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Virtual reality and naturalistic developmental behavioral interventions for children with autism spectrum disorder

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ABSTRACT

Background: Naturalistic Developmental Behavioral Interventions (NDBI) have been evaluated as the most promising interventions for children with autism spectrum disorder. In recent years, a growing body of literature suggests that technological advancements such as Virtual Reality (VR) are promising intervention tools. However, to the best of our knowledge no studies have combined evidence-based practice with such tools.
Aim: This article aims to review the current literature combining NDBI and VR, and provide suggestions on merging NDBI-approaches with VR.
Methods: This article is divided into two parts, where we first conduct a review mapping the research applying NDBI-approaches in VR. In the second part we argue how to apply the common features of NDBI into VR-technology.
Results: Our findings show that no VR-studies explicitly rely on NDBI-approaches, but some utilize elements in their interventions that are considered to be common features to NDBI.
Conclusions and implications: As the results show, to date, no VR-based studies have utilized NDBI in their intervention. We therefore, in the second part of this article, suggests ways to merge VR and NDBI and introduce the term Virtual Naturalistic Developmental Behavioral Interventions (VNDBI). VNDBI is an innovative way of implementing NDBI which will contribute in making interventions more accessible in central as well as remote locations, while reducing unwanted variation between service sites. VNDBI will advance the possibilities of individually tailoring and

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widen the area of interventions. In addition, VNDBI can provide the field with new knowledge on effective components enhancing the accuracy in the intervention packages and thus move forward the research field and clinical practice.

What this paper adds

This paper is the first to systematically investigate the current research combining best evidence-based practice within interventions on autism spectrum disorders with high-immersive technological tools. Research has shown that such tools are accepted amongst the majority of autistic individuals, and we suggest merging the most promising intervention approaches with the technology, thus enhancing both the clinical practice and the research field.

1. Part I

1.1. Introduction

Autism spectrum disorder (autism from hereon) is a condition marked by persistent challenges in social communication and the presence of repetitive behavior patterns, restricted interests, and activities (American Psychiatric Association, 2013). The worldwide prevalence of the diagnosis is estimated to be approximately one percent (Lord et al., 2020).

These characteristics intrinsic to the diagnosis may lead to detrimental effects for the personal, social, and professional development of children with autism. While some challenges can be mitigated by public education leading to a more inclusive society (e.g., Gillespie-Lynch, Kapp, Brooks, Pickens, & Schwartzman, 2017; Kapp, Gillespie-Lynch, Sherman, & Hutman, 2013), the acquisition and improvement of relevant skill-sets by children with autism themselves remains central. While a growing body of research suggests that children with autism benefit from social skills interventions (NICE-guidelines, 2013; Sandbank et al., 2020), it is not definite which intervention types are most successful in terms of effectiveness and efficacy. To date, clinical judgment on the effects on autism interventions based on best evidence practice remains unclear (Green & Garg, 2018). For example, social communication interventions for children with autism typically build on theoretical accounts of developmental cascades (e.g., Masten & Cicchetti, 2010) where intervention effects first improve behaviors or skills proximal to the intervention targets and later translate into more distal effects alleviating symptom severity (Green & Garg, 2018; Nordahl-Hansen, Fletcher-Watson, McConachie, & Kaale, 2016). However, an evidence gap exists regarding social communication intervention's effectiveness due to the limited number of randomized controlled trials (RCT) conducted and the relatively small sample sizes in the extant studies (Green & Garg, 2018).

Many interventions for children with autism suffer from high costs and low practical feasibility due to requirements of specific and hard-to-get training, as well as logistical challenges to accessibility due to geographical constraints combined with a lack of qualified personnel and resources (Lang et al., 2010). These weaknesses are in many ways addressed by the strengths of virtual reality (VR) programs. VR is the collective term describing artificial environments used to simulate or differentiate the real world by generating realistic images or other sensations simulating a presence in the virtual environment. VR can be presented with non-geographical restricted and affordable consumer products such as head-mounted displays enabling the users to be surrounded, interact, and get sensory feedback directly in the environment. Conversely, however, VR approaches to intervention currently lack theoretical grounding (Howard & Gutworth, 2020), and larger studies using RCTs evaluating the effectiveness of VR as an intervention tool for children with autism are lacking (Nordahl-Hansen et al., 2020).

Research using technology based on established intervention approaches is warranted (Sandbank et al., 2020). Within autism research, a recent meta-analysis (Sandbank et al., 2020) suggested Naturalistic Developmental Behavioral Interventions (NDBI) to be the most promising approaches within autism interventions. Considering that VR-tools, on the one hand, might help to make interventions that are hard to get more available, but on the other hand, lack theoretical foundation, we will look further into the possibilities of basing the VR-interventions on the promising theoretical ground of NDBI-approaches. Until now, there are no studies systematically investigating the combination of VR and NDBI. However, research on autism and VR are rapidly emerging (Dechsling, Sütterlin, & Nordahl-Hansen, 2020), and there is a need to identify research utilizing both VR and elements of NDBI.

We divide this article into two parts. Part 1 provides an overview of the research field on autism and the use of NDBI-approaches in VR, where we conduct a systematic review of intervention approaches within autism research combined with high-immersive VR-technology. In Part 2, we present and suggest possibilities of combining elements from the promising NDBI-approaches with VR-technology.

1.1.1. Naturalistic Developmental Behavioral Interventions

In their meta-analysis, Sandbank et al. (2020) identified Naturalistic Developmental Behavioral Interventions (NDBI) as the most promising intervention approach for children with autism. NDBI is a collective term for interventions drawing on techniques from behavior analysis and developmental psychology (Schreibman et al., 2015), involving the combination of "adult-led, behavioral teaching methods with child-led routines and taught to a natural developmental progression within naturalistic settings" (Sandbank et al., 2020, p. 8). Examples of NDBI are the Early Start Denver Model (ESDM; Dawson et al., 2010); the Joint Attention, Social Play, Engagement, and Regulation (JASPER; Kasari, Freeman, & Paparella, 2006); Pivotal Response Treatment (PRT; Koegel, Koegel, Harrower, & Carter, 1999; see Minjarez, Bruinsma, & Stahmer, 2020, and Schreibman et al., 2015 for extensive descriptions). The researchers in the consensus-article by Schreibman et al. (2015) identified three core elements and 13 different interventional strategies falling under the NDBI umbrella after summarizing the content and the results from many years of intervention evaluations. The core elements of NDBI entail: a) training a wide range of skills rather than specific skills in discrete trials, b) an emphasis on the learning context being naturalistic, and that c) the intervention combines different elements and strategies to boost learning in various settings. The different interventional strategies are listed as: *1. Three-part contingency; 2. Manualized practice; 3. Fidelity ofimplementation criteria; 4. Individualized treatment goals; 5. Ongoing measure of progress; 6. Child-initiatedteaching episodes; 7. Environmental arrangement; 8. Natural reinforcement and related methods for enhancing the motivation of the child; 9. Use of prompting and prompt fading; 10. Balanced turns within object or social play routines; 11. Modelling; 12. Adult imitation of the child's language, play, or body movements; 13. Broadening the attentional focus of the child*. Schreibman et al. (2015) called for continued innovation in implementing NDBI in clinical practice in order for it to be more available and widely delivered in community settings. Sandbank et al. (2020) also addressed the need to integrate advanced technology with established non-technological approaches to develop more effective interventions.

