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Review

High-Functioning Autism and Virtual Reality Applications: A Scoping Review

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Abstract: In recent years, the number of applications of virtual reality (VR) for the Autism spectrum disorder (ASD) population has increased and has become one of the most suitable tools to address the psychological needs of these individuals. The present scoping review aims to provide a literature mapping of experimental studies that have used immersive and semi-immersive VR for assessments or interventions specifically addressing high-functioning autism. A total of 23 papers were included and analyzed following PRISMA guidelines. The identified studies concerned social skills (11 papers), eye gaze and joint attention (3 papers), motor learning (3 papers), job training (2 papers), and other aims or rationales (4 papers). The evidence shows that, despite the intellectual potential of high-functioning ASD individuals, little research has been conducted to provide interventions that offer concrete training to improve their adaptive functioning. In addition, the percentage of individuals below 18 years of age is representative of half of the included studies, so aiming future studies at the early stages of development might be an asset in preparing the next generation of young adults to cope with age-related challenges, as early assessments and interventions are more likely to produce major long-term effects.

Keywords: high-functioning autism; virtual reality; autism spectrum disorder

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1. Introduction

Autism spectrum disorder (ASD) is an innate neurodevelopmental condition characterized by impairments in social communication and interaction, as well as the presence of repetitive and stereotyped behaviors and interests [1,2]. The spectrum connotation stands for a functional diagnosis entailing heterogeneous levels of general functioning and severity [3]. Consistent with this conceptualization of the diagnosis in clinical psychology and psychiatry, ASD is considered a continuum rather than settled into categories and thresholds [4]. A tentative way to depict differences between ASD individuals across the spectrum has been proposed by Jill Eyal through the Autism Matrix [5]. The classification is based on two axes depicting intellectual disability based on measurable Intelligence Quotient (IQ) and deficits in social-adaptive functioning.

Although the Autism Matrix is based on individual patient phenotypes, it is still not representative of ASD functioning: diagnostic tools based on the International Classification of Functioning, Disability, and Health (ICF) are more suitable methods for investigating all-around abilities. International consensus on diagnostic classification [1] recommends using a functional assessment approach for individuals with an intellectual disability (ID), whereas no explicit recommendation is made for those without an ID [6]. Although IQ might poorly represent the spectrum conceptualization, its measurement remains a valuable clinical indicator for adjusting the level of support based on cognitive impairment [6,7].

Starting from the aforementioned premises, nowadays, it is common in clinical practice to address ASD individuals based on their overall functioning. In particular, individuals with high-functioning autism (HFA) are characterized by a spectrum of abilities often associated with expectations of greater functional skills, higher IQ, milder autistic symptoms, and better quality of life, despite contradictory clinical evidence [6]. A partial overlap of definitions between HFA and Asperger syndrome (AS) still exists, and the terms are sometimes used interchangeably [6], despite both AS and HFA not being used in DSM-5 [8]. This term first appeared four decades ago, referring to individuals with IQs $\geq$ 70 [9,10]. HFA individuals might exhibit peak cognitive abilities [3]; hyperlexia [11]; enhanced perception; talent in music, mathematics, calculation, visual–spatial processing; and rote memory [3,12,13]. In the frame of this research, we will use HFA to refer to a group of individuals with linguistic and/or cognitive abilities that are above or near average for their age [14].

1.1. Immersive VR: Technology Overview and Potential

ASD is a lifelong condition [15]; although there is no particular accepted treatment for ASD, a growing consensus on behavioral and educational intervention programs is flourishing [16], and technology might offer useful solutions.

Virtual reality (VR) is one of the emerging and most promising technologies for interventions in healthcare [17] and for training, education, and support for ASD individuals, particularly in children [18]. VR can be defined as a three-dimensional (3D) computer-simulated environment [19], incorporating visual, auditory, and sometimes haptic feedback [20]. According to Mujber and colleagues, VR can be classified into three categories [21]: non-immersive, semi-immersive, and fully immersive systems. The level of immersion refers to the extent to which the displays are extensive and able to surround the user, stimulating the senses [22]. The more extensive the displays, the more the user's sensory systems are accommodated [22,23]. Higher levels of immersion might lead to an increased sense of presence [24], defined as the psychological consequence of immersion [23].

Non-immersive systems are desktop-based (e.g., PC or tablet) and use joypads or keyboards for interaction. Semi-immersive systems consist of large screens or surface projections with moderate levels of immersion and interaction. Lastly, immersive systems comprise Head-Mounted Displays (HMDs) and Cave Automatic Virtual Environment (CAVE) systems, both enabling high levels of interaction and immersion [21]. HMD devices include a head motion tracking system that generates two graphical displays, one for each eye, according to the user's point of view. HMDs are rapidly growing as a consumer product [25], as they are becoming more affordable and easier to use. Several products are available on the market, both for gaming and for educational and training purposes [25]. CAVE technology consists of a four-screen room (three walls and a floor) equipped with four stereoscopic projectors, a tracking system, and stereoscopic glasses provided with markers to change the point of view in VR accordingly [26,27].

In recent years, the number of applications of VR for the ASD population has escalated [16,28,29], and VR has become one of the most suitable tools for addressing the psychological needs of individuals with ASD [16]. This is because of the possibility of practicing in a safe and controlled environment endowed with higher degrees of realism, making VR interventions or assessments more enjoyable and clinical outcomes more reliable and transferrable in the real world [30].

The majority of the studies on ASD and VR focus on strategies to learn and practice social skills [28,31,32]. A recent scoping review [33] discusses the use of VR- and augmented reality (AR)-based social interventions for ASD individuals, outlining that there are still gaps to be addressed. Among these, limits include the paucity of studies with HMDs, the methodological lack of rigorous design, and the scarce number of participants enrolled in the experimental studies. Alongside social skills, life skills (e.g., shopping, driving, and street crossing) have also been found to be worthy of VR training applications [16,18] given the fact that these real-world scenarios might be challenging for ASD individuals.

To date, several reviews have been conducted to evaluate VR technology as a support for individuals with ASD. Due to the pervasive difficulties in the social domain, Parsons and

Mitchell reviewed the potential of VR in social skills training, outlining some perspectives on the most common interventions [34]. In 2013, Irish conducted a review of single-user virtual environments to teach social communication skills [35]. Lorenzo and colleagues provided a state-of-the-art review about immersive VR as a learning tool for ASD students [31], resulting in social or emotional skills as the most targeted ones. Mesa-Gresa and colleagues focused on VR for ASD children, reporting the effectiveness of the interventions included in their systematic review by mainly addressing social and emotional skills [17].

Some authors have reviewed the literature in terms of technologies aimed at supporting individuals with ASD. The systematic review by Aresti-Bartolome and Garcia-Zapirain identified how VR and AR mainly address the topics of "communication and interaction" and "social learning and imitation skills" to support individuals with ASD [29]. Boucenna and colleagues [36] provided an overview of the information communication technology used in children with ASD, distinguishing between interacting environments (implemented in computers or input devices), VR, avatars, serious games, and telerehabilitation. Shadab Khan and coauthors distinguished assessment and intervention tools for the ASD population, envisioning the following types: social robots, mobile learning, serious gaming, virtual reality, edutainment, virtual learning environment, and AR [37].

Other reviews on the pediatric ASD population have been published [18,38]; however, they lack a systematic approach. In 2021, Dechsling and colleagues reviewed the literature on high-immersive technological tools and ASD best practice interventions, particularly focusing on the Naturalistic Developmental Behavioral Intervention (NDBI) [33]. Although no studies have relied on VR to provide NDBI, the authors concluded that such tools are acceptable and promising for ASD.

Also, meta-analyses have been conducted on the effectiveness of technology-based interventions for the ASD population. Grynszpan and colleagues focused particularly on computer gaming software, interactive DVDs, and shared active surfaces [39]. With the growing number of VR applications, in 2021, Karami and colleagues published a meta-analysis solely on the effectiveness of VR for ASD rehabilitation and training purposes [16].

1.2. Aim of the Scoping Review

Compared with the aforementioned studies, the present scoping review aims to provide a literature mapping of experimental studies that have used immersive and semi-immersive VR for the assessment or interventions specifically addressing HFA without aiming the search strategy at a particular age group or topic. To the best of our knowledge, such a scoping review has not been conducted yet. This scoping review was conducted to answer the following research questions:

(a) For which purposes is VR adopted in HFA?
(b) Are the aims and tasks proposed to the participants age-dependent?
(c) Are there neglected or unexplored areas that are worth investigating?

2. Materials and Methods

To pursue the study aims, a scoping review was identified as the most suitable approach, as it allows us to depict a broader understanding of what is known about a research topic without excluding sources based on their quality [40].

To perform the current scoping review, we followed the six-stage methodology by Arksey and O'Malley [41]: (1) identifying the research question; (2) searching for relevant studies; (3) selecting studies; (4) charting the data; (5) collating, summarizing, and reporting the results; and (6) optional consultation with stakeholders to discuss and validate the findings [42]. Additionally, the PRISMA-ScR checklist was used to guide reporting [43]. No ethical approval was required for this study, as the results were extracted from published papers without primary data collection.

2.1. Identifying Relevant Studies

Considering the recent spread of VR and the novelty of the topic, this search was conducted on two multidisciplinary data libraries: PubMed and Scopus. The following search string was chosen: "Asperger syndrome" OR "Asperger's" OR "high-functioning autism" AND "Virtual reality". Research articles were included if they respected the following eligibility criteria:

- Focus on the use of VR and people with ASD;
- Pre-experimental, quasi-experimental, and true experimental designs;
- Journal or conference papers;
- Focus on immersive and semi-immersive VR;
- Focus on HFA individuals;
- Written in English language.

