Characteristics, Advantages, and Disadvantages of Extended Reality Interventions to Increase Emotion Regulation in Children with Autism Spectrum Disorder: A Scoping Review

Vanessa Schubert

Department of Positive Clinical Psychology and Technology,

Faculty of Behavioral, Management and Social Sciences (BMS),

University of Twente

Under the supervision of Dr. Tessa Dekkers and Dr. Anneke Sools

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Abstract

Background: Emotion dysregulation is a common transdiagnostic factor in children with autism that increases ASD symptoms and explains the comorbidity with anxiety disorders. Traditional treatments for emotion dysregulation demonstrate moderate to low effect sizes. Extended reality (XR)-based interventions as a new form of treatment may address the limitations of traditional treatment such as being overly didactic. This review aims to identify the characteristics, advantages, and disadvantages of extended reality interventions to increase emotion regulation in children with ASD.

Method: A scoping review was conducted and the databases *SCOPUS*, *Web of Science*, and *IEEE Xplore* were screened for articles describing interventions aimed at children with ASD and focused on VR or AR. Articles were included when the outcome measured emotion regulation, the paper was written in English, German, or Dutch, and was published in a peer-reviewed journal after 2013. Reviews were excluded.

Results: Out of 1038 identified papers, five were included for review. Results indicated that interventions varied in their characteristics, including the use of different technological equipment and variations in their duration. However, advantages and disadvantages were similar across interventions. All interventions named safe and controlled exposure as the main advantage of XR approaches. No disadvantages were found.

Conclusion: Due to the major advantage of providing children with a safe and engaging environment to face their fears, XR-based interventions demonstrate high potential to treat emotion dysregulation, if disadvantages are identified and taken into account and more research is conducted to establish effective interventions.

Keywords: Autism spectrum disorder, ASD, children, emotion regulation, virtual reality, augmented reality, extended reality

Introduction

Autism spectrum disorder (ASD) is a neurodevelopmental disorder that emerges in childhood and "is characterized by deficits in social communication and the presence of restricted interests and repetitive behaviors" (Hodges et al., 2020, p. 55). Although ASD manifests differently in each individual, children with ASD tend to be withdrawn, struggle with emotion regulation, and demonstrate limited speech abilities. Furthermore, they display repetitive behaviors, such as hand flapping or rocking, and demonstrate slower cognitive development compared to neurotypical children (Luciano, 2016). There are different treatment options available for children with ASD. This review will focus on extended reality interventions that aim to increase emotion regulation in children with ASD, as a way to treat ASD and anxiety transdiagnostically.

More explicitly, ASD has been shown to have a high comorbidity with anxiety disorders. Approximately every second child with autism suffers from comorbid clinical anxiety, mainly specific phobia, obsessive-compulsive disorder, and social anxiety (Vasa & Mazurek, 2015). Researchers have found that anxiety symptoms in children with ASD are often challenging to distinguish from typical ASD symptoms. In many cases, anxiety symptoms can manifest as intensified ASD symptoms. For example, children who experience both ASD and anxiety tend to exhibit heightened levels of anger and nervousness. They also frequently avoid social situations, unlike children with ASD who do not experience anxiety (Beck et al., 2020).

The high comorbidity rates between the disorders can to some extent be explained by transdiagnostic mechanisms. These mechanisms are factors that are present across multiple disorders and contribute to the maintenance or onset of a disorder (Lynch et al., 2021). In other words, in transdiagnostic research, disorders are not viewed as distinct and separate entities but rather as potentially explained by a shared underlying mechanism (Krueger &

Eaton, 2015). Given the high comorbidity between ASD and anxiety, it is crucial to examine underlying factors that may explain this comorbidity. More specifically, Krueger and Eaton (2015) stress the importance of paying attention to these factors since they are essential in explaining why certain disorders persist. The researchers even suggest that prioritizing transdiagnostic factors is essential in developing effective interventions. Hence, taking a transdiagnostic approach in therapy might allow for addressing the core mechanisms of multiple comorbid disorders simultaneously.