1.1.2. Virtual reality

VR technology involves displaying an artificial environment, typically containing visual and auditory stimuli, to end-users. The virtual environment can be set up to do various tasks with a high level of flexibility due to advances in software development. The highest level of immersion provided by mobile equipment is realized in VR Head-Mounted Displays (HMD), where the goggles provide a sense of virtual environment surrounding the user completely (see Bradley & Newbutt, 2018; Newbutt, Bradley, & Conley, 2020 for discussions on autism and HMD). Miller and Bugnariu (2016) provided an applicable classification of different levels of immersion of VR, stating that HMD and surrounding projections represents the highest level of immersion. The surrounding projections can be realized using Cave Automatic Virtual Environment (CAVE), which presents a pseudo-three-dimensional environment using several two-dimensional projected displays around the user or using motion sensors cameras such as Kinect (Howard & Gutworth, 2020). VR is considered suitable to simulate naturalistic situations regardless of location (Miller, Wiederhold, Miller, & Wiederhold, 2020) and allows creating training environments otherwise inaccessible in daily life. Augmented Reality (AR), in comparison, provides artificial visual and auditory information superimposed on the veridical, real-world environment making it suitable to prompt directly upon the environment.

Since the early high-immersive VR-studies (Jung et al., 2006; Max & Burke, 1997), there has been an increasing number of studies using VR/AR and computer-based tools in autism research. The number of VR/AR/computer-based publications in 2018 alone exceeds the total number of such publications during the previous 17 years (Dechsling et al., 2020). High-immersive VR, such as HMD, has several benefits related to the autism community and its heterogeneity, as VR can be tailored to individual needs. VR can provide a less stressful (Didehbani, Allen, Kandalaft, Krawczyk, & Chapman, 2016) but realistic environment with opportunities to practice skills with user-friendly levels of sensory and social stimuli (Bradley & Newbutt, 2018). A range of studies with adults and children with autism, acceptability, enjoyment, and high motivation when using VR and HMDs have been well acknowledged (2020, Dechsling et al., 2020; Malihi et al., 2020; Newbutt, Sung, Kuo, & Leahy, 2016). Expectably, caregivers and professionals desire better and more accessible technological tools supporting and educating individuals with autism (Putnam, Hanschke, Todd, Gemmell, & Kollia, 2019).

In this article, we address the call for innovative ways of implementing NDBI (Schreibman et al., 2015) and the proposal of applying advanced technology to established interventions (Howard & Gutworth, 2020; Sandbank et al., 2020). Through a systematic literature review, we aim in Part 1 to identify studies on autism interventions applying VR technology to implement NDBI or NDBI-featured approaches; and in Part 2, present and make suggestions on key elements in combining VR and NDBI.

1.2. Methods

1.2.1. Search strategy

In this study, we consulted the PRISMA-guidelines (Moher, Liberati, Tetzlaff, Altman, & The PRISMA Group, 2009). We searched the following databases: Education Research Complete, ERIC, PsycINFO, PubMed, IEEE Xplore, and the search platform Web of Science in April 2020. The following search string was used: (Pervasive development disorder OR pdd OR pdd-nos OR pervasive developmental disorder not otherwise specified OR autism OR autistic OR Autism Spectrum Disorder OR autism spectrum disorders OR Asperger OR asd OR autism spectrum condition* OR asc) AND (Virtual Reality OR vr OR hmd OR Head-mounted display OR Immersive Virtual Environment OR Augmented Reality OR Artificial Reality OR Oculus OR Immersive Technolog* OR Mixed Reality OR Hybrid Reality OR Immersive Virtual Reality System OR 3D Environment* OR htc vive OR cave OR Virtual Reality Exposure OR vre). The search was limited to peer-reviewed publications in English and human participants.

1.2.2. Inclusion and exclusion criteria

Included publications (peer-reviewed articles in journals or peer-reviewed conference proceedings [which is common within the field of information technology]) were written in English in full texts and published in 2010 or later. The publications were required to 1) involve participants with autism with a mean age of 18 years or younger; 2) use either VR or AR with HMD's (including AR-goggles) or CAVE or high-immersive Kinect; and 3) provide sufficient information about their procedure in order to be identified as NDBI or not (criteria from Sandbank et al., 2020, see below).

Publications before 2010 and grey literature were excluded along with publications using lower-immersive tools such as desktops, smartphones. Publications in which the participants do not act or interact in the virtual environment were also excluded.

1.2.3. Screening and data extraction

First, we used EndNote x9 to remove duplicates and screen titles and abstracts for records on ASD and VR/AR. Next, authors AD and SO used the systematic review web and mobile app Rayyan (Ouzzani, Hammady, Fedorowicz, & Elmagarmid, 2016) to screen the abstracts for language (since some publications present English abstracts though written in another language) and inclusion of participants, and went on to screen full texts for participant' age, apparatus used (HMD, CAVE, Kinect), and interventional studies with sufficient description. The screening process was blinded using the blinding-feature from Rayyan. Inter-coder agreement (Cohen's Kappa; Cohen, 1960) is reported in *Results*. Disagreement was resolved by discussion and reaching consensus by the coders.

To identify NDBI-studies, we used the criteria provided by Sandbank et al. (2020). According to these criteria, an intervention was regarded as NDBI if it applied one of the following approaches: Incidental Teaching, Pivotal Response Treatment, Early Start Denver Model, Enhanced Milieu Teaching, Reciprocal Imitation Training, Project ImPACT, JASPER, SCERTS, Early Achievements, and Prelinguistic Milieu Teaching. An intervention was also considered as NDBI if it "combined adult-led, behavioral teaching methods with child-led routines and taught to a natural developmental progression within naturalistic settings" (Sandbank et al., 2020, p. 8).

Based on these criteria, we first searched in the included articles full-text for the terms "NDBI", "naturalistic", and the names of all the above-mentioned intervention approaches and their abbreviations. We then evaluated each article to assess whether it contained the key interventional elements or features accordant with NDBI (Schreibman et al., 2015).

1.3. Results

Eighteen articles were identified meeting the inclusion criteria (see Fig. 1 for the study selection process) after screening 305 records. Removing the blinding function of Rayyan (Ouzzani et al., 2016) revealed six disagreements between coders, which were resolved by discussion. Cohen's Kappa was calculated as $k = .66$, which is considered substantial agreement (Cohen, 1960).

None of the first 18 included articles mentioned NDBI terms according to the criteria of Sandbank et al. (2020). One (De Luca et al., 2019) of 18 articles included an ESDM reference in their discussion, yet the study itself did not apply NDBI. Ten studies applied elements of NDBI, but none of them were fully in line with all criteria (Table 1).