Articles were excluded according to the following exclusion criteria:

- Unavailability of abstract and/or full text;
- Reviews;
- Lack of pertinence to the topic of VR;
- Use of non-immersive VR systems;
- Only participants with IQ scores < 70 in the study sample;
- Theoretical or methodological work not including participants with ASD.

2.2. Study Selection

The study selection was organized in sequential steps. After removing all duplicates, three authors (M.C., C.D., and E.M.) independently screened the articles considering the eligibility criteria and the presence in the title or abstract of the following words:

- "Virtual reality", "3D environment", or "virtual environment" (without distinction between types of VR);
- "ASD"; "autism spectrum disorders" (without further specification of the clinical diagnosis or age range distinction).

The papers that did not meet the characteristics required were discarded, whereas disagreements were resolved by consensus or by discussion between all authors.

2.3. Charting the Data

The data extraction was performed by three authors (M.C., C.D., and E.M.) and was organized using a spreadsheet (Microsoft Excel version 2403, Microsoft Office Professional Plus 2016). The following information was extracted: author(s), year of publication, country, study quality, aims, study design, sample, technology equipment, VR scenario, outcome measure, information on VR session (frequency, duration when available), and task performed (see Supplementary Materials).

2.4. Collecting, Summarizing, and Reporting the Results

As already mentioned, ASD can be conceptualized as a spectrum of abilities; individuals may vary significantly in their functioning, and the scientific literature reflects this variability. To deal with this heterogeneity, the authors decided to divide the results into five areas of assessment or intervention, as follows:

- Social skills;
- Motor learning;
- Eye gaze and joint attention;
- Job training;
- Other.

3. Results

3.1. Features of the Included Studies

The number of records identified in the databases through the search string was 975. After preliminary screening based on the title and abstracts, 146 articles were considered suitable for the second step, which encompassed reading the full texts and distinguishing the works by the type of VR used. Of the 146 papers, 71 did not involve immersive or semi-immersive VR, and 17 were theoretical/methodological and thus discarded. Then, the 58 selected were screened to identify only those focusing on HFA. This resulted in 23 eligible papers included in this review, of which there were five conference proceedings and 18 full journal papers, as shown in Figure 1.

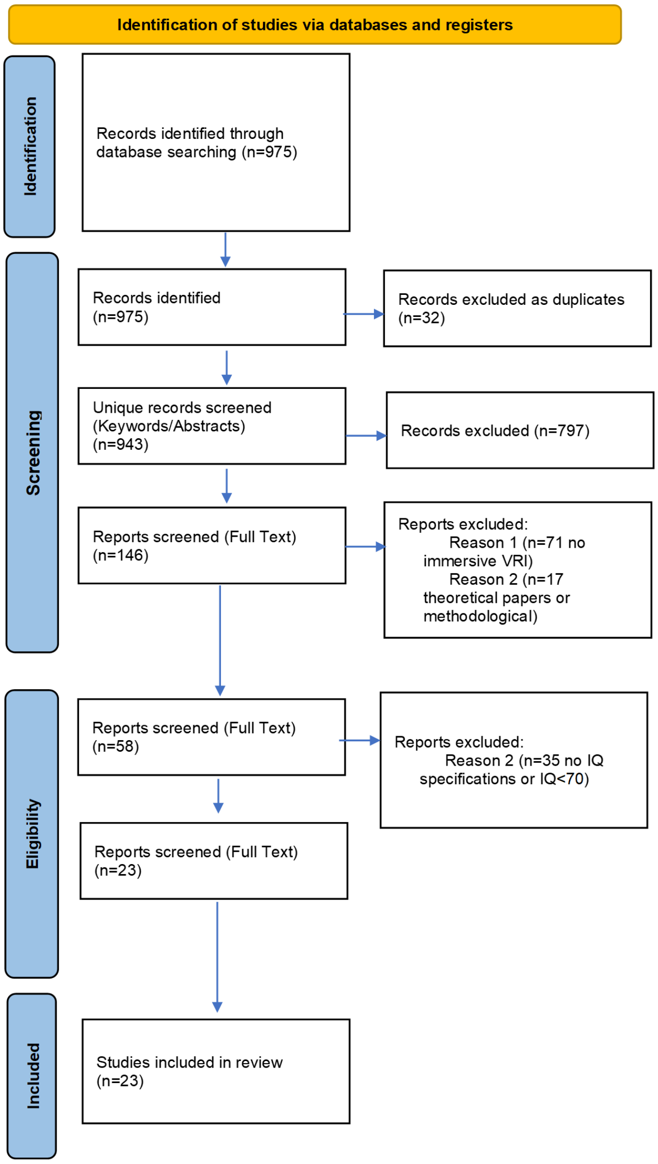

Figure 1. Flowchart of the paper selection process.

Table 1 provides an overview of the main characteristics of the included studies. Most of the studies were conducted in North America (nine papers) and Europe (eight papers), with fewer contributions from Asia (five papers) and Australia (one paper).

Table 1. Summary of the studies included in the scoping review. PE: pre-experiment; QE: quasi-experiment; TE: true experiment; WASI: Wechsler Abbreviated Scale Intelligence; WISC: Wechsler Intelligence Scale for Children; IQ: Intelligence Quotient; FSIQ: Full Scale IQ Test; TD: typically developing; CAST: Childhood Autism Spectrum Test; HMD: Head-Mounted Display; ASD: autism spectrum disorder.

First Author, Year, and Reference	Country	Study Type	Type of VR	Total Sample (N), Sex (m, f), and Age (Range)	IQ and Test (If Available)	Aims	Task
McCleery 2020 [44]	USA	QE	HMD	60 ASD, 12–38 y	75–132, WASI-II	To examine and assess safety, usability, and feasibility of immersive VR training for ASD individuals interacting with police officers.	Answering different questions asked by virtual law enforcement officers.
Fitzgerald 2018 [45]	Australia	TE	HMD	2 male ASD; 25 y and 31 y	1 IQ not specified; 1 IQ = 87; WISC-III	To compare the effectiveness of video modeling and virtual reality for teaching adults with ASD.	Paper-folding activities.
Ip 2018 [46]	China	TE	CAVE	94 ASD; m = 86, f = 8; 6–12 y	95 (Raven's test mean); 19.1 (CAST mean)	To enhance emotional and social adaptation skills of ASD children.	Interaction with and observation of a virtual environment and observation of how their peers interacted with the scenario.
Parish-Morris 2018 [47]	USA	QE	HMD	28 ASD; 12–37 y	76–120, WASI-II	To describe safety and feasibility of an immersive virtual reality application designed to teach essential skills to ASD adolescents and adults.	Answering different questions asked by virtual law enforcement officers.
Amaral 2017 [48]	Portugal	QE	HMD	13 TD; m = 7, f = 6; 21–26 y 4 male ASD; 15–22 y	IQ > 70, FSIQ	To ascertain the usability and feasibility of a novel system with a paradigm that uses social joint attention cues.	Joint attention cueing.
Greffou 2012 [49]	Canada	TE	CAVE	16 ASD and 34 TD; 12–33 y	IQ mean range, 98.75–101.13	To assess postural behavior in ASD in response to immersive visual environments.	Fixating a red dot located at the horizon and maintaining balance.
Herrero 2020 [50]	Spain	QE	HMD	7 ASD; m = 6, f = 1; 8–15 y and 7 TD	NA	To design and validate a learning intervention to improve social and emotional competencies of HFA students using VR.	Social interaction with several avatars.
Yeh 2020 [51]	Taiwan	PE	HMD	10 ASD; students from grades 1 to 8	IQ from 70 to 105	To develop and test the efficacy of VR scenarios for social skill learning in ASD students.	Social interaction with avatars representing classmates.
Tarantino 2019 [52]	Italy	QE	HMD	6 ASD; m = 6, f = 0; 21–23 y	IQ from 73 to 98	To evaluate two state-of-the-art HMDs in terms of acceptability, usability, and engagement capability.	Interactive photorealistic and non-photorealistic scenarios; exploration of historic sites and items.
Mul 2019 [53]	United Kingdom	QE	HMD	22 ASD; m = 14, m = 8; 29 TD; m = 16, f = 13; overall age range 18–53	IQ mean = 110.1, WASI II	To test VR as a tool to assess whether bodily self-consciousness in ASD is altered as a result of multisensory processing differences.	Audiotactile integration task for peripersonal space.
Biffi 2018 [54]	Italy	QE	SI-VR	15 ASD; m = 14, f = 1; mean age 9.8 y 16 TD; m = 15, f = 1; mean age 10.0 y	IQ >80, WISC-IV	To describe gait pattern and motor performance during discrete perturbation of children with ASD compared with TD peers.	Walking task with perturbations.