Emotion Dysregulation as a Transdiagnostic Factor in ASD and Anxiety

One major transdiagnostic factor that has been linked to comorbid anxiety and ASD in children is emotion dysregulation. Emotion dysregulation refers to “the inability to adjust or control one’s emotions” and mainly manifests as meltdowns, aggressive behavior, and self-injury in children with ASD (Vasa & Mazurek, 2015, p. 4; Mazefsky et al., 2013). This is likely due to the inherent difficulty that children with ASD have in verbally expressing their emotions, which often results in physical outbursts (Mazefsky, et al., 2013). Furthermore, other symptoms common in ASD, such as hypersensitivity, lack of perspective taking, and delayed information processing, also interfere with emotion regulation and often lead to intense tantrums and emotional reactions (Mazefsky, et al., 2013).

Researchers found that emotion regulation impairments seem to be a significant factor that can increase the likelihood of developing an anxiety disorder among children with ASD (Beck et al., 2020). More specifically, the above-mentioned symptoms related to ASD decrease the ability to regulate one’s emotions, which subsequently can lead to the development of anxiety (Mazefsky & Herrington, 2014). For instance, children with ASD who have difficulties to verbalize their emotions might consequently be unable to regulate their emotional responses, since they cannot explain to others how they feel. This suppression of emotions and the low tolerance of stressful situations can then be a precursor for developing an anxiety disorder (Mazefsky & Herrington, 2014).

Due to emotion dysregulation being an important transdiagnostic factor linking ASD and anxiety, treatment programs should focus on increasing emotion regulation in children with ASD to reach long-lasting and effective treatment outcomes (Mazefsky & Herrington, 2014).

Traditional Treatment Approaches

A limited number of interventions are available that aim to increase emotion regulation in children with ASD. Those interventions are typically based on traditional treatment approaches such as cognitive behavioral therapy (CBT), exposure therapy and (coping) skills training (Beck et al., 2020). In these programs, children receive psychoeducation and evaluate their negative thought patterns and triggers.

For instance, Shaffer et al. (2022) developed an intervention called *Regulating Together* to increase emotion regulation among children ages 8 to 18 with ASD. This intervention is based on CBT and includes teaching children CBT skills, mindfulness training, and homework assignments. *Regulating Together* seems to have the potential to increase emotion regulation among children with ASD. However, the results depended on the children's developmental stage and different outcomes were found for younger children and adolescents. While younger children demonstrated a higher increase in emotion regulation, older children mainly exhibited an increase in flexibility, but not emotion regulation. Furthermore, the long-term effects of *Regulating Together* still have to be studied.

In general, CBT programs designed for children with ASD tend to have low to moderate effects (Bossenbroek et al., 2020). This is likely due to CBT programs not taking the specific needs of children with ASD into account. More specifically, many children with ASD suffer from cognitive impairments which makes it difficult for them to process new information (Bossenbroek et al., 2020). However, CBT treatment is strongly based on didactic exercises and conveying theoretical concepts, which in itself tends to be a counterproductive approach for this population (Bossenbroek et al., 2020). Moreover, Bossenbroek et al. (2020) stated how the didactic nature of CBT poses a major challenge in ASD treatment since it leads to low motivation to participate among many children with ASD. For instance, a crucial part of CBT treatment involves homework assignments. However, Koegel et al. (2010) found that it is generally fairly difficult to motivate children with ASD to complete an exercise if they are not intrinsically motivated themselves.

Lastly, Bossenbroek et al. (2020) found that most programs that aim to decrease anxiety in this population provide the children with decontextualized exercises that do not accurately represent the children's real-life struggles. In other words, the children practice new skills within a setting that they usually do not deal with in reality. As a result, children find it challenging to transfer the acquired skills and apply them in real-life situations where they are needed. Due to these factors, many CBT programs aiming to increase emotion regulation among children with ASD tend to be unsustainable and yield low long-term success. This is in line with research by Weston et al (2016) who reviewed 47 studies on the effectiveness of CBT treatment to treat anxiety and ASD symptoms within the ASD population. 17 of those studies were aimed at children with ASD and the researchers found low to moderate effect sizes for these interventions. Therefore, due to the afore-mentioned reasons, ASD treatment needs to better fit the children's needs and abilities.

