the long-term impact of the changes observed from the use of these technologies should be studied. To this end, it is imperative to use experimental models that examine their use over time. In addition, emphasis should be placed on personalizing the needs of each individual. Personalization seems to have a positive effect on the results of the interventions. Also, research should delve into how to build these technologies so that they are more user-friendly. Finally, adequate training should be provided to the user and the person's carers to ensure maximum results.

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