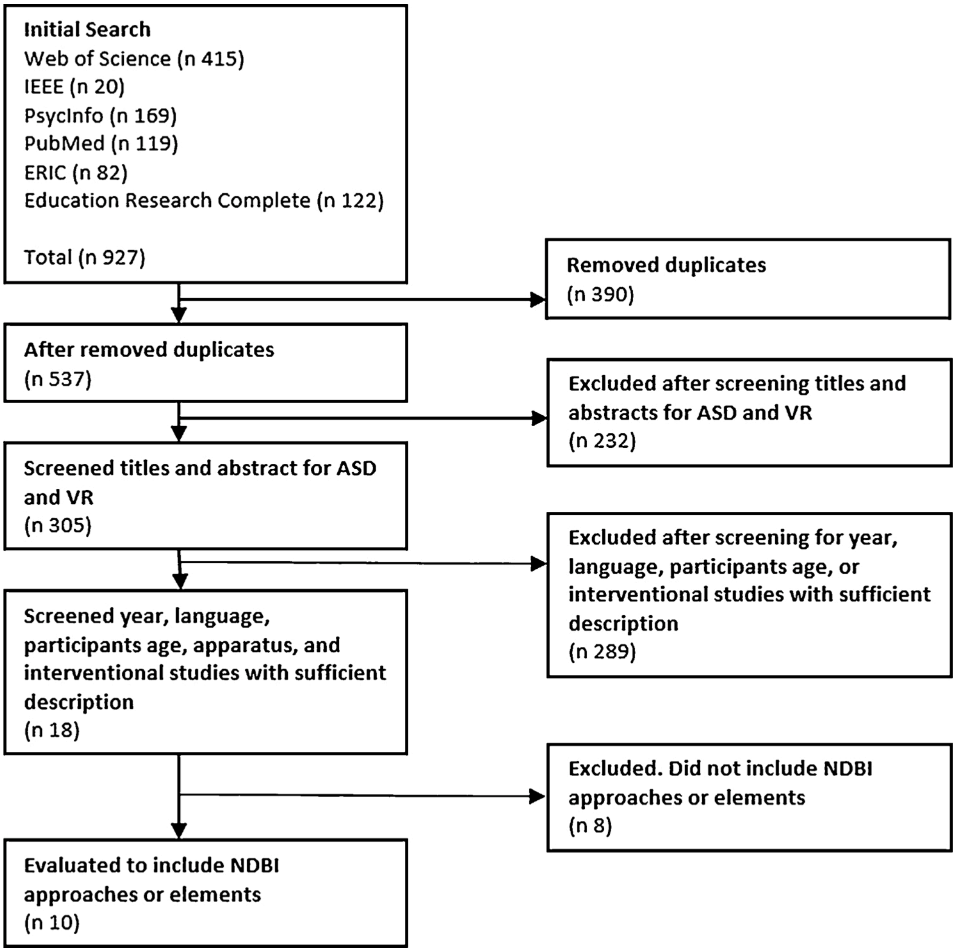

Fig. 1. *Note.* Flow chart of the study selection process.

Table 1
Summary of the ten publications applying NDBI features.

Authors, year	Design (n), tools	Type of intervention	NDBI feature (s)*
Beach and Wendt (2016)	Case study (2), HMDs	Social skills through observing scenarios	4, 7, 11, 13
Cheng, Huang, and Yang (2015)	Multiple single-case (3), HMDs	Social skills using animated social models	1, 2, 5, 7, 9, 11
Halabi et al. (2017)	Case-study (3), CAVE or HMDs	Social scenarios to enhance communication skills	2, 7, 11
Ip et al. (2018)	Case-study (36), 4-side VR CAVE	Learning scenarios to enhance social skills and emotion regulation	1, 2, 6, 7, 8, 9, 10
Liu, Salisbury, Vahabzadeh, and Sahin (2017)	Feasibility study (2), Smartglasses	Enhancing social gaze and emotion recognition	1, 9
Lorenzo et al. (2016)	Case-control (40), semi-cave and robot	Learning emotional scripts	1, 2, 5, 7, 8, 9, 11
Lorenzo et al. (2013)	Case-study (20), Kinect w/3D glasses	Training social and emotional skills in a school setting	1, 2, 7, 8, 9, 11
Ravindran, Osgood, Sazawal, Solorzano, and Turnacioglu (2019)	Feasibility/pilot study (12), HMD cardboard setup w/smartphone	Joint attention exercise	2, 7, 9, 13
Uzuegbunam, Wong, Cheung, and Ruble (2018)	Feasibility/pilot study (3), Kinect v2 w/ touchscreen	Social greeting behavior through social narratives	1, 2, 5, 7, 9
Vahabzadeh et al. (2018)	Feasibility study (4), Smartglasses	Training facial attention, mutual gaze and emotion recognition	1, 5, 9

Note. *1. Three part contingency; 2. Manualized practice; 3. Fidelity of implementation criteria; 4. Individualized treatment goals; 5. Ongoing measure of progress; 6. Child-initiated ieaching episodes; 7. Environmental arrangement; 8. Natural reinforcement and related methods for enhancing motivation of the child; 9. Use of prompting and prompt fading; 10. Balanced turns within object or social play routines; 11. Modeling; 12. Adult imitation of the child's language, play, or body movements; 13. Broadening the attentional focus of the child.

Among the publications analysed in this review, none involved RCT, and only one out of the ten studies that involved NDBI features included a control group. Four studies were case-studies, one was a multiple single-case study, and the remaining four publications were feasibility studies. All of the publications targeted social skills. The frequencies of applying different apparatuses such as HMD, Smartglasses, or CAVE were evenly distributed across studies. As shown in Table 1, the studies adopted a variety of combinations of different NDBI features. Ip et al. (2018) and Lorenzo, Pomares, and Lledo, 2013; Lorenzo, Lledo, Pomares, & Roig, 2016) combined the largest amount (up to 7) of features in the analysed sample.

1.4. Discussion

1.4.1. Aim 1: the review

The first aim of this article was to identify studies applying VR-tools to implement NDBI or NDBI-featured approaches. The systematic literature review revealed that no high immersive VR/AR-intervention mentioned NDBI. In addition, only 10 studies were found to apply immersive VR that incorporated some NDBI features. Given that NDBI has been acknowledged in several publications as the best evidence-based practice (Maye, Sanchez, Stone-MacDonald, & Carter, 2020); Sandbank et al., 2020; Tiede & Walton, 2019), our review indicates gaps in both research and application in leveraging VR for implementing NDBI for children with autism.

Technology-aided approaches building upon established effective methods, such as NDBI, might prove to be more effective and offer an innovative and sustainable way of delivering evidence-based interventions. Such technology-aided interventions can be extended to remote settings. As indicated in a recent NDBI study, the treatment fidelity of the technology-aided trials was comparable to that of the traditional face-to-face onsite training (Shire, Baker Worthman, Shih, & Kasari, 2020).