Extended Reality-Based Treatment Approaches

One way to tackle the aforementioned limitations of CBT treatment is to incorporate technology-based interventions to increase emotion regulation. In the past few years, researchers have been especially interested in extended reality interventions. Extended reality is an umbrella term that comprises virtual reality (VR), augmented reality (AR), and mixed reality (Vasarainen et al., 2021). This review will solely focus on VR and AR as part of extended reality.

Virtual reality interventions are based on fictional environments and typically involve the use of a head-mounted display that projects the participant into a virtual but highly immersive and realistic environment. The environment can be chosen by a professional and provides the participant with the opportunity to engage and experience a real-life situation that is fictional (Sze & Horace, 2018). VR-based interventions are becoming increasingly more popular for treatments targeting children with ASD. This is mainly due to its potential to significantly increase the motivation of children to participate in treatment as well as help them to practice a specific skill in a fun and immersive way (Karami et al., 2021).

For instance, Bossenbroek et al. (2020) developed a VR biofeedback game called *DEEP* to reduce anxiety in children with autism by increasing their emotion regulation skills. Thereby, the researchers developed a VR environment that taught the children diaphragmatic breathing techniques, which is a skill that can increase interoceptive awareness and consequently, emotion regulation. In *DEEP*, the children were asked to explore an underwater fantasy world in which their movement was controlled by slow breathing. Results indicated that daily anxiety levels decreased for most participants and lasted for around two hours after the intervention. Bossenbroek et al. (2020) suggested that the children learned how to control their breathing patterns, which in turn, allowed them to regulate their breathing during emotionally-charged situations in real-life. Consequently, the children learned a versatile self-regulation tool which they can apply in situations that are stressful or overwhelming.

Contrary to virtual reality, augmented reality works primarily with real-life settings instead of fully virtual environments. More explicitly, in AR, individuals experience the real-world with an addition of computer-generated add-ons. The interactive digital content is placed on top of what a person views and aims to highlight specific elements to help people analyze their environment (Vasarainen et al., 2021). Depending on the target group, different elements can be enhanced. For instance, AR is used to help children with ASD in recognizing the emotions of other people (Wedyan et al., 2021). Since many children with ASD struggle with emotion recognition, digital add-ons (e.g. in form of emojis) can help these children to recognize what others might feel in a given moment. Moreover, Wedyan et al. (2021) found that AR technology can help to reduce symptoms of anxiety in this population by providing them with a safe environment to practice those skills.

Although these technologies are on the rise, the development of extended reality interventions is still in its early stages. This is especially the case for interventions that target emotion regulation among children with ASD. Even though there are studies that evaluate XR interventions for individuals with ASD, there are none that specifically look at increasing emotion regulation using XR within this population (Karami et al., 2022). As this is a relatively underexplored research area, further studies are necessary to optimize XR interventions like the DEEP game and develop evidence-based XR treatment programs. Furthermore, it should be explored if and how the aforementioned advantages of XR-based interventions emerge in clinical practice.

The Current Study

Based on the effect emotion dysregulation has on the development of comorbid disorders within the ASD population as well as the potential extended reality interventions have, this review aims to answer the following research question: What are the characteristics, advantages, and disadvantages of VR and AR interventions to increase emotion regulation among children with autism spectrum disorder? With this research question, this study aims to map out the existing literature on the topic and provide recommendations for future research and clinical practice.

Method

Study Design

This study constituted of a scoping review as the objective was to map out the existing literature on VR and AR interventions that aim to increase emotion regulation among children with ASD. The review followed *PRISMA* guidelines for writing literature reviews to ensure transparent and replicable reporting (Rethlefsen et al., 2021).

Eligibility Criteria

A number of eligibility criteria were formulated by the researcher in order to narrow down the literature search to the most relevant articles to answer the research question.