Table 1. *Cont.*

First Author, Year, and Reference	Country	Study Type	Type of VR	Total Sample (N), Sex (m, f), and Age (Range)	IQ and Test (If Available)	Aims	Task
Bozgeyikli 2017 [55]	USA	QE	HMD	9 ASD; mean age 25.4 y 9 TD; mean age 29.0 y	IQ >70	To explore the effectiveness of a virtual reality system in training individuals with ASD on six vocational transferrable job skills.	Vocational training on transferrable job skills.
Ip 2016 [56]	Japan	PE	SI-VR	Pilot study: 20 ASD; 6–9 y Experimental study: 33 ASD; 6–11 y	IQ > 70	VR-enabled system to facilitate social adaptation training for school-aged children with clinical or suspected diagnosis of ASD.	Six VR training scenarios.
Cheng 2014 [57]	Taiwan	PE	HMD	3 ASD; m = 3, f = 0; 9–11 y	IQ >70, WASI	To investigate the performance of data gloves and stereoscopic projection in mitigating the impairment of social etiquettes in children with ASD.	Interaction with virtual objects and characteristics immersed in a virtual environment.
Cheng 2015 [58]	Taiwan	PE	HMD	3 ASD; m = 3, f = 0; 12–13 y	IQ = 84, 82, 80 (FISQ)	To determine the effectiveness of a 3D system in promoting the comprehension of social protocols in individuals with ASD.	Twenty-four problem-based social questions developed for use with a VR system.
Jarrold 2013 [59]	USA	QE	HMD	37 ASD; 8–16 y 54 TD; 8–16 y	IQ >71 (WASI)	To simulate public speaking tasks in VR to study social attention and its association with classroom learning in students with HFA.	VR public speaking paradigm with cued and non-cued conditions.
Trepagnier 2002 [60]	USA	QE	HMD	5 ASD; m = 4, f = 1; mean age 18.4 y 6 TD; m = 4, f = 2; mean age 19.5 y	NA	To clarify the character of face gaze in ASD.	Series of images of faces and objects presented stereoscopically in VR.
Cook 2014 [61]	United Kingdom	QE	CAVE	10 ASD; m = 8, f = 2; mean age 14.74 12 TD; m = 10, f = 2; mean age 15.79	Mean IQ = 116.6 (WASI)	To investigate the biological specificity of interference effects for action observation in ASD using VR.	Interaction with a virtual reality agent in either human or robot form.
Amaral 2018 [62]	Canada	QE	HMD	15 ASD; m = 15, f = 0; 16–38 y	Mean IQ = 102.53 (FSIQ)	To test usability and feasibility of 3 EEG setups combined with a VR headset as part of a novel system.	Joint attention assessment task with avatars gazing or pointing cues.
Newbutt 2016 [63]	USA	QE	HMD	Phase 1: 40 ASD; m = 32, f = 8; 17–53 y	Mean IQ range = 83.58–86.63 (WASI)	To investigate willingness to use and acceptability of VR-HMDs among people with ASD.	Series of 3D immersive experiences in VR.
Bozgeyikli 2018 [64]	USA	QE	SI-VR	15 ASD; m = 11, f = 4; mean age = 22.73 y 15 TD; m = 10, f = 5; mean age = 25.80 y	NA	To examine the effects of various attributes of user interfaces designed for VR.	Tasks involving sorting, fetching, and aligning boxes on two workstations, moving boxes on two conveyor belts, and a vocational task of finding boxes.
Lorenzo 2013 [65]	Spain	QE	SI-VR	20 ASD; m = 16, f = 4; 8–15 y	NA	To determine the possible inclusion of immersive virtual reality as a support tool and learning strategy in ASD.	Executive functions in school learning and social competence.
Lorenzo 2016 [66]	Spain	TE	SI-VR	20 ASD; m = 14, f = 6; 7–12 y 20 TD; m = 15, f = 5; 7–12 y	NA	To evaluate immersive VR to improve and train the emotional skills of students with ASD.	Immersive environments allowing students to train and develop social skills in a structured, visual, and continuous manner.

Figure 2 shows the temporal distribution of publications from 2002 to April 2021.

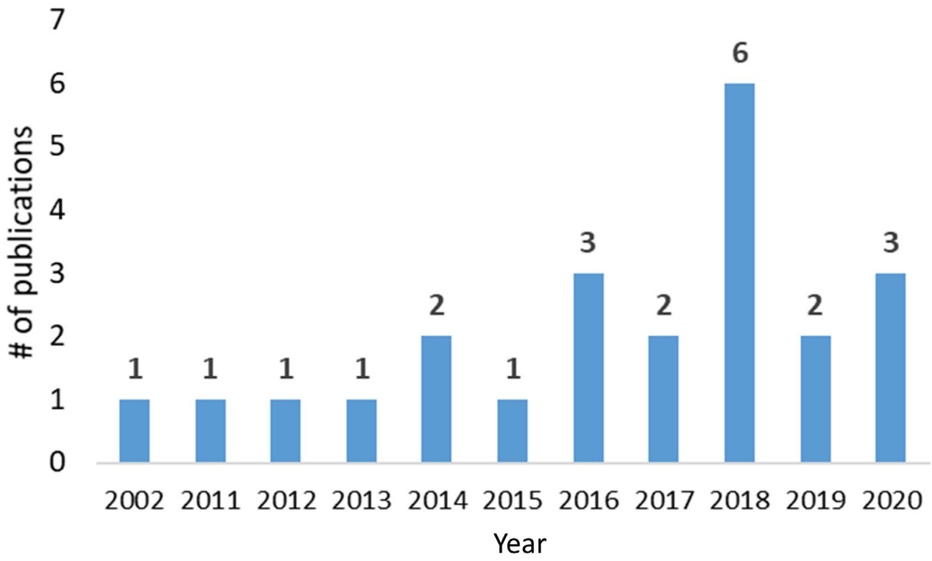

Figure 2. Number of publications by year.

The majority of the studies were classified as quasi-experimental (65.2%), whereas a minority were true experimental (17.4%) or pre-experimental (17.4%) studies. Both quasi-experimental and true experimental types aim to manipulate the independent variables to register expected outcomes on the dependent ones. The main difference is that researchers, in quasi-experiments, do not perform a randomized assignment of the participants to the conditions. On the other hand, in pre-experimental studies, participants are usually observed before and after a treatment (one group pre-test/post-test) to see if it generates potential changes [67]. Table 2 reports the classification of the included papers accordingly.

Table 2. Classification of the included papers according to the definition of Campbell and Stanley [67]. N: number of papers.

Type of Research	N	%
Quasi-experimental	15	65.2
True experimental	4	17.4
Pre-experimental	4	17.4

Regarding the study design, the majority of the studies were "single group" (N = 12), followed by "two-group" (N = 9) and "single-subject" designs (N = 2).

The population of the experimental studies included in the current review involved both healthy subjects and participants with ASD: 9 publications (39.1%) involved more than 30 participants, whereas 14 included fewer than 30 participants (60.9%). Finally, the number of ASD participants involved in the 23 studies was higher than that of the healthy controls (494 and 215, respectively).

The number of participants, grouped as ASD and healthy subjects, for each of the 23 publications is presented in Figure 3. Overall, the sample size ranged from 2 to 94 participants.

The majority of the studies focused on participants below 18 years of age (N = 13, 56.5%), whereas a smaller number of papers included participants above 18 years (N = 9, 39.1%). Only one paper (4.4%) included participants both above and below 18 years.

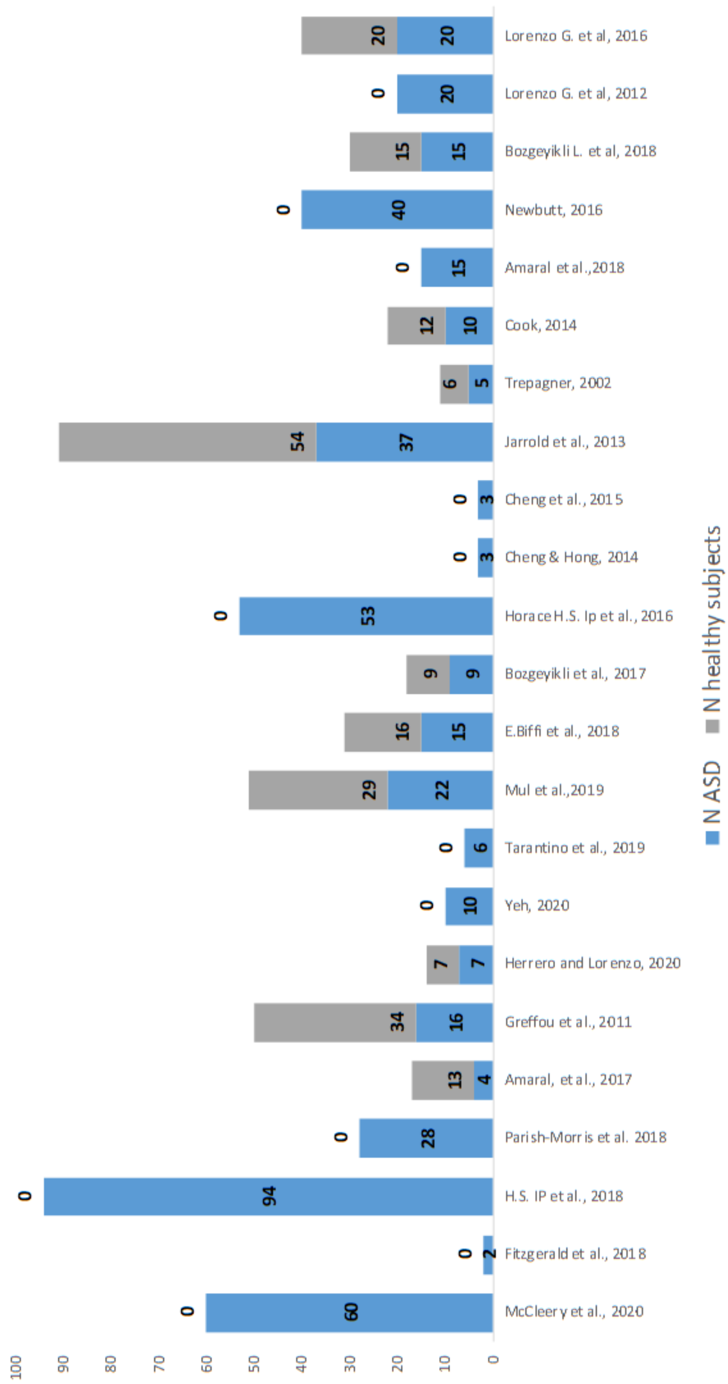

Figure 3. Number of participants for each included paper [42–44,46–51,54–62,65–68] considering ASD subjects (in blue) and healthy subjects (in gray). N: number of papers.