Considering the effectiveness of NDBI and the overall acceptance of VR by individuals with autism, we suggest merging VR-technology with NDBI and hereby introduce *Virtual Naturalistic Developmental Behavioral Interventions* (VNDBI). We propose to implement elements of NDBI through the use of Virtual Reality. In the following section (Part 2), we present suggestions on how to apply VR to implement and strengthen NDBI, although not exhaustively covering all possibilities provided by VR.

2. Part II

2.1. Aim 2: suggestions for implementing NDBI in VR

In Part 2, we carve out some suggestions that can move the field forward. First, we address how future research should take advantage of evidence-based practice from traditional autism interventions combined with VR-technology. Second, we suggest how using rigorous designs with different conditions might be particularly important to investigate the effects of technology based interventions, such as VR, taking into account its rapid development (Shic et al., 2019) and that autism is a heterogeneous condition.

2.1.1. Virtual Naturalistic Developmental Behavioral Interventions

When merging the VR and NDBI into VNDBI, we consider the core components and common features of NDBI approaches, which we suggest applying through VR-technology. First, we elaborate on how the three core components correspond to the opportunities provided by VR. Second, we expand on how the 13 common features of NDBI-approaches (Schreibman et al., 2015) could be utilized through VR and the possible advantages of these features in VNDBI compared to traditional NDBI.

2.1.1.1. Core components. The core components of NDBI suggest (1 - "Nature of learning targets") training a variety of skills concurrently instead of training specific skills discreetly. This emphasizes training skills, which serves as "door-openers" for other types of behavior, for example, social communication skills, imitation, and joint attention (Schreibman et al., 2015). These intervention targets may be integrated into several VR sessions that have other main targets as well. If needed, VR allows decomposing complex and nuanced social skills into its core components to work on each of these skills isolated, with the complexity increasing as the child obtains mastery. It will be possible to adjust the complexity and level of difficulty in accordance with the current master criteria to ensure reinforcers, even close to discrete trials, if needed. For example, joint attention, which can be described as sharing attention with others to events, persons or objects (Kasari et al., 2006), are complex skills involving a multistep process of dyadic engagement, for instance through gazing towards an object before returning to dyadic engagement. Responding to joint attention in VR will typically involve the participant orienting towards a person (i.e., avatar), dyadic engagement, followed by the avatar diverting the attention to another avatar or object before the attention automatically comes back to the avatar after some time, wherein dyadic engagement occurs together with an acknowledgment of intersubjectivity by the avatar. Depending on where in this multistep process the child is having difficulty, you are able to work on specific skills (e.g., orienting towards the person/avatar) before chaining (orienting followed by dyadic engagement), and thereby increase the complexity by varying delays, shapes, and determinism of the avatar's contingent reactions.

The core component (2 - "Nature of learning contexts") focus on training in naturalistic settings rather than in a strictly controlled environment often represented in discrete trial training. The context and social landscape are important, and these are often provided by adult-child engagement (Schreibman et al., 2015). In VR, this engagement can be done via avatars looking both like peers and adults. As many social norms apply in a variety of settings (e.g., home, school, playground), the possibility of a rapid and successive shift of environments may show VR as an effective tool for facilitating generalization (which has shown to be challenging in autism research; Carruthers, Pickles, Slonims, Howlin, & Charman, 2020). A virtual context gives an opportunity to train in otherwise inaccessible situations (e.g., traffic, crowds, etc.), which is an important feature that surpasses the opportunity we can provide outside VR. As noted above, a joint attention process in VR can be trained in a discrete format selecting specific elements that need to be rehearsed. However, the possibilities of rapid shifts and controlling the virtual surroundings and settings allow us to train these skills even in virtual naturalistic environments. E.g., orienting together with an avatar towards a peer or adult approaching the playground, or towards cars or dangers in traffic, etc.

The third core component is (3 - "Nature of development-enhancing strategies") combining different elements and strategies (the common features) to boost learning in various settings. The virtual environment gives the opportunity to combine several elements and strategies, without the need for extra hands, and collect important data simultaneously. These data may be shared and evaluated in order to develop better and automated methods and reconstructions to further support therapist teaching and delivery.

2.1.1.2. Common features of NDBI. Below are the common features of NDBI identified in Schreibman et al. (2015), marking critical components thought to contribute to and to influence the effectiveness of NDBI intervention. Below, we describe each of these components as traditionally defined and then discuss how they may be adapted, supported, and/or enhanced in a VNDBI.

2.1.1.2.1. Three-part contingency. The three-part contingency is a term describing that antecedent stimuli, behavior, and the immediate consequence of the behavior are contingent. This means that the function of an antecedent stimulus is producing behavior while the consequence of this behavior affects the future probability of producing such behavior in the presence of similar antecedent stimuli. For example, if a child, when seeing milk (antecedent stimulus): asks for milk (behavior/response), then gets milk (consequence; in this example a reinforcer) - the positive reinforcement will increase the probability that the child would again ask for milk in similar contexts.

Antecedents might sometimes be difficult to observe and identify. However, VR could support interventionist identification of antecedents and key behaviors, in addition to the delivery of reinforcers. The algorithmic capabilities of the VR-platform can increase automation by possibly detecting and classifying contingencies automatically. Temporal windowing, with machine vision and data mining techniques, could aid further in the identification leading to even more powerful automation. Hence, consequences could be delivered more powerfully, quickly, and precisely contingent on the child's performance with rapid selection preplanned by a therapist or scripted by algorithms that eventually are able to detect the most effective reinforcement.

Programming three-part contingencies are feasible in a virtual environment as the discriminative (antecedent) stimuli may be presented in various valences, and the reinforcers are given through programmed consequences on the predefined target response. This will ensure that the correct response is reinforced according to the plan. However, in some instances of behavior that is just below the threshold for reinforcement, the program may not be able to detect situations where a trained professional would reinforce on account of shaping. In some cases, we cannot pre-program flexible enough, but in return, a programmed consequence will ensure that only the desired behaviors are reinforced which limits the amount of incorrect reinforcements.

2.1.1.2.2. Manualized practice. NDBI approaches commonly provide manuals with detailed procedures for caregivers, trainers, etc., to follow during interventions. However, training and feedback to accurately follow such procedures are needed (Schreibman et al., 2015). As the VNDBI can be programmed and tailored in advance, it is necessary and easy to follow the intervention manual with some training for the individuals administering the intervention.

2.1.1.2.3. Fidelity of implementation criteria. To ensure correct usage and internal validity, NDBI approaches focus on assessing treatment fidelity. However, in traditional NDBI, it might be difficult to assess treatment fidelity due to the flexible art of the interventions. VR gives an opportunity to collect data on the treatment fidelity without using additional personnel or resources as it monitors both the behavior of the child and interventionist. Hence, pre-scripted interventions may be fairly simple to monitor, and prospective adjustments, changes, or specific tailoring will easily be recorded.

2.1.1.2.4. Individualized treatment goals. Due to individual differences in development, an important feature in NDBI-approaches is choosing developmentally suitable treatment goals. As noted by Schreibman et al. (2015), most NDBI-approaches use standardized assessments and observation as guidance when selecting meaningful skills for each individual. VR may add valuable insights to the evaluation tools, and considering the need for tailored intervention to reach the individualized treatment goals, a wide range of environments and exercises can easily be accessed in VR.