PICO Framework

In order to systematically identify important eligibility criteria, the *PICO* framework was used (Eriksen & Frandsen, 2018). The *PICO* framework is a commonly-used model that helps researchers to specify their research question(s) based on the following four categories: Population (P), Intervention (I), Comparison (C), and Outcome (O). Within this study, the population was defined as children between the ages of zero and 18 who received a clinical diagnosis for autism spectrum disorder. The interventions had to be either VR- or AR-based. Next, the comparison variable was not defined since it was irrelevant for answering the research question. Lastly, the outcome of the interventions had to evaluate emotion regulation in the children after participating in the intervention. The aforementioned variables were used as inclusion criteria in the current study and needed to be fulfilled for a study to be included in the scoping review.

Using the *PICO* model, relevant search terms were identified to find eligible articles. The search terms were chosen based on the electronic databases' suggested mesh terms as well as by identifying repeated mentions of specific key terms across literature. The identified search terms that were used for the literature search can be found below (see *table 1*).

Additional Inclusion and Exclusion Criteria

Besides the above-mentioned inclusion criteria within the *PICO* framework, additional eligibility criteria were formulated by the researcher to narrow down the literature search further. The studies had to be written in English, Dutch, or German. Furthermore, they had to be published in a peer-reviewed journal. Excluded were literature reviews as well as articles that were published before 2013 in order to focus on the most recent technological advances.

Table 1.

Pool of Search Terms Used for Creating Search Strings Organized in PICO Categories.

Population (P)	**Intervention (I)**	**Outcome (O)**
Autism spectrum disorder	Virtual reality	Emotion regulation
ASD	VR	Emotional regulation
Autism	Augmented reality	Self-regulation
Autistic	AR	Dysregulation
Children	E-health	Co-regulation
Adolescents	Technology	
Youths	Extended reality	

Based on the above-mentioned key terms, three search strings were created to search the electronic databases *SCOPUS*, *Web of Science*, and *IEEE Xplore* for literature (see *Appendix 1*).

Information Sources and Search Strategy

In order to find relevant articles, the databases *SCOPUS*, *Web of Science*, and *IEEE Xplore* were selected. These databases were chosen because they cover a wide range of psychology-related articles as well as focus on recent technological advances. The three databases were searched by the researcher between February and May 2023. After the search was completed, the online software *Covidence* was used, which is a tool that facilitates and helps researchers to keep record of the article screening and data extraction process (Kellermeyer, et al., 2018). The articles were exported from each database and imported into *Covidence*, where they were screened on a title and abstract, and subsequently, full-text basis. This way, the data extraction process was documented entirely, which increased transparency and enabled future replication.

Risk of Bias Assessment

Since this study was a scoping review, the risk of bias was not assessed. The focus of this study was on providing an overview of the existing literature on the given topic and not on assessing the effectiveness or methodological limitations of the included studies. Thus, assessing the risk of bias was not essential (Munn et al., 2018).

Synthesis of Results

The results were synthesized by taking a thematic analysis approach and extracting data by organizing them into themes. This way, information could be extracted systematically in order to answer the research question. More specifically, the three main themes (characteristics, advantages, and disadvantages) were derived from the research question and functioned as the basis for the data extraction process. Subsequently, the extracted data was presented in form of tables (see *table 2* to *4*) as well as synthesized in text-form.