Considering the technology (Table 3), HMDs were used in most of the studies (15 papers, 65.2%). Only five studies (21.7%) focused on semi-immersive VR, followed by immersive CAVE (three papers, 13.1%).

Table 3. Distribution of the papers based on the type of immersive technology. N: number of papers.

Type of Immersive Technology	N	%
HMD	15	65.2
Cave	3	13.1
Semi-immersive VR	5	21.7

3.2. Investigated Dimensions

VR can create worlds in which it is possible to interact with controlled factors. It has been proven that this technology can be used as a support tool in different areas such as social interaction and task learning [29].

In the present work, the VR scenarios developed for high-functioning ASD are divided into the following categories: social interaction, eye gaze and joint attention, motor learning, job training, and others. Table 4 provides an overview of the number of papers related to each category, considering VR technology classified by the level of immersion.

Table 4. Distribution of papers considering the defined 5 categories (i.e., social interaction, eye gaze and joint attention, motor learning, job training, and others), divided according to the type of technology. SI-VR: semi-immersive VR.

Category	HMD	Cave	SI VR
Social skills	7	1	3
Eye gaze and Joint attention	3	/	/
Motor learning	/	2	1
Job training	1	/	1
Other	4	/	/

3.2.1. Social Skills

This section summarizes the studies using VR environments with a specific focus on social skills, which was the most represented category in the reviewed papers. Five papers investigated social skills simulating interactions with police officers [44,47] or peers [50,57,59]. Social adaptation was targeted by three papers [46,56,58]. Three papers focused both on social interaction and social adaptation [51,65,66].

Parish-Morris and colleagues employed mobile immersive VR commercial software (Police Safety Module, Floreo), delivered through a smartphone, a tablet, and a headset, aimed at fostering social skills in HF ASD while interacting with police officers [47]. The system's usability, as well as feasibility and safety, were evaluated. Results on 28 participants showed good feasibility and no adverse effects associated with this VR experience. Also, McCleery and colleagues examined the feasibility of immersive VR training for HF ASD individuals interacting with police officers [44]. They used the same commercial software used by Parish-Morris and implemented a 6-week treatment, asking HFA participants to interact with law enforcement officers. The results showed that participants reported high levels of enjoyment and usability, thus encouraging them to participate in further VR sessions.

Aside from the specific situation of interacting with a police officer, researchers have focused on socialization with peers and how to support it [50,57,59]. Jarrold and colleagues simulated a VR public speaking task to assess social attention in the HF ASD population. The results showed atypical attention, as measured by gaze orienting or number of looks, fixation length, and the average duration of fixations that the participants oriented toward avatars seated around a table in a 3D classroom. Another example of socialization with peers included in this review concerns the social etiquette of HF ASD children in a 3D simulation of a real scenario: an amusement park system [57]. The participants were asked to explore and familiarize themselves with the virtual environment and to choose appropriate answers according to social etiquette, experiencing consequent feedback with an animation. The results showed that the participants benefited from the 3-month VR intervention, with improved outcomes in social etiquette skills. The most recent contribution regarding socialization with peers was published by Herrero and Lorenzo in 2020. Their research focused on the exercise of social and emotional competencies in two VR environments, a school classroom and a backyard garden, each involving two teachers and six children. Characters (or avatars) represented different personalities and ethnicities, and HF ASD individuals could choose from a predefined set of options that would influence the consequent avatar's behavior. The results are promising for educational purposes regarding HF ASD individuals, who might benefit from this intervention and experience better adaptation in social contexts [50].

Aside from social interaction, VR is used to deliver interventions regarding ASD individuals' adaptability to specific life scenarios. Cheng and colleagues aimed to determine the effectiveness of two VR scenarios, a classroom and a bus stop, to improve social skills and understanding: For the bus scenario, some of the target behaviors were to stay in line, choose a seat on the bus, or give up a seat. For the classroom scenario, some of the targeted behaviors were to say "hello" or to raise a hand before questions. Preliminary evidence on three HF ASD individuals showed promising results, suggesting that VR may be an effective learning environment for ASD individuals [58].

Ip and colleagues presented VR as a tool for emotional and social adaptation skills in a sample of HF ASD children, 20 in a preliminary test and 33 in a subsequent experimental study. They proposed six learning scenarios that can be summarized as follows: preparation for going to school in the early morning; social occasions that could happen on the way to school and in the classroom; attending the library or the tuck shop; lessons about the playground; and four different seasons with peaceful background sounds [56]. Comparing pre- and post-assessments, significant improvements occurred in the primary outcomes (emotion expression and regulation; social interaction), whereas no statistically significant differences were found in the secondary outcomes (emotion recognition and adaptive skills).

In 2018, Ip and colleagues tested a four-sided CAVE virtual environment to enhance the emotional and social adaptation skills of HF ASD children [46]. In total, 94 children underwent a 14-week intervention, with significant improvements in emotional expression and regulation and social interaction.

Further studies have investigated both social interaction and adaptation. Lorenzo and colleagues proposed a new immersive IVR system to improve the learning and social skills of HF ASD students [65]. Two VR environments, a school playground and a bedroom, and 32 supportive tasks to address executive functions in school learning (e.g., planning and decision-making) and social skills were proposed, with documented improvements.

A few years later, the same authors compared their IVR training program with a desktop computer version [66]. The significant presence of more appropriate emotional behaviors occurred in the IVR environment conditions, making the IVR a useful tool for the acquisition and development of emotional competencies in HF ASD students.

Finally, another attempt was made by Yeh and Meng [51]. Four scenarios (a classroom, an exhibition, restaurants, and a park) were developed and tested on 10 HF ASD students, with improvements in inappropriate behaviors and environmental adaptability.

3.2.2. Eye Gaze and Joint Attention

Eye gaze and joint attention might be impaired in ASD individuals, with resulting difficulties in social attention and interaction. Trepagnier and colleagues compared eye gaze in HF ASD and a control group [60]: participants were asked to look at a series of images (faces and objects) presented stereoscopically in VR and then to indicate which image they had already seen by saying "yes" or "no". The results showed that ASD participants displayed less fixation on the central area of the face with respect to control subjects, thus lending evidence to the hypothesis that individuals on the autism spectrum might suffer from impairments in face processing.

Amaral and colleagues combined EEG measures in three different experimental setups with a VR headset to perform a novel social attention paradigm combined with a P-300 Brain–Computer Interface (BCI): the immersive virtual environment comprised two parts, each consisting of 10 blocks of events. The overall aims of the studies were to ascertain the usability of the EEG setups and to test their feasibility in the ASD population. The participants were asked to look at the stimuli, and particularly for the second part, they were instructed to look at an avatar's face and notice to which of the objects it turned its head. The results showed that realistic social cues and immersive BCI could be used to investigate joint attention in the HF ASD population, thus opening new perspectives for rehabilitation or assessment purposes [48].

Finally, in 2018, Amaral and colleagues performed a feasibility clinical trial to improve social attention in the HF ASD population: by utilizing, for 4 months, the BCI paradigm described above, 15 HF ASD participants improved their neuropsychological outcome measures, providing some promising evidence for future interventions [62].

3.2.3. Motor Learning

Motor difficulties are often associated with ASD. To measure the atypical postural reactivity of ASD individuals, Greffou and colleagues simulated different types of oscillations in a 3D environment [49]. Using fully immersive VR technology, a virtual tunnel was designed to sway at different frequencies using the "virtual tunnel paradigm" [68]. Posture adaptation was studied by altering visual stimuli: a tunnel with an inner checked pattern was presented in a static or dynamic setting; the latter also provided motion oscillation at three frequencies (0.125, 0.25, or 0.5 Hz). To assess body adaptation, the head's movements were tracked. Sixteen HF ASD individuals, divided into two groups according to age group (12–15 or 16–33), and thirty-four typically developing (TD) subjects were included in the study in order to assess whether postural reactivity can be considered a function of development. From the results, it emerges that ASD users are able to transfer sensory information to a motor pattern unless fast visual stimuli integration is required.

Biffi and colleagues evaluated gait patterns and motor performance in children with HF ASD compared with TD peers [54]. The gaits participants were assessed in semi-immersive VR with a treadmill. Then, subjects underwent a perturbation phase consisting of 20 trials with one single-belt acceleration. Finally, a post-perturbation gait analysis was performed. The results showed an altered gait pattern in children with ASD but a moderate adaptation to perturbation in both groups.

In another study by Cook and colleagues [61], matched HF ASD and TD participants were asked to perform sinusoidal arm movements while observing a virtual reality agent in two forms (human and cobot). The agent performed a gesture at a biological motion or at a constant velocity, and participants were asked to follow the actor's movement in a congruent or incongruent way. The experiment took place in an immersive CAVE and involved 22 participants, including 10 HF ASD individuals. Results for the interference effect, caused by observing an incongruent action made by another agent, showed that individuals with ASD, in contrast to what was observed in the TD group, did not exhibit any interference effect.