2.1.1.2.5. Ongoing measurement of progress. Collecting data is important in order to evaluate the effectiveness of the interventions. Further, to be able to adjust the intervention according to the individual's performances and learning to ensure effects, it is necessary to measure the ongoing progress. This represents a challenge in traditional NDBI as the ongoing measuring of progress is both time consuming and at risk of human errors. VR has an advantage in collecting data on various measures at the same time, giving an opportunity to adjust the interventions concurrently to reach the treatment goals.

2.1.1.2.6. Child-initiated teaching episodes. A child-initiated episode often ensures a natural motivational factor for the child and thus represents a nice training opportunity. These opportunities might be hard to find in some instances. However, a VR-based incidental teaching format enables child-initiated teaching episodes and environmental arrangement that exceeds the possibilities provided in real-life. It is possible to present situations known to elicit motivating operations in the child or present a choice based task where the child is able to choose the preferred training episode. Alternatively, interventionists can craft an environment that motivates a particular child to conduct a teaching episode that is deemed to be most relevant or helpful.

2.1.1.2.7. Environmental arrangement. NDBI-approaches use various methods in arranging the environment so that the child has to interact with others. A virtual environment can be arranged in numerous ways with the ability to simulate environments and situations that are usually impractical or inaccessible in traditional training. It could help with generalization by allowing skills to be trained in multiple environments or structure additional complexity into tasks to make them more challenging or varying to aid in improving flexibility. The environmental arrangement in VR may also be advantageous when presenting less stressful social environments and more safe than, for instance, traffic situations.

2.1.1.2.8. Natural reinforcement and related methods for enhancing motivation of the child. It is crucial with effective reinforcers in regards to motivational operations and in order to learn new and sustain behaviors. Important natural reinforcers are stimuli asked for by the child or the explicit praise and positive emotional feedback provided by the interventionist. In VR, it is possible to shape the valence of various reinforcers with, for example, exaggerating natural social reinforcers or increasing/decreasing the salience of the reinforcement contingent on the child's skill level in particular skills. What stimuli that serve as reinforcers will vary between individuals, situations, and current state-of-mind, which implies the need for frequent reinforcer assessments. Considering the enjoyment reported, gaming in VR may sometimes serve as a reinforcer per se.

2.1.1.2.9. Use of prompting and prompt fading. Prompting refers to cues aimed at helping the child in eliciting the appropriate behavior to produce a reinforcer contingent on the antecedent stimulus. Such prompts might be instructions, gestures, or physical prompts. Since the child's visual experiences in VR can be monitored on a laptop, tablet, or smartphone, the trainer can prompt the child (also physically in some instances) when it is using the HMD. However, the environmental arrangement possibilities provided by VR make visual and auditory prompting and prompt fading in VR more flexible than in real-life. For instance, visual and auditory prompts in VR can vary in many ways in terms of salience and delivered contingent on, for example, eye-gaze or behavioral approximation towards an object or persons. These prompts can, in turn, be automatically faded in their nature as given by a program selected by the trainer or as a product of an algorithm.

2.1.1.2.10. Balanced turns within objects or social play routines. Mutual engagement and interactions, such as turn-taking, is important in social learning. One of the advantages of VR in training balanced turns is that the balance can be made very explicit with visual and auditory supports that otherwise would be very difficult to provide to the child in a less obtrusive way. For instance, an indicator in the child's peripheral vision (e.g., timer, hourglass, level bar, etc.) of the appropriate amount of time to wait for a turn could be used in order to provide feedback on the (short or too long) time spent. Turn-taking can be trained in various contexts such as the playground, public transportation, conversations, ball games, video games, etc. The visual prompting such as indicators combined with salient reinforcers can further strengthen the concept.

2.1.1.2.11. Modelling. Demonstrating the target behavior for the child is sometimes regarded both as a teaching method and as prompts. For example, imitation in itself is an important developmental skill that might be trained by reinforcing appropriate imitations of a model (e.g., movements or language). Imitation as a generalized skill will, in turn, be important in order to acquire other skills, such as skills where modelling might serve as an important instructional cue (e.g., how to put on a jacket). VR technology has advantages such as utilizing modelling partners that appear to simulate more complex situations than what is feasible in real life. Modelling by peers or avatars is also a feat that we hypothesize will improve the effects compared to adult modelling only.

2.1.1.2.12. Adult imitation of the child's language, play, or body movements. As noted, modelling and imitation are closely related. However, adult imitating of the child is emphasized due to its influence on the child's attention towards the adult (Schreibman et al., 2015). Using VR with both peer and adult avatars may improve the effects. Vocal imitation through, for instance, a voice modulator can make it a funnier activity for the child, and detection of body movements could be scripted into a variety of forms with an endless number of avatars (peers and adults or characters) increasing the child's attentiveness.

2.1.1.2.13. Broadening the attentional focus of the child. Indications that children with autism might have attentional characteristics such as stimulus over selectivity (i.e., focus on specific details of a stimulus instead of the stimulus as a whole) have led to an emphasis on a variety of settings and material in various NDBI-approaches. Even though this phenomenon has shown not to be autism specific, it is still something to be aware of in case of failure to generalize the discriminative functions of resembling stimuli. The various features of NDBI-approaches are believed to broaden the attentional focus of the child. However, eye-tracking VR may detect such stimulus over selectivity at earlier stages, giving the interventionist opportunities to effectively address this matter. (Fig. 2).

These common features of NDBI-approaches identified by Schreibman et al. (2015) are listed as "active ingredients within the multicomponent interventions" (p. 2422) in need of empirical analysis in regards to their contributions. Utilizing VNDBI will potentially provide additional information regarding the contribution of the different elements broadly and at the individual level. The opportunity to collect data through the HMD provides a new level of possibilities in regards to analyzing progress during the intervention and not limited to the results from, e.g., post-tests. Complex mediator analyses could provide the field with important knowledge of developmental trajectories and possibly cascading intervention effects.

These arguments suggest that there are opportunities for using VR to support interventions with various features in NDBI. For instance, combining teaching strategies with an assessment of treatment fidelity or ongoing progress measures requires personnel and resources, hence more training of personnel. The fact that VR can assist in implementing these complex combinations during interventions might make it easier to implement and sustain NDBI-approaches for children with autism. However, it is likely that some features will be better solved in real-life, but a combination of virtual and real-life training might be even better.