Results

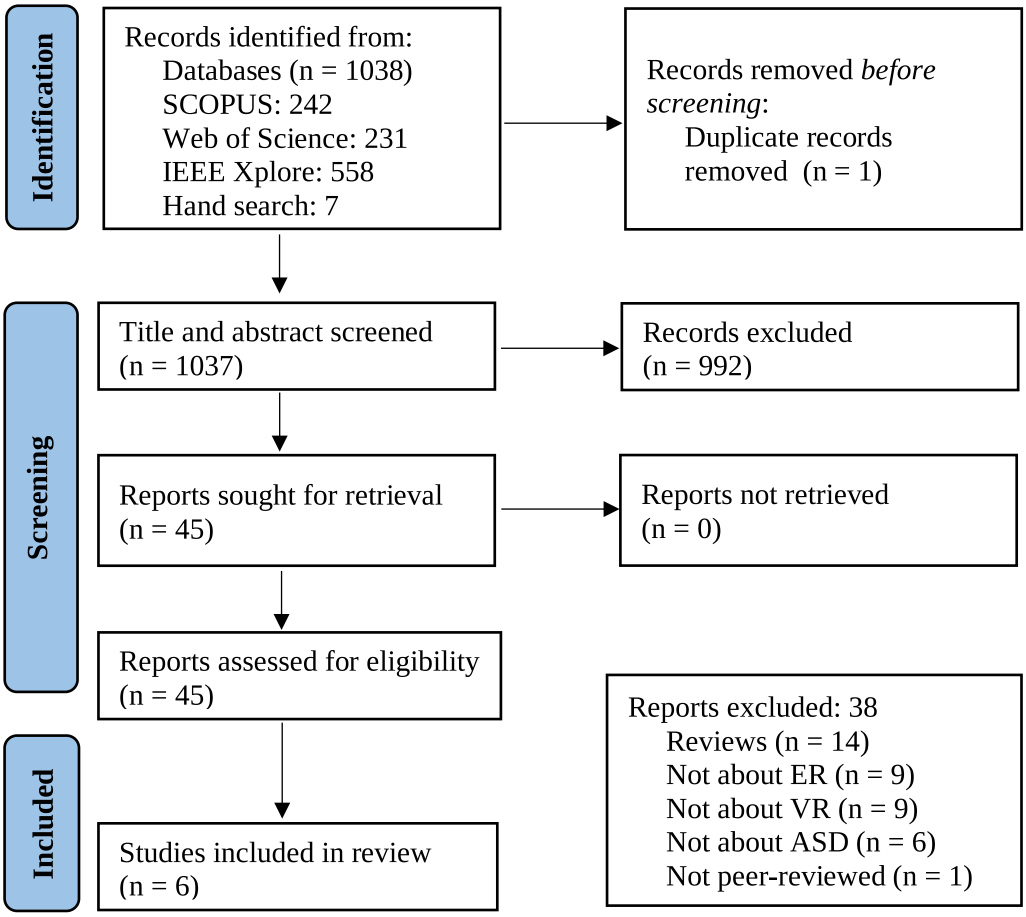
Study Selection Process

An initial screening of the most relevant electronic databases using the identified search strings yielded 1038 hits in total. Out of these 1038 hits, 242 were found on *SCOPUS*, 231 on *Web of Science*, and 558 on *IEEE Xplore*. An addition of seven articles were identified by the researcher through handsearching the references of relevant literature reviews in the research field. Next, the above-mentioned articles were exported from each database in RIS format and imported into the online software *Covidence*.

Within *Covidence*, the records were first scanned for duplicates and consequently, one duplicate was removed, resulting in a total of 1037 articles. Afterwards, the title and abstract of these articles were screened for relevance by the researcher. If they fulfilled the eligibility criteria, they were moved to the full-text review stage. If they did not, they were excluded and removed. In total, 992 records were excluded, and 45 records remained to be assessed on a full-text basis. Out of 45 records, 38 had to be removed due to various reasons which can be found in the figure below (see *figure 1*). The most common reasons for exclusion were that the studies consisted of literature reviews or that they did not have a focus on either emotion regulation or virtual reality. This left a total of six papers that fulfilled all criteria and that were included in the current scoping review. The screening and data extraction process was conducted independently by the researcher but was supervised by the supervisor. The *PRISMA* flow chart summarizing the screening process can be found below (see *figure 1*).

Figure 1

PRISMA flow chart of the literature screening process



Initially, six studies were included in the current scoping review. Since two articles contained information about the same study, they were treated as one and solely Ip and colleagues' (2018) paper was used for data extraction (Ip, et al., 2018; Yuan & Ip, 2018). Thus, a total of five studies were eventually used for the scoping review. The data extraction was divided into three categories, starting with general information about the studies (*table 2*), following with data about the interventions' characteristics (*table 3*), and lastly, summarizing the interventions' advantages, disadvantages, and the participants' reactions to the interventions (*table 4*).