3.2.4. Job Training

Finding job opportunities and maintaining an occupation in the long term is a challenge for ASD individuals, whatever their functioning level. In the present study, only two papers met the inclusion criteria and discussed the use of immersive VR as a tool for supporting employment for people with HF ASD.

Bozgeyikli and colleagues developed an immersive VR system to train vocational skills in a group of HF ASD individuals: cleaning, loading the back of a truck, money management, shelving, environmental awareness, and social skills. The results were promising both for the improvements in the targeted skills and for the possibility of transferring what the ASD individuals learned [55].

The same group in 2018 explored the user experience of 15 HF ASD individuals undergoing immersive VR tasks; scenarios simulating three warehouse tasks were evaluated based on five design attributes: instruction methods, visual fidelity, view zoom, clutter, and motion [64]. The results indicated that avoiding verbal instructions is preferable, as well as low visual fidelity, normal view zoom, no clutter, and no motion.

3.2.5. Other

Four papers did not meet the common aims or rationale to constitute separate categories, and all included participants above the legal age in the data collection.

Fitzgerald and colleagues compared the effectiveness of VR and video modeling as valid interventions in supporting ASD learning using a paper-folding task [45]. This task offered meaningful opportunities to develop problem-solving skills and creativity and to integrate visual and motor coordination. The intervention was conducted on two HF ASD participants, resulting in better outcomes related to video modeling strategies.

Another work evaluated the engagement of immersive VR experienced through two different headsets: Oculus Rift and HoloLens [52]. The results showed that the interpretation of the engagement aspects was different for the ASD and TD participants: some VR features, e.g., a diminished sense of presence and photorealism, might hinder the experience of TD individuals while promoting that of the HF ASD group. Also, VR was found to be more appropriate for learning applications, while mixed reality was more useful for coping with anxiety, fear, and phobias in social situations.

Investigating the acceptance and quality of immersive VR through HMDs for the ASD population could be interesting for promoting their subsequent uses. Newbutt and colleagues tested the Oculus Rift headset on 29 (Phase 1) and 11 (Phase 2) participants to evaluate the willingness, acceptance, sense of presence, and immersion of HF ASD individuals [63]. The results showed preliminary evidence suggesting that negative effects while wearing an HMD are limited; on the contrary, ASD participants generally accepted the VR headset and were willing to complete the VR tasks. Spatial presence, engagement, and ecological validity were also documented. Finally, the authors argued that realism might facilitate the generalization of the VR content, suggesting the need for further research.

Finally, Mul and colleagues [53] investigated bodily self-consciousness in ASD and TD participants using immersive VR as a tool to set up a full-body illusion. The authors demonstrated a smaller peripersonal space in ASD participants, suggesting altered bodily self-consciousness.

4. Discussion

The present study aimed to provide literature mapping of experimental studies that involve immersive VR for HF ASD assessment and intervention.

Virtual reality applications are emerging in clinical settings that can be paired with existing intervention treatments and actual assessment practices, offering therapists wider control and customization of content and patients a safer and more private context in which to be exposed [69]. Also, VR offers the possibility of generating realistic environments where users can experience a sense of immersion and its psychological consequences on perception, that is, the sense of presence [20].

Technology-based interventions are emerging, and several systematic reviews have been published to evaluate their effects on specific skills, but only the contribution of [17] focused on the effectiveness of VR-based interventions in ASD. This contribution, however, included only children and adolescents and did not specify the technological device, the degree of immersion, or the specifications of the overall clinical functioning in the spectrum.

The papers included in the present scoping review were mainly based on HMD technology. This might be due to the fact that this technology offers different commercial solutions, some of them easily affordable for professionals or target users. Aside from economic aspects, VR headsets are portable and flexible solutions that do not need complex setups, allowing for at-home use. Also, HMD solutions offer a wide range of immersion in the virtual environment (360 degrees) and interactions endowing the user with motion-tracking systems.

The majority of these studies were explorative, and only four studies were classified as true experiments. This trend was confirmed by a recent scoping review [33] discussing the need to implement randomized-controlled trials (RCTs) to better evaluate the effectiveness of VR interventions, as well as their reproducibility. Further studies with larger samples and a solid research design are needed to bring more evidence and reduce research biases. Because VR technology-based interventions are an innovative approach to intervention, usability, safety, feasibility, and pilot studies in the form of quasi-experimental design are represented in the included studies [44,47,48,52,62–64], thus indicating that explorative research in this field is ongoing and still required before any clinical use. The novelty of this approach is also explained by the low number of participants in most of the studies and by the scarce presence of control groups [33]. Further investigations should consider the need for more consistent studies, alongside the significant need to encourage the free and informed participation of people with autism in the research process [70]: individuals on the spectrum might be vulnerable, especially those characterized by profound language and/or cognitive impairments. According to the model of person-oriented research ethics, it is possible to envision practical strategies to address ASD needs, especially when participants under legal age are involved in data collection, by providing information to create a predictable environment using different and alternative communication methods (e.g., visual support) and setting up the physical environment to address sensory sensitivities, as well as the social context, to increase predictability and control (e.g., punctuality; the familiarity of the researcher or the room setting). Also, it should be taken into account that ASD individuals might be key informants and, consequently, contribute actively to designing the research process by bringing their perspectives.

Regarding the first and second research questions, to date, VR applications with high-functioning ASD individuals are promising, and it is relevant to understand the purposes they have been used for, individually and considering age groups. Confirming the evidence from recent literature reviews, social skills are the most targeted in ASD interventions. The papers included in this review targeted both social interaction and/or adaptation. This demonstrates that addressing social functioning as a core fragility to be supported in a person's lifespan remains the most discussed topic.

Recent evidence confirms the link between eye gaze cueing and joint attention [71], which refers to the use of the perceived gaze direction to automatically shift visual attention and orient it to the same object/individual that other people are looking at. Among the available technologies, HMDs have the potential to study eye gaze behavior in VR environments. Three studies included in this review assessed the eye gaze behavior and joint attention of HF ASD adults by using HMDs to gain a better understanding of these attention mechanisms. All the included studies were aimed at adolescents and adults and did not propose a specific intervention. Further research is needed since joint attention deficits are an early-developing social communication skill [72], and early intervention through VR could be beneficial. These results taken together might be supportive evidence of the early difficulties of ASD individuals and their subsequent need for support, including the ones characterized by the high-functioning phenotype. Even at an early age, autistic children manifest a tendency to favor non-social stimuli [33]; when encountering society, ASD individuals might suffer from isolation and low-quality peer interactions, with escalating negative effects also registered in the linguistic domain [73].

Alongside socio-communicative manifestations, motor difficulties have been reported even in early descriptions of the ASD disorder [74]. Atypical movements and deficits in locomotor abilities are common across the spectrum, with consequences such as limited exploration of surrounding spaces, limited interaction with the environment, and an overall impact on quality of life [75]. The papers included in this review assessed postural balance [49], gait pattern [54], and upper limb movements [61] using motion-tracking systems to assess motor performance quantitatively. These papers only reported the use of CAVE and semi-immersive systems, while HMDs were not used. This could be due to the fact that wearing a headset might lead to a higher risk of falls, hindering the vestibular and visual system [76] and causing cybersickness due to visual-vestibular conflicts [77]. Two papers on motor skills included in the current review refer to a group of participants below 18 years of age, potentially due to the fact that early assessments and interventions are recommended. Only the contribution of Greffou and colleagues [49] included both children and adults in order to investigate if postural behavior might differ as a function of development: the results confirmed the contingency of age and motor behavior. Chronological age has been described as a possible determinant of postural hypo-reactivity, but more investigation is needed to combine immersive VR applications and different age groups across different motor domains.

Another domain that emerged from the papers included in this scoping review is represented by job training. The need for VR to promote independence and autonomy is well documented, thus enabling the exercise of adaptive and functional behaviors in a controlled and safe environment [78] and enabling effective skill interventions that might be implemented by occupational therapists in their practices [79].

Two papers included in this review were dedicated to job training for HF ASD participants older than 18 years, with a specific focus on immersive VR for vocational skills. The exclusive use of HMDs in these papers might be supported by the fact that interventions on job skills might benefit from the portability of VR applications in future applications (e.g., in corporate contexts). Regarding age range, ASD is indeed classified as a neurodevelopmental disorder, with consequences that endure through adulthood. Despite good education and motivation, HF ASD individuals do not reach employment rates above 50%, which is alarming [80]. This is especially true considering that the abilities of HF ASD people might be potentially fruitful for many working environments. Vocational skills have the potential to be transferred to various occupations. The papers included in this review did not focus on specific jobs but rather on training the most common soft skills that might be important for better employability outcomes. However, training for specific jobs might be beneficial for adults with ASD: a recent review [81] reveals that, after a preliminary task analysis, different domain applications might benefit from a VR training experience, including those intended for the workforce (e.g., training for maintenance to prevent injuries or fatalities, wind turbine assembly, or other specific factory line operations).

Considering the vital role of maintaining successful employment in promoting mental well-being, it should be noted that ASD individuals face significant challenges in the attainment of long-lasting jobs. Strategies for successful employment include assistive technology [82], non-immersive VR [83–85], and video modeling [86]. However, (immersive) VR for job training might result in better learning outcomes compared with the traditional video modeling strategy [45]. VR represents, indeed, an opportunity for ASD individuals to learn in a stress-free environment through practical experience [58]. Furthermore, considering the need for ASD people to be supported in the transition to employment, intervening in the early stages of development might be useful in training vocational skills.