2.1.2. *Individual needs and normative considerations*

Even though recent research shows that individuals with autism express acceptability and enjoyment towards using HMDs (e.g., Dechsling et al., 2020; Malihi et al., 2020; Newbutt et al., 2020), it is important to consider each individual's acceptability in addition to other normative considerations such as values, interests and possible outcomes (see Dechsling et al., 2020). Motion sickness (or cybersickness) is a term used to describe a sickness notion described as dizziness or nausea induced by HMDs, which has caused a reluctance in some individuals to use HMDs. Hard- and software developers have, in recent years, incorporated motion sickness control in their devices to cope with that problem making HMDs even more user-friendly. HMDs are considered more practical than CAVE in terms of the flexibility of location and load of equipment. However, as a principle, VNDBI should not be restricted to HMD only as some individuals might gain more profit or motivation by using other tools. For instance, CAVE may be used for children who have sensory issues involving the placement of goggles on their heads, and augmented reality might be used for situations where it is helpful to aid in generalization from virtual to the real world. There will also be instances where a virtual environment presented on a laptop or tablet will be the most feasible. Until research has concluded empirically that one modality (e.g., HMD, CAVE, or other) is superior, the choice of equipment is mostly based on normative arguments and should rely on the individual's preferences whenever possible. This in turn call for an involvement of individuals with autism in developing tools and taking this field forward.

2.1.3. *Evidence-based practice*

VNDBI based approaches may greatly expand the accessibility of NDBI for children with autism across socioeconomic strata. VR can also be a cost-effective alternative demanding fewer resources and can be used at various locations, not only in schools where most treatment sessions take place. However, our review finds little evidence for the use of VR-interventions. The low number of studies published and few studies using comparison groups makes inferences of VR-intervention effects difficult. Considering the potential of VR technology might have for individuals with autism, as well as the call from various researchers in taking advantage of new technology and investigate its effectiveness (Sandbank et al., 2020; Schreibman et al., 2015; Zervogianni et al., 2020) we see it as natural to use the best evidence-based practice available from traditional interventions. In this respect, NDBIs is a sensible choice.

Fig. 2. *Note.* Illustration by VisuMedia.

However, considering the scarcity of evidence for VR-interventions for autistic groups, there is a need for studies using designs that can assess whether NDBI delivered in VR is effective. This means there is a need for more RCTs. However, trials using rigorous single-case designs and multiple single-case designs deploying newly developed statistical methods (Shadish, 2014) can contribute to shed light on important factors and mechanisms as well.

Advances in technological interventions are occurring at a rapid pace that opens up opportunities for a combination of traditional and new statistical data analyses (Shic et al., 2019). The potential of such hybrid solutions in regards to measures of outcome where, for instance, traditional outcomes are combined with in-built technologies available for HMDs (e.g., eye-tracking) could strengthen inferences from trials.

Due to the recency of VR-interventions for children with autism it will also be interesting to investigate different modalities as conditions in trials. For instance, it is comparing effects between groups that receive only VR-intervention to groups that receive VR-intervention plus traditional interventions and only traditional intervention. In addition to comparing effects in general between such groups, this might give information on potential generalization or non-generalization of the targeted intervention content.

2.1.4. Limitations and future research

We consider the broad spectrum of search platforms in our search strategy as a strength when conducting systematic reviews on technological and autism related topics since publications are made in various areas. However, it is always a possibility that publications have remained undetected. The low amount of included publications makes it problematic to assess any effect on VR studies applying features found in NDBI but is an important finding in itself. The evaluation of the included publications in terms of the indications of NDBI features was conducted qualitatively and may contain inaccuracies. Which elements included in various studies may not be an important finding in its own right but provides indications on where to find examples of implementing such elements. Lack of relevant publications does not call for more papers per se, but considering the arguments for technological evidence-based interventions, the reported acceptability amongst stakeholders, and our recommendations on merging VR and NDBI, we suggest a call for such papers.

Our suggestions on the advantages of VNDBI are not absolute or exhaustive. There are likely to be more reasons as to how and why VR is advantageous but also arguments contradicting ours. Some of our arguments are normative and should be discussed as such. On the other hand, our descriptive arguments we encourage to be tested empirically.

Other important limitations of this study are related to the choices we made in terms of the literature search strategies. First, we did not search for grey literature (studies that are not published in a peer-reviewed journal), which presents the potential bias. Excluding grey literature increases the impact of publication bias, a common validity threat for systematic reviews (Cooper et al., 2019). Second, including only studies written in English could have presented language bias. However, exclusion based on language is often necessary due to, for example, time constraints (Gough, Oliver, & Thomas, 2017). Finally, we did not apply quality appraisal of the studies and this should be considered when interpreting the findings from our study.

2.2. Overall conclusion

No studies explicitly combine VR and NDBI-approaches, even though a few studies have utilized some components. We have addressed a number of possibilities provided by VR that can improve future research in developing and implementing NDBI-approaches. We suggest that VNDBI opens up novel research opportunities as it addresses an under-researched area where high immersive VR is combined with promising intervention approaches.

Advanced technologies such as VR can contribute substantially to future ASD-interventions: (1) the use of VR can reduce unwanted treatment variation between service sites, as VR approaches can be standardized. (2) The use of VR can provide additional flexibility for tailoring intervention environments and scenarios to individual needs, making a significant step towards more fully personalized and targeted treatments. (3) Compared to conventional treatments, VR interventions can be less resource-demanding, bearing high investment-gain efficiency, and are especially suitable for highly intensive interventions.

The embedding of the intervention in the HMD-VR environment de-couples the need for intervention from the need for highly trained and rare specialists providing 1:1 interventions with a physical presence. This empowers teachers and caregivers in daily contact with the children and uses centralized and digitally accessible expertise to a wider range of beneficiaries. Which provides the use of digital means a new level of sustainability in terms of interventions that are personally delivered (by teachers and caregivers) but centrally quality-assured by scientists - providing novel and easy-to-use opportunities for dissemination and benefits not geographically restricted. VNDBI could make it possible to advance the opportunities in evaluating the accuracy of intervention techniques and measurement, providing the research field with new knowledge in decomposing the intervention packages in the most effective formats. We encourage researchers to embrace the technology's innovative possibilities to further develop and improve rigorous and accessible intervention tools for individuals with autism and other developmental conditions that might benefit from it.

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Anders Dechsling: Conceptualization, Methodology, Formal analysis, Investigation, Writing - original draft, Visualization.

Frederick Shic: Writing - original draft, Writing - review & editing. **Dajie Zhang:** Writing - review & editing. **Peter B. Marschik:** Methodology, Writing - review & editing. **Gianluca Esposito:** Methodology, Writing - review & editing. **Stian Orm:** Formal analysis, Investigation, Writing - review & editing. **Stefan Sütterlin:** Methodology, Writing - review & editing, Supervision. **Tamara Kalandadze:** Writing - review & editing. **Roald A. Øien:** Writing - review & editing. **Anders Nordahl-Hansen:** Conceptualization, Methodology, Writing - original draft, Supervision, Project administration.

References

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders (DSM-5)*. American Psychiatric Publishing.

Beach, J., & Wendt, J. (2016). Using virtual reality to help students with social interaction skills. *Journal of the International Association of Special Education, 16*(1), 26–33.

Bradley, R., & Newbutt, N. (2018). Autism and virtual reality head-mounted displays: A state of the art systematic review. *Journal of Enabling Technologies, 12*(3), 101–113. https://doi.org/10.1108/JET-01-2018-0004.