Table 2.

General Information About the Included Studies.

Author(s)	Year	Title	Country of origin	Study design	Study population	Aim of the study	Outcomes/ Significant findings
Bossenbroek et al.	2020	Efficacy of a Virtual Reality Biofeedback Game (*DEEP*) to Reduce Anxiety and Disruptive Classroom Behavior: Single-Case Study	Netherlands	Single-case study	Eight Dutch adolescents between 12 and 17 years old; seven boys, one girl; attended secondary special school; all received a diagnosis for ASD and/or ADHD	To test the effectiveness of the VR biofeedback game *DEEP* to reduce anxiety + disruptive classroom behavior in children with ASD and increase emotion regulation skills	Significant reduction in anxiety levels and disruptive classroom behavior; children experienced a calm state for 2 hours after intervention + were able to apply skills outside of VR environment
Ip et al. [a]	2018	Enhance Emotional And Social Adaptation Skills For Children With Autism Spectrum Disorder: A Virtual Reality Enabled Approach	Hong Kong	Experiment	94 Chinese children between 6 and 12 years old; 86 boys, 8 girls; all received a clinical diagnosis of ASD	To test a VR-enabled training program to enhance emotional and social adaptation skills in children with ASD	Significant improvements in emotion expression, regulation, and social-emotional reciprocity
Liu et al.	2017	Feasibility of an Autism-Focused Augmented Reality Smartglasses System for Social communication and Behavioral coaching	USA	Feasibility study	Two American boys; eight and nine years old; both received a clinical diagnosis of ASD	To test the feasibility of AR smart glasses in aiding children in improving their social communication and behavioral skills (such as self-regulation)	Significant reduction of ASD symptoms 24 hours after intervention, improved non-verbal communication, and social engagement

Table 2 continued.

Author(s)	Year	Title	Country of origin	Study Design	Study population	Aim of the study	Outcomes/ significant findings
Lorenzo et al.	2016	Design and Application of an Immersive Virtual Reality System to Enhance Emotional Skills for Children with Autism Spectrum Disorders	Spain	Quasi experiment	40 children between 7 and 12 years old; 29 boys, 11 girls; all received a clinical diagnosis of ASD	To propose the design and application of an immersive virtual reality system to improve and train the emotional skills of students with autism	Significant improvement in the children's emotional competences; increase in appropriate emotional behaviors in VR environment and real-life; outcomes are higher in experimental group than in control group
Romero-Ayuso et al.	2020	Self-regulation in Children with Neurodevelopmental Disorders "SR-MRehab: Un Colegio Emocionante": A Protocol Study	Spain	Protocol study of a randomized controlled trial	(Planned, not carried out yet): Children between 6 and 11 years who are diagnosed with neurodevelopmental disorders (ASD and/or ADHD)	To test a non-immersive virtual reality system that aims to improve self-regulation skills in children with neurodevelopmental disorders	No results are available yet; primary outcomes tested will be emotional perception and emotional regulation

a. Ip and colleagues (2018) have used the same intervention as Yuan and colleagues (2018). This intervention is reported here once.

Table 3.

Intervention Characteristics of the Included Studies.