Further perspectives on HF ASD and VR have been investigated in the reviewed papers: Mul and colleagues studied self-consciousness [53], while the remaining papers discussed the impact of VR on user experiences. In particular, VR experiences using different commercial headsets were compared [52], and aspects that promote engagement were evaluated. The quality of immersive experiences and the consequent acceptance and willingness to use HMD solutions have been documented by Newbutt and colleagues: limited negative effects and good engagement were reported [63]. By fostering the robustness of studies dealing with user engagement and experience (comparing diverse VR technologies and their levels of immersion), future studies might implement standardized metrics in data collection regardless of the specific purpose of the research. This might be useful for collecting evidence about the actual implementation of VR applications in people with ASD, encompassing investigations on developmental age and innovative age-appropriate methods.

Regarding the third aim of this review, one of the key areas of intervention was the development of interventions that offer concrete training to improve the adaptive functioning of people with HF ASD. The paucity of publications in this sense might be related to the fact that this scoping review was aimed only at a specific part of the spectrum, which is a novel asset of the present work and those related to the broader research area of autism.

Early assessments and interventions are more likely to produce major long-term effects [87]; the percentage of individuals below 18 years of age is representative of half of the included studies, so aiming future studies at early stages of development might be an asset in preparing the next generation of young adults to cope with age-related challenges. Another topic of research is the design and testing of VR applications to teach HF ASD adolescents and young adults the procedures and activities of specific jobs.

This work has some limitations. Our scoping review carried out a literature search on PubMed and Scopus, focusing on clinical and biomedical literature and covering a wide number of journals and contents. Further investigation should also include the Web of Science (WoS) or other interdisciplinary databases that include contributions from different areas. Also, the search strategy could be improved: the search string was generic and did not specify the type of VR (i.e., semi-immersive or immersive). Nevertheless, the subsequent screening of papers followed a strict methodology. Also, it should be kept in mind that this scoping review focused only on high-functioning ASD individuals; hence, individuals below ID thresholds who might experience the most difficulties in the usage of VR applications are not represented.

5. Conclusions

Despite the spread of immersive VR, little research has been conducted on HF ASD individuals: the absence of intellectual disability does not exclude the presence of age-related challenges that need to be supported. ASD is a neurodevelopmental disorder, but adulthood implies the ability to adapt to different scenarios that might specifically benefit from VR exposure and training.

Overall, the present review offers an overview of the uses of immersive and semi-immersive VR in HF ASD individuals. This approach provides a broad understanding of VR in HF ASD individuals, thus answering the first research question. We were able, indeed, to identify five purposes for which VR can be adopted for HF ASD.

Concerning the second research question, the papers aimed at children focused only on social skills and motor learning topics. On the other hand, HF ASD adults were included in studies related to eye gaze, joint attention, and job training.

Commercial immersive virtual reality applications are spreading; HMD solutions are gradually becoming more accessible and accurate in generating computer-simulated 3D environments, with expected outcomes in immersion and a sense of presence that will foster learning and engagement. Notably, very few data have been reported on these topics, so future investigation is needed. In this sense, the present scoping review offers an advantage for future researchers seeking to combine the VR level of immersion with its psychological consequences on presence.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/app14073132/s1, Table S1: Extended summary of the studies.

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References

1. American Psychiatric Association. *Diagnostic and Statistical Manual of Mental Disorders: DSM-5TM*, 5th ed.; American Psychiatric Publishing, Inc.: Arlington, VA, USA, 2013; ISBN 978-0-89042-554-1, 978-0-89042-555-8.
2. Zeidan, J.; Fombonne, E.; Scorah, J.; Ibrahim, A.; Durkin, M.S.; Saxena, S.; Yusuf, A.; Shih, A.; Elsabbagh, M. Global prevalence of autism: A systematic review update. *Autism Res.* **2022**, *15*, 778–790. [CrossRef] [PubMed]
3. Ousley, O.; Cermak, T. Autism Spectrum Disorder: Defining Dimensions and Subgroups. *Curr. Dev. Disord. Rep.* **2014**, *1*, 20–28. [CrossRef]
4. Tuena, C.; Chiappini, M.; Repetto, C.; Riva, G. *Artificial Intelligence in Clinical Psychology*, 2nd ed.; Elsevier: Amsterdam, The Netherlands, 2022; ISBN 9780128186978.
5. Eyal, G.; Oncular, E.; Oren, N.; Rossi, N. *The Autism Matrix*; Wiley: Hoboken, NJ, USA, 2011.
6. Alvares, G.A.; Bebbington, K.; Cleary, D.; Evans, K.; Glasson, E.J.; Maybery, M.T.; Pillar, S.; Uljarević, M.; Varcin, K.; Wray, J.; et al. The misnomer of 'high functioning autism': Intelligence is an imprecise predictor of functional abilities at diagnosis. *Autism* **2020**, *24*, 221–232. [CrossRef] [PubMed]
7. Bishop, S.L.; Farmer, C.; Thurm, A. Measurement of Nonverbal IQ in Autism Spectrum Disorder: Scores in Young Adulthood Compared to Early Childhood. *J. Autism Dev. Disord.* **2015**, *45*, 966–974. [CrossRef] [PubMed]
8. de Giambattista, C.; Ventura, P.; Trerotoli, P.; Margari, M.; Palumbi, R.; Margari, L. Subtyping the Autism Spectrum Disorder: Comparison of Children with High Functioning Autism and Asperger Syndrome. *J. Autism Dev. Disord.* **2019**, *49*, 138–150. [CrossRef] [PubMed]
9. Ameli, R.; Courchesne, E.; Lincoln, A.; Kaufman, A.S.; Grillon, C. Visual memory processes in high-functioning individuals with autism. *J. Autism Dev. Disord.* **1988**, *18*, 601–615. [CrossRef] [PubMed]
10. Szatmari, P.; Bartolucci, G.; Bremner, R.; Bond, S.; Rich, S. A follow-up study of high-functioning autistic children. *J. Autism Dev. Disord.* **1989**, *19*, 213–225. [CrossRef] [PubMed]
11. Goldberg, T.E. On hermetic reading abilities. *J. Autism Dev. Disord.* **1987**, *17*, 29–44. [CrossRef] [PubMed]
12. Happe, F. Autism: Cognitive deficit or cognitive style? *Trends Cogn. Sci.* **1999**, *3*, 216–222. [CrossRef]
13. Meilleur, A.A.S.; Jelenic, P.; Mottron, L. Prevalence of Clinically and Empirically Defined Talents and Strengths in Autism. *J. Autism Dev. Disord.* **2015**, *45*, 1354–1367. [CrossRef]
14. Diehl, J.; Tang, K.; Thomas, B. High-Functioning Autism (HFA) BT. In *Encyclopedia of Autism Spectrum Disorders*; Volkmar, F.R., Ed.; Springer: New York, NY, USA, 2013; pp. 1504–1507. ISBN 978-1-4419-1698-3.
15. Whiteley, P.; Carr, K.; Shattock, P. Is Autism inborn and lifelong for everyone? *Neuropsychiatr. Dis. Treat.* **2019**, *15*, 2885–2891. [CrossRef]
16. Karami, B.; Koushki, R.; Arabgol, F.; Rahmani, M.; Vahabie, A.H. Effectiveness of Virtual/Augmented Reality–Based Therapeutic Interventions on Individuals with Autism Spectrum Disorder: A Comprehensive Meta-Analysis. *Front. Psychiatry* **2021**, *12*, 665326. [CrossRef]
17. Mesa-Gresa, P.; Gil-Gómez, H.; Lozano-Quilis, J.A.; Gil-Gómez, J.A. Effectiveness of virtual reality for children and adolescents with autism spectrum disorder: An evidence-based systematic review. *Sensors* **2018**, *18*, 2486. [CrossRef] [PubMed]
18. Parsons, S.; Cobb, S. State-of-the-art of virtual reality technologies for children on the autism spectrum. *Eur. J. Spec. Needs Educ.* **2011**, *26*, 355–366. [CrossRef]
19. Gorini, A.; Riva, G. Virtual reality in anxiety disorders: The past and the future. *Expert Rev. Neurother.* **2008**, *8*, 215–233. [CrossRef]
20. Tuena, C.; Pedroli, E.; Trimarchi, P.D.; Gallucci, A.; Chiappini, M.; Goulene, K.; Gaggioli, A.; Riva, G.; Lattanzio, F.; Giunco, F.; et al. Usability issues of clinical and research applications of virtual reality in older people: A systematic review. *Front. Hum. Neurosci.* **2020**, *14*, 93. [CrossRef] [PubMed]
21. Mujber, T.S.; Szecsi, T.; Hashmi, M.S.J. Virtual reality applications in manufacturing process simulation. *J. Mater. Process. Technol.* **2004**, *155–156*, 1834–1838. [CrossRef]
22. Slater, M.; Linakis, V.; Usoh, M.; Kooper, R. Immersion, presence and performance in virtual environments. In Proceedings of the ACM Symposium on Virtual Reality Software and Technology, Hong Kong, China, 1–4 July 1996; pp. 163–172.
23. Riva, G. From virtual to real body: Virtual reality as embodied technology. *J. Cyber Ther. Rehabil.* **2008**, *1*, 7–22.
24. Diemer, J.; Alpers, G.W.; Peperkorn, H.M.; Shiban, Y.; Mühlberger, A. The impact of perception and presence on emotional reactions: A review of research in virtual reality. *Front. Psychol.* **2015**, *6*, 111605. [CrossRef]
25. Renganayagalu, S.K.; Mallam, S.C.; Nazir, S. *Effectiveness of VR Head Mounted Displays in Professional Training: A Systematic Review*; Springer: Dordrecht, The Netherlands, 2021; Volume 26, ISBN 0123456789.
26. Pedroli, E.; Greci, L.; Colombo, D.; Serino, S.; Cipresso, P.; Arlati, S.; Mondellini, M.; Boilini, L.; Giussani, V.; Goulene, K.; et al. Characteristics, usability, and users experience of a system combining cognitive and physical therapy in a virtual environment: Positive bike. *Sensors* **2018**, *18*, 2343. [CrossRef]
27. Pedroli, E.; Cipresso, P.; Greci, L.; Arlati, S.; Boilini, L.; Stefanelli, L.; Rossi, M.; Goulene, K.; Sacco, M.; Stramba-Badiale, M.; et al. An immersive motor protocol for frailty rehabilitation. *Front. Neurol.* **2019**, *10*, 462970. [CrossRef]
28. Dechsling, A.; Sütterlin, S.; Nordahl-Hansen, A. Acceptability and Normative Considerations in Research on Autism Spectrum Disorders and Virtual Reality. In *Proceedings of the Augmented Cognition, Human Cognition and Behavior*; Schmorrow, D.D., Fidopiastis, C.M., Eds.; Springer International Publishing: Cham, Switzerland, 2020; pp. 161–170.