Carruthers, S., Pickles, A., Slonims, V., Howlin, P., & Charman, T. (2020). Beyond intervention into daily life: A systematic review of generalisation following social communication interventions for young children with autism. *Autism Research, 13*(4), 506–522. https://doi.org/10.1002/aur.2264.

Cheng, Y., Huang, C.-L., & Yang, C.-S. (2015). Using a 3D immersive virtual environment system to enhance social understanding and social skills for children with autism spectrum disorders. *Focus on Autism and Other Developmental Disabilities, 30*(4), 222–236. https://doi.org/10.1177/1088357615583473.

Cohen, J. (1960). A coefficient of agreement for nominal scales. *Educational and Psychological Measurement, 20*(1), 37–46. https://doi.org/10.1177/001316446002000104.

Cooper, H. M., Hedges, L. V., & Valentine, J. C. (Eds.). (2019). *The handbook of research synthesis and meta-analysis* (3rd ed.). New York: The Russel Sage Foundation.

Dawson, G., Rogers, S., Munson, J., Smith, M., Winter, J., Greenson, J., et al. (2010). Randomized, controlled trial of an intervention for toddlers with autism: The Early Start Denver Model. *Pediatrics, 125*(1), e17–e23. https://doi.org/10.1542/peds.2009-0958.

De Luca, R., Leonardi, S., Portaro, S., Le Cause, M., De Domenico, C., Colucci, P. V., et al. (2019). Innovative use of virtual reality in autism spectrum disorder: A case-study. *Applied Neuropsychology Child*. https://doi.org/10.1080/21622965.2019.1610964.

Dechsling, A., Sütterlin, S., & Nordahl-Hansen, A. (2020). Acceptability and normative considerations in research on autism spectrum disorders and virtual reality. In D. Schmorrow, & C. Fidopiastis (Eds.), *Augmented cognition. Human cognition and behavior. HCII 2020. Lecture notes in computer science* (p. 12197). Cham: Springer. https://doi.org/10.1007/978-3-030-50439-7_11.

Didehbani, N., Allen, T., Kandalaft, M., Krawczyk, D., & Chapman, S. (2016). Virtual Reality Social Cognition training for children with high functioning autism. *Computers in Human Behavior, 62*, 703–711. https://doi.org/10.1016/j.chb.2016.04.033.

Gillespie-Lynch, K., Kapp, S. K., Brooks, P. J., Pickens, J., & Schwartzman, B. (2017). Whose expertise is it? Evidence for autistic adults as critical autism experts. *Frontiers in Psychology, 8*. https://doi.org/10.3389/fpsyg.2017.00438.

Gough, D., Oliver, S., & Thomas, J. (2017). *An introduction to systematic reviews*. Sage.

Green, J., & Garg, S. (2018). Annual Research Review: The state of autism intervention science: Progress, target psychological and biological mechanisms and future prospects. *Journal of Child Psychology and Psychiatry, 59*(4), 424–443. https://doi.org/10.1111/jcpp.12892.

Halabi, O., El-Seoud, S. A., Alja'am, J. M., Alpona, H., Al-Hemadi, M., & Al-Hassan, D. (2017). Design of immersive virtual reality system to improve communication skills in individuals with autism. *International Journal of Emerging Technologies in Learning, 12*(5), 50–64. https://doi.org/10.3991/ijet.v12i05.6766.

Howard, M. C., & Gutworth, M. B. (2020). A meta-analysis of virtual reality training programs for social skill development. *Computers & Education, 144*. https://doi.org/10.1016/j.compedu.2019.103707.

Ip, H. H. S., Wong, S. W. L., Chan, D. F. Y., Byrne, J., Li, C., Yuan, V. S. N., et al. (2018). Enhance emotional and social adaptation skills for children with autism spectrum disorder: A virtual reality enabled approach. *Computers & Education, 117*, 1–15. https://doi.org/10.1016/j.compedu.2017.09.010.

Jung, K.-E., Lee, H.-J., Lee, Y.-S., Cheong, S.-S., Choi, M.-Y., Suh, D.-S., et al. (2006). The application of a sensory integration treatment based on virtual reality-tangible interaction for children with autistic spectrum disorder. *PsychNology Journal, 4*(2), 145–159. https://doi.org/10.1037/e695432011-076.

Kapp, S. K., Gillespie-Lynch, K., Sherman, L. E., & Hutman, T. (2013). Deficit, difference, or both? Autism and neurodiversity. *Developmental Psychology, 49*(1), 59–71. https://doi.org/10.1037/a0028353.

Kasari, C., Freeman, S., & Paparella, T. (2006). Joint attention and symbolic play in young children with autism: A randomized controlled intervention study. *Journal of Child Psychology and Psychiatry, 47*(6), 611–620. https://doi.org/10.1111/j.1469-7610.2005.01567.x.

Koegel, L. K., Koegel, R. L., Harrower, J. K., & Carter, C. M. (1999). Pivotal response intervention I: Overview of approach. *Journal of the Association for Persons with Severe Handicaps, 24*(3), 174–185. https://doi.org/10.2511/rpsd.24.3.174.

Lang, R., O'Reilly, M. F., Sigafoos, J., Machalicek, W., Rispoli, M., Shogren, K., et al. (2010). Review of teacher involvement in the applied intervention research for children with autism Spectrum disorders. *Education and Training in Autism and Developmental Disabilities, 45*(2), 268–283. https://www.jstor.org/stable/23879811.

Liu, R. P., Salisbury, J. P., Vahabzadeh, A., & Sahin, N. T. (2017). Feasibility of an autism-focused augmented reality smartglasses system for social communication and behavioral coaching. *Frontiers in Pediatrics, 5*. https://doi.org/10.3389/fped.2017.00145.

Lord, C., Brugha, T. S., Charman, T., Cusack, J., Dumas, G., Frazier, T., et al. (2020). Autism spectrum disorder. *Nature Reviews Disease Primers, 6*(1), 1–23. https://doi.org/10.1038/s41572-019-0138-4.

Lorenzo, G., Pomares, J., & Lledo, A. (2013). Inclusion of immersive virtual learning environments and visual control systems to support the learning of students with Asperger syndrome. *Computers & Education, 62*, 88–101. https://doi.org/10.1016/j.compedu.2012.10.028.

Lorenzo, G., Lledo, A., Pomares, J., & Roig, R. (2016). Design and application of an immersive virtual reality system to enhance emotional skills for children with autism spectrum disorders. *Computers & Education, 98*, 192–205. https://doi.org/10.1016/j.compedu.2016.03.018.

Malihi, M., Nguyen, J., Cardy, R. E., Eldon, S., Petta, C., & Kushki, A. (2020). Short report: Evaluating the safety and usability of head-mounted virtual reality compared to monitor-displayed video for children with autism spectrum disorder. *Autism, 24*(7), 1924–1929. https://doi.org/10.1177/1362361320934214.

Masten, A. S., & Cicchetti, D. (2010). Developmental cascades. *Development and Psychopathology, 22*(3), 491–495. https://doi.org/10.1017/S0954579410000222.