Author(s)	VR Environment	Fiction or Non-Fiction?	Avatars Present?	Interactivity?	Level of Immersion	Gamified Elements?	Length of VRI/ARI	Technologies used	Underlying Mechanism
Bossenbroek et al.	Serious game consisted of an underwater fantasy world in which movement was controlled by slow breathing; included meditative features	Fiction	No	Yes (Participants' breathing was synchronized with the movement of plants in the underwater fantasy world)	High	Yes (Exploration game; no goals within the game)	Six sessions a 45 minutes for four weeks	VR headset + breathing belt with stretch sensors measuring diaphragmatic breathing	Breathing/ relaxation
Ip et al.	VRI included 6 learning scenarios that represented a typical school day of a child in Hong Kong, in which children could practice social skills; one learning scenario focused specifically on emotion control/regulation and relaxation strategies	Non-Fiction	Yes	Yes (Participants interacted with objects and avatars)	High	Yes (Game-based learning scenarios increasing in difficulty)	28 sessions for 14 weeks	4-side immersive virtual reality environment (half-CAVE), non-intrusive motion tracking, head-mounted display	Exposure/ relaxation
Liu et al.	Two serious games (*Face Game*, *Emotion Game*) that helped children to recognize emotions and overcome their fear of eye contact through exposure, virtual add-ons (e.g. emojis), and rewards	Non-Fiction	No	Yes (Participants interacted with real human beings)	Low	Yes (Two games are played that use emojis, cartoons, and rewards)	One single (trial) session	Augmented reality smart-glass-system (called Brain Power System) AR smart glasses, and two AI-based game apps	Exposure

Table 3 continued.

Author(s)	VR Environment	Fiction or Non-Fiction?	Avatars Present?	Interactivity?	Level of Immersion	Gamified Elements?	Length of VRI/ARI	Technologies used	Underlying Mechanism
Lorenzo et al.	Children were presented with 10 social situations and the corresponding appropriate behavior (e.g. playground or birthday party settings)	Non-Fiction	Yes	Yes (Participants interacted with avatars)	High	Yes (Gamified learning scenarios, use of rewards and positive reinforcement)	40 sessions a 35 minutes; once per week	Immersive Virtual Reality System (IVRS) in form of a semi cave and a robot with an eye-in-hand camera system to track emotional responses of the children in real-time	Exposure
Romero-Ayuso et al.	Children will engage with stories or games in which they work on emotion or cognitive regulation; children can engage with virtual objects by using their hands	Non-Fiction	Yes	Yes (Participants will interact with avatars and virtual objects)	High	Yes (Perspective games, guessing games, games with social stories)	10 sessions a 50 minutes; once a week; follow up six months post study	Non-immersive virtual reality system, computer, Kinect motion sensor to control body movements	Exposure

Note. CAVE = Cave automatic virtual environment, VRI = virtual reality intervention, ARI = augmented reality intervention

Table 4.

Advantages, Disadvantages, and Reactions of the Children to the VRIs of Included Studies.

Author(s)	Advantages	Disadvantages	Children's Reactions
Bossenbroek et al.	VRI was developed to increase motivation to participate among children; generalizability of learned skills; children were able to use skills outside of the VR environment; provided a safe and controlled environment to practice ER skills	Not discussed by the authors	All children participated and followed through with the treatment; no drop outs; one child mentioned that she was able to use learned skills to calm down during an exam
Ip et al.	High generalizability to real-world scenarios; VRE represented real-life situations of children in Hong Kong; provided a safe environment to practice ER skills; scenarios could be controlled and individualized for each child's needs; post-assessment was conducted under real-life conditions, suggesting generalizability of skills	Not discussed by the authors	Positive feedback was received from the children and caregivers; no drop outs
Liu et al.	Uses affordable materials; more easily accessible compared to VR interventions; uses real settings instead of virtual/ unrealistic environments; might be more applicable to reality; children enjoyed the intervention	Not discussed by the authors	Children mentioned that the intervention was engaging and fun; they tolerated the smart glasses well

Table 4 continued.

Author(s)	Advantages	Disadvantages	Children's Reactions
Lorenzo et al.	Social situations are designed based on real situations where the students have shown difficulties; thus, high generalizability to real-life; high degree of interactivity; gamified scenarios are engaging and speak to the children's needs	Not discussed by the authors	No available data
Romero-Ayuso et al.	Generalizability to real-life situations; researchers chose scenarios that are as natural as possible + ended sessions with asking the children how they can apply the learned skills in real-life; technology chosen is non-immersive and thus, more likely to be accepted by all children; technology is comparably low in cost, which increases accessibility	Not discussed by the authors	No available data

Article Characteristics

All five articles were published between 2016 and 2020. Two studies were conducted in Spain and three in the Netherlands, United States, and Hong Kong respectively. Furthermore, all five articles were intervention studies, consisting of either a single-case study, an experiment, a feasibility study, a quasi-experiment, or a protocol study of a randomized controlled trial. As of now, four of these studies have been fully carried out while one study still needs to be tested on children (Romero-Ayuso et al., 2020). The data collection was supposed to be carried out between January and April 2021, but due to the COVID-19 pandemic, it has been postponed until further notice. More detailed information about the article characteristics can be found in *Table 2* and *3*.