29. Aresti-Bartolome, N.; Garcia-Zapirain, B. Technologies as support tools for persons with autistic spectrum disorder: A systematic review. *Int. J. Environ. Res. Public Health* **2014**, *11*, 7767–7802. [CrossRef] [PubMed]
30. Parsons, S. Authenticity in Virtual Reality for assessment and intervention in autism: A conceptual review. *Educ. Res. Rev.* **2016**, *19*, 138–157. [CrossRef]
31. Lorenzo, G.; Lledó, A.; Arráez-Vera, G.; Lorenzo-Lledó, A. The application of immersive virtual reality for students with ASD: A review between 1990–2017. *Educ. Inf. Technol.* **2019**, *24*, 127–151. [CrossRef]
32. Howard, M.C.; Gutworth, M.B. A meta-analysis of virtual reality training programs for social skill development. *Comput. Educ.* **2020**, *144*, 103707. [CrossRef]
33. Dechsling, A.; Orm, S.; Kalandadze, T.; Sütterlin, S.; Øien, R.A.; Shic, F.; Nordahl-Hansen, A. Virtual and Augmented Reality in Social Skills Interventions for Individuals with Autism Spectrum Disorder: A Scoping Review. *J. Autism Dev. Disord.* **2021**, *52*, 4692–4707. [CrossRef]
34. Parsons, S.; Mitchell, P. The potential of virtual reality in social skills training for people with Autistic Spectrum Disorders. *J. Intellect. Disabil. Res.* **2002**, *46*, 430–443. [CrossRef]
35. Irish, J.E.N. Can I sit here? A review of the literature supporting the use of single-user virtual environments to help adolescents with autism learn appropriate social communication skills. *Comput. Hum. Behav.* **2013**, *29*, A17–A24. [CrossRef]
36. Boucenna, S.; Narzisi, A.; Tilmont, E.; Muratori, F.; Pioggia, G.; Cohen, D.; Chetouani, M. Interactive Technologies for Autistic Children: A Review. *Cognit. Comput.* **2014**, *6*, 722–740. [CrossRef]
37. Khan, M.S.; Mohamadali, N.A.K.; Maher, Z.A.; Nisa, S.Q.; Shaikh, H.; Shah, A. Information technology (IT) based intervention among individuals with ASD (autism spectrum disorder): A review. In Proceedings of the 2019 IEEE International Conference on Innovative Research and Development (ICIRD), Jakarta, Indonesia, 28–30 June 2019.
38. Parsons, T.D.; Rizzo, A.A.; Rogers, S.; York, P. Virtual reality in paediatric rehabilitation: A review. *Dev. Neurorehabil.* **2009**, *12*, 224–238. [CrossRef]
39. Grynszpan, O.; Weiss, P.L.; Perez-Diaz, F.; Gal, E. Innovative technology-based interventions for autism spectrum disorders: A meta-analysis. *Autism* **2014**, *18*, 346–361. [CrossRef] [PubMed]
40. Levac, D.; Colquhoun, H.; O'Brien, K.K. Scoping studies: Advancing the methodology. *Implement. Sci.* **2010**, *5*, 69. [CrossRef] [PubMed]
41. Arksey, H.; O'Malley, L. Scoping studies: Towards a methodological framework. *Int. J. Soc. Res. Methodol. Theory Pract.* **2005**, *8*, 19–32. [CrossRef]
42. Pham, M.T.; Rajić, A.; Greig, J.D.; Sargeant, J.M.; Papadopoulos, A.; Mcewen, S.A. A scoping review of scoping reviews: Advancing the approach and enhancing the consistency. *Res. Synth. Methods* **2014**, *5*, 371–385. [CrossRef] [PubMed]
43. Tricco, A.C.; Lillie, E.; Zarin, W.; O'Brien, K.K.; Colquhoun, H.; Levac, D.; Moher, D.; Peters, M.D.J.; Horsley, T.; Weeks, L.; et al. PRISMA extension for scoping reviews (PRISMA-ScR): Checklist and explanation. *Ann. Intern. Med.* **2018**, *169*, 467–473. [CrossRef]
44. McCleery, J.P.; Zitter, A.; Solórzano, R.; Turnacioglu, S.; Miller, J.S.; Ravindran, V.; Parish-Morris, J. Safety and Feasibility of an Immersive Virtual Reality Intervention Program for Teaching Police Interaction Skills to Adolescents and Adults with Autism. *Autism Res.* **2020**, *13*, 1418–1424. [CrossRef] [PubMed]
45. Fitzgerald, E.; Yap, H.K.; Ashton, C.; Moore, D.W.; Furlonger, B.; Anderson, A.; Kickbush, R.; Donald, J.; Busacca, M.; English, D.L. Comparing the effectiveness of virtual reality and video modelling as an intervention strategy for individuals with Autism Spectrum Disorder: Brief report. *Dev. Neurorehabil.* **2018**, *21*, 197–201. [CrossRef] [PubMed]
46. Ip, H.H.S.; Wong, S.W.L.; Chan, D.F.Y.; Byrne, J.; Li, C.; Yuan, V.S.N.; Lau, K.S.Y.; Wong, J.Y.W. Enhance emotional and social adaptation skills for children with autism spectrum disorder: A virtual reality enabled approach. *Comput. Educ.* **2018**, *117*, 1–15. [CrossRef]
47. Parish-Morris, J.; Solórzano, R.; Ravindran, V.; Sazawal, V.; Turnacioglu, S.; Zitter, A.; Miller, J.S.; McCleery, J.P. Immersive virtual reality to improve police interaction skills in adolescents and adults with autism spectrum disorder: Preliminary results of a phase i feasibility and safety trial. *Annu. Rev. CyberTherapy Telemed.* **2018**, *2018*, 50–56.
48. Amaral, C.P.; Simões, M.A.; Mouga, S.; Andrade, J.; Castelo-Branco, M. A novel Brain Computer Interface for classification of social joint attention in autism and comparison of 3 experimental setups: A feasibility study. *J. Neurosci. Methods* **2017**, *290*, 105–115. [CrossRef]
49. Greffou, S.; Bertone, A.; Hahler, E.M.; Hanssens, J.M.; Mottron, L.; Faubert, J. Postural hypo-reactivity in autism is contingent on development and visual environment: A fully immersive virtual reality study. *J. Autism Dev. Disord.* **2012**, *42*, 961–970. [CrossRef] [PubMed]
50. Herrero, J.F.; Lorenzo, G. An immersive virtual reality educational intervention on people with autism spectrum disorders (ASD) for the development of communication skills and problem solving. *Educ. Inf. Technol.* **2020**, *25*, 1689–1722. [CrossRef]
51. Yeh, C.C.; Meng, Y.R. Exploring the Social Interaction of Autistic Students of Elementary and Junior High School Students through the Teaching of Social Skills in Virtual Reality. In Proceedings of the 2020 Indo–Taiwan 2nd International Conference on Computing, Analytics and Networks (Indo-Taiwan ICAN), Rajpura, India, 7–15 February 2020; pp. 41–44.
52. Tarantino, L.; De Gasperis, G.; Di Mascio, T.; Pino, M.C. Immersive applications: What if users are in the autism spectrum? An experience of headsets engagement evaluation with ASD users. In Proceedings of the 17th International Conference on Virtual-Reality Continuum and Its Applications in Industry, Brisbane, QLD, Australia, 14 November 2019; pp. 10–17.