Max, M. L., & Burke, J. C. (1997). Virtual reality for autism communication and education, with lessons for medical training simulators. *Studies in Health Technology and Informatics, 39*, 46–53. https://doi.org/10.1037/e705192011-005.

Maye, M., Sanchez, V. E., Stone-MacDonald, A., & Carter, A. S. (2020). Early Interventionists' Appraisals of Intervention Strategies for Toddlers with Autism Spectrum Disorder and Their Peers in Inclusive Childcare Classrooms. *Journal of Autism and Developmental Disorders, 50*(11), 4199–4208. https://doi.org/10.1007/s10803-020-04456-w.

Miller, H. L., & Bugnariu, N. L. (2016). Level of immersion in virtual environments impacts the ability to assess and teach social skills in autism spectrum disorder. *Cyberpsychology, Behavior and Social Networking, 19*, 246–256. https://doi.org/10.1089/cyber.2014.0682.

Miller, I. T., Wiederhold, B. K., Miller, C. S., & Wiederhold, M. D. (2020). Virtual reality air travel training with children on the autism Spectrum: A preliminary report. *Cyberpsychology, Behavior and Social Networking, 23*(1), 10–15. https://doi.org/10.1089/cyber.2019.0093.

Minjarez, M. B., Bruinsma, Y., & Stahmer, A. C. (2020). Considering NDBI models. In Y. Bruinsma, M. B. Minjarez, L. Schreibman, & A. C. Stahmer (Eds.), *Naturalistic developmental behavioral interventions for autism spectrum disorder* (pp. 21–42). Paul H. Brookes Publishing Co.

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & The PRISMA Group. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *PLoS Medicine, 6*(7). https://doi.org/10.1371/journal.pmed.1000097.

National Institute for Health and Care Excellence. (2013). *Autism spectrum disorder in under 19s: Support and management* [Clinical guideline CG170] https://www.nice.org.uk/guidance/cg170/resources/autism-spectrum-disorder-in-under-19s-support-and-management-pdf-35109745515205.

Newbutt, N., Bradley, R., & Conley, I. (2020). Using virtual reality head-mounted displays in schools with autistic children: Views, experiences, and future directions. *Cyberpsychology, Behavior and Social Networking, 23*(1), 23–33. https://doi.org/10.1089/cyber.2019.0206.

Newbutt, N., Sung, C., Kuo, H., & Leahy, M. J. (2016). The potential of virtual reality technologies to support people with an autism condition: A case study of acceptance, presence and negative effects. *Annual Review of Cybertherapy and Telemedicine, 14*, 149–154.

Nordahl-Hansen, A., Dechsling, A., Sütterlin, S., Børtveit, L., Zhang, D., Øien, R. A., et al. (2020). An overview of virtual reality interventions for two neurodevelopmental disorders: Intellectual disabilities and autism. In D. Schmorrow, & C. Fidopiastis (Eds.), *Augmented cognition. Human cognition and behavior. HCII 2020. Lecture notes in computer science* (vol. 12197). Cham: Springer. https://doi.org/10.1007/978-3-030-50439-7_17.

Nordahl-Hansen, A., Fletcher-Watson, S., McConachie, H., & Kaale, A. (2016). Relations between specific and global outcome measures in a social-communication intervention for children with autism spectrum disorder. *Research in Autism Spectrum Disorders, 29–30*, 19–29. https://doi.org/10.1016/j.rasd.2016.05.005.

Ouzzani, M., Hammady, H., Fedorowicz, Z., & Elmagarmid, A. (2016). Rayyan — a web and mobile app for systematic reviews. *Systematic Reviews, 5*(210). https://doi.org/10.1186/s13643-016-0384-4.

Putnam, C., Hanschke, C., Todd, J., Gemmell, J., & Kollia, M. (2019). Interactive technologies designed for children with autism: Reports of use and desires from parents, teachers, and therapists. *ACM Transactions on Accessible Computing, 12*(3), 1–37. https://doi.org/10.1145/3342285.

Ravindran, V., Osgood, M., Sazawal, V., Solorzano, R., & Turnacioglu, S. (2019). Virtual reality support for joint attention using the floreo joint attention module: Usability and feasibility pilot study. *JMIR Pediatrics and Parenting, 2*(2). https://doi.org/10.2196/14429.

Sandbank, M., Bottema-Beutel, K., Crowley, S., Cassidy, M., Dunham, K., Feldman, J. I., et al. (2020). Project AIM: Autism intervention meta-analysis for studies of young children. *Psychological Bulletin, 146*(1), 1–29. https://doi.org/10.1037/bul0000215.

Schreibman, L., Dawson, G., Stahmer, A. C., Landa, R., Rogers, S. J., McGee, G. G., et al. (2015). Naturalistic developmental behavioral interventions: Empirically validated treatments for autism Spectrum disorder. *Journal of Autism and Developmental Disorders, 45*(8), 2411–2428. https://doi.org/10.1007/s10803-015-2407-8.

Shadish, W. R. (2014). Analysis and meta-analysis of single-case designs: An introduction. *Journal of School Psychology, 52*(2), 109–122. https://doi.org/10.1016/j.jsp.2013.11.009.

Shic, F., Dommer, K. J., Atyabi, A., Mademtzi, M., Øien, R. A., Kientz, J. A., et al. (2019). Advancing technology to meet the needs of young children with ASD: Considerations for infants and toddlers. In K. Chawarska, & F. R. Volkmar (Eds.), *Advances in research on infants with autism spectrum disorder*. Guilford Press.

Shire, S. Y., Baker Worthman, L., Shih, W., & Kasari, C. (2020). Comparison of face-to-face and remote support for interventionists learning to deliver JASPER intervention with children who have autism. *Journal of Behavioral Education, 29*(2), 317–338. https://doi.org/10.1007/s10864-020-09376-4.

Tiede, G., & Walton, K. M. (2019). Meta-analysis of naturalistic developmental behavioral interventions for young children with autism spectrum disorder. *Autism, 23*(8), 2080–2095. https://doi.org/10.1177/1362361319836371.

Uzuegbunam, N., Wong, W. H., Cheung, S. C. S., & Ruble, L. (2018). MEBook: Multimedia social greetings intervention for children with autism Spectrum disorders. *IEEE Transactions on Learning Technologies, 11*(4), 520–535. https://doi.org/10.1109/TLT.2017.2772255.

Vahabzadeh, A., Keshav, N. U., Abdus-Sabur, R., Huey, K., Liu, R. P., & Sahin, N. T. (2018). Improved socio-emotional and behavioral functioning in students with autism following school-based smartglasses intervention: Multi-stage feasibility and controlled efficacy study. *Behavioral Sciences, 8*(10), 85. https://doi.org/10.3390/bs8100085.

Zervogianni, V., Fletcher-Watson, S., Herrera, G., Goodwin, M., Pérez-Fuster, P., Brosnan, M., & Grynszpan, O. (2020). A framework of evidence-based practice for digital support, co-developed with and for the autism community. *Autism, 24*(6), 1411–1422. https://doi.org/10.1177/1362361319898331.