53. Mul, C.L.; Cardini, F.; Stagg, S.D.; Sadeghi Esfahlani, S.; Kiourtsoglou, D.; Cardellicchio, P.; Aspell, J.E. Altered bodily self-consciousness and peripersonal space in autism. *Autism* **2019**, *23*, 2055–2067. [CrossRef] [PubMed]
54. Biffi, E.; Costantini, C.; Ceccarelli, S.B.; Cesareo, A.; Marzocchi, G.M.; Nobile, M.; Molteni, M.; Crippa, A. Gait pattern and motor performance during discrete gait perturbation in children with autism spectrum disorders. *Front. Psychol.* **2018**, *9*, 413283. [CrossRef] [PubMed]
55. Bozgeyikli, L.; Bozgeyikli, E.; Raij, A.; Alqasemi, R.; Katkoori, S.; Dubey, R. Vocational rehabilitation of individuals with autism spectrum disorder with virtual reality. *ACM Trans. Access. Comput.* **2017**, *10*, 1–25. [CrossRef]
56. Ip, H.H.S.; Wong, S.W.L.; Chan, D.F.Y.; Byrne, J.; Li, C.; Yuan, V.S.N.; Lau, K.S.Y.; Wong, J.Y.W. Virtual reality enabled training for social adaptation in inclusive education settings for school-aged children with autism spectrum disorder (ASD). In *Blended Learning: Aligning Theory with Practices: Proceedings of the 9th International Conference, ICBL 2016, Beijing, China, 19–21 July 2016*; Lecture Notes in Computer Science (including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics); Springer: Berlin/Heidelberg, Germany, 2016.
57. Cheng, Y.; Hong, S.X. Learning impacts of using data glove and stereoscopic projection with virtual environment for enhancing the social etiquettes in autistic spectrum conditions. In Proceedings of the 2014 IEEE 14th International Conference on Advanced Learning Technologies, Athens, Greece, 7–10 July 2014; Volume 2014, pp. 586–589.
58. Cheng, Y.; Huang, C.L.; Yang, C.S. Using a 3D immersive virtual environment system to enhance social understanding and social skills for children with autism spectrum disorders. *Focus Autism Other Dev. Disabl.* **2015**, *30*, 222–236. [CrossRef]
59. Jarrold, W.; Mundy, P.; Gwaltney, M.; Bailenson, J.; Hatt, N.; Mcintyre, N.; Kim, K.; Solomon, M.; Novotny, S.; Swain, L. Social attention in a virtual public speaking task in higher functioning children with autism. *Autism Res.* **2013**, *6*, 393–410. [CrossRef]
60. Trepagnier, C.; Sebrechts, M.M.; Peterson, R. Atypical face gaze in autism. *Cyberpsychology Behav.* **2002**, *5*, 213–217. [CrossRef]
61. Cook, J.; Swapp, D.; Pan, X.; Bianchi-Berthouze, N.; Blakemore, S.J. Atypical interference effect of action observation in autism spectrum conditions. *Psychol. Med.* **2014**, *44*, 731–740. [CrossRef]
62. Amaral, C.; Mouga, S.; Simões, M.; Pereira, H.C.; Bernardino, I.; Quental, H.; Playle, R.; McNamara, R.; Oliveira, G.; Castelo-Branco, M. A feasibility clinical trial to improve social attention in Autistic Spectrum Disorder (ASD) using a brain computer interface. *Front. Neurosci.* **2018**, *12*, 357512. [CrossRef]
63. Newbutt, N.; Sung, C.; Kuo, H.J.; Leahy, M.J.; Lin, C.C.; Tong, B. Brief Report: A Pilot Study of the Use of a Virtual Reality Headset in Autism Populations. *J. Autism Dev. Disord.* **2016**, *46*, 3166–3176. [CrossRef] [PubMed]
64. Bozgeyikli, L.L.; Bozgeyikli, E.; Katkoori, S.; Raij, A.; Alqasemi, R. Effects of virtual reality properties on user experience of individuals with autism. *ACM Trans. Access. Comput.* **2018**, *11*, 1–27. [CrossRef]
65. Lorenzo, G.; Pomares, J.; Lledó, A. Inclusion of immersive virtual learning environments and visual control systems to support the learning of students with Asperger syndrome. *Comput. Educ.* **2013**, *62*, 88–101. [CrossRef]
66. Lorenzo, G.; Lledó, A.; Pomares, J.; Roig, R. Design and application of an immersive virtual reality system to enhance emotional skills for children with autism spectrum disorders. *Comput. Educ.* **2016**, *98*, 192–205. [CrossRef]
67. Campbell, D.T.; Stanley, J.C. The Post Test-Only Control Group Design. In *Experimental and Quasi-Experimental Designs for Research*; Rand Mcnally College Publishing Co.: Chicago, IL, USA, 1996; pp. 25–31.
68. Greffou, S.; Bertone, A.; Hanssens, J.M.; Faubert, J. Development of visually driven postural reactivity: A fully immersive virtual reality study. *J. Vis.* **2008**, *8*, 15. [CrossRef] [PubMed]
69. Riva, G.; Baños, R.M.; Botella, C.; Mantovani, F.; Gaggioli, A. Transforming experience: The potential of augmented reality and virtual reality for enhancing personal and clinical change. *Front. Psychiatry* **2016**, *7*, 222151. [CrossRef] [PubMed]
70. Cascio, M.A.; Weiss, J.A.; Racine, E. Person-Oriented Research Ethics to Address the Needs of Participants on the Autism Spectrum. *Ethics Hum. Res.* **2020**, *45*, 2–16. [CrossRef] [PubMed]
71. Frischen, A. Europe PMC Funders Group Gaze Cueing of Attention. *Differences* **2007**, *133*, 694–724.
72. Bakeman, R.; Adamson, L.B. Coordinating attention to people and objects in mother–infant and peer–infant interaction. *Child Dev.* **1984**, *55*, 1278–1289. [CrossRef]
73. Gale, C.M.; Eikeseth, S.; Klintwall, L. Children with Autism Show Atypical Preference for Non-Social Stimuli. *Sci. Rep.* **2019**, *9*, 10355. [CrossRef]
74. Asperger, H. Die "Autistischen Psychopathen" im Kindesalter. *Arch. Psychiatr. Nervenkr.* **1944**, *117*, 76–136. [CrossRef]
75. Lai, M.C.; Lombardo, M.V.; Baron-Cohen, S. Autism. *Lancet* **2014**, *383*, 896–910. [CrossRef] [PubMed]
76. Howarth, P.A.; Costello, P.J. The occurrence of virtual simulation sickness symptoms when an HMD was used as a personal viewing system. *Displays* **1997**, *18*, 107–116. [CrossRef]
77. Kim, H.; Kim, D.J.; Chung, W.H.; Park, K.A.; Kim, J.D.K.; Kim, D.; Kim, K.; Jeon, H.J. Clinical predictors of cybersickness in virtual reality (VR) among highly stressed people. *Sci. Rep.* **2021**, *11*, 12139. [CrossRef] [PubMed]
78. Carnett, A.; Neely, L.; Gardiner, S.; Kirkpatrick, M.; Quarles, J.; Christopher, K. Systematic Review of Virtual Reality in Behavioral Interventions for Individuals with Autism. *Adv. Neurodev. Disord.* **2023**, *7*, 426–442. [CrossRef]
79. Mak, G.; Zhao, L. A systematic review: The application of virtual reality on the skill-specific performance in people with ASD. *Interact. Learn. Environ.* **2023**, *31*, 804–817. [CrossRef]
80. Vogeley, K.; Kirchner, J.C.; Gawronski, A.; Van Elst, L.T.; Dziobek, I. Toward the development of a supported employment program for individuals with high-functioning autism in Germany. *Eur. Arch. Psychiatry Clin. Neurosci.* **2013**, *263*, 197–203. [CrossRef]

81. Xie, B.; Liu, H.; Alghofaili, R.; Zhang, Y.; Jiang, Y.; Lobo, F.D.; Li, C.; Li, W.; Huang, H.; Akdere, M.; et al. A Review on Virtual Reality Skill Training Applications. *Front. Virtual Real.* **2021**, *2*, 645153. [CrossRef]
82. Chen, J.L.; Leader, G.; Sung, C.; Leahy, M. Trends in Employment for Individuals with Autism Spectrum Disorder: A Review of the Research Literature. *Rev. J. Autism Dev. Disord.* **2015**, *2*, 115–127. [CrossRef]
83. Strickland, D.; Coles, C.; Southern, L. JobTIPS: A Transition to Employment Program for Individuals with Autism Spectrum Disorders. *J. Autism Dev. Disord.* **2013**, *43*, 2472–2483. [CrossRef]
84. Smith, M.J.; Ginger, E.J.; Wright, K.; Wright, M.A.; Taylor, J.L.; Humm, L.B.; Olsen, D.E.; Bell, M.D.; Fleming, M.F. Virtual reality job interview training in adults with autism spectrum disorder. *J. Autism Dev. Disord.* **2014**, *44*, 2450–2463. [CrossRef] [PubMed]
85. Smith, M.J.; Pinto, R.M.; Dawalt, L.; Smith, J.D.; Sherwood, K.; Miles, R.; Taylor, J.; Hume, K.; Dawkins, T.; Baker-Ericzén, M.; et al. Using community-engaged methods to adapt virtual reality job-interview training for transition-age youth on the autism spectrum. *Res. Autism Spectr. Disord.* **2020**, *71*, 101498. [CrossRef] [PubMed]
86. Van Laarhoven, T.; Winiarski, L.; Blood, E.; Chan, J.M. Maintaining vocational skills of individuals with autism and developmental disabilities through video modeling. *Educ. Train. Autism Dev. Disabil.* **2012**, *47*, 447–461.
87. National Research Council. *Educating Children with Autism*; Lord, C., McGee, J.P., Eds.; The National Academies Press: Washington, DC, USA, 2001; ISBN 978-0-309-21001-0.