Characteristics of the Interventions

All five interventions were aimed at children who received a clinical diagnosis of autism spectrum disorder and a total of 144 children with ASD between the ages six and 17 participated in the interventions. Out of the 144 children, 124 were boys and 20 were girls. One study is still ought to test their intervention on children with ASD and hence, were not included in the total participant number.

Furthermore, four interventions were VR-based and one was AR-based. The main aim of the interventions was to test a form of VR intervention (VRI) or AR intervention (ARI) to increase emotion regulation skills in children with ASD. This was achieved by either exposing the children to a fictional, non-fictional, or real-life scenario. In fact, three VR interventions used non-fictional environments that were developed to be as close to reality as possible. For instance, Ip et al. (2018) developed a VRI that represented a Chinese child's school day as accurately as possible. Other VR environments included birthday parties or classroom settings (see *Figure 2*). On the other hand, Bossenbroek et al. (2020) worked with an entirely fictional VR environment and exposed children to an underwater fantasy world that included meditative features, such as slowly moving plants (see *Figure 3*). Lastly, the ARI worked with real-life scenarios and solely used digital cues such as emojis or cartoons to enhance the learning experience.

Within the design rationale of these interventions, a number of similarities and differences were found. Firstly, all five interventions demonstrated a high level of interactivity. In four out of five studies, this was achieved by letting children interact with other avatars, virtual objects, or actual human beings. In the *DEEP* study, interactivity was achieved through biofeedback. Thus, the children's breathing patterns were synchronized with the movement of the underwater plants. This way, children were made aware of their breathing patterns and could control their own movement as well as the movement of the plants by changing their speed of breathing.

Next, all five interventions incorporated some form of gamified elements into their interventions. For instance, one intervention used guessing games, perspective games, and social story games within their VR environment. Depending on the children's age, these games were played either using puppets or role-play. In the perspective game for instance, the child and therapist would take turns describing a situation within the environment from each person's perspective. Other interventions used for example rewards or game-based learning scenarios that increased in difficulty with each scenario.

Minor differences within the design rationale were found concerning the level of immersion and the use of avatars within the environments. More specifically, all four VRIs demonstrated a high level of immersion due to the nature of the technology used. In other words, the technologies used for these interventions are designed to create high levels of immersion for the user. This was for instance achieved through the head-mounted display or the half-CAVE which separates a person from the outside world, as can be seen in *Figure 4*. The ARI on the other hand demonstrated a low level of immersion. This is due to its nature of working with real-life scenarios and not aiming to project individuals into a virtual world. Furthermore, three VRIs made use of avatars within their environments. This way, children were able to engage with other characters during the intervention. In all three interventions, the avatars represented other humans, such as classmates, teachers, or strangers. In the *DEEP* study, the participant was on his own and did not face any other virtual humans within the VR environment. For the ARI, avatars were not necessary since the intervention worked with real-life humans, such as the children's parents. Lastly, four out of five studies used exposure as the main underlying mechanism, while Bossenbroek et al. (2020) focused on diaphragmatic breathing and relaxation as their underlying mechanisms.

Concerning the types of technology that were used in the interventions, a high level of variety was found. More specifically, technological devices ranged from non-immersive AR systems to fully immersive half-CAVE environments (i.e. VR rooms in which each wall is a projection screen, creating high levels of immersion). Consequently, different types of technologies were needed depending on the intended level of immersion. While some interventions worked with computer vision systems or a head-mounted display, others required the setup of entire VR-CAVEs to create a fully immersive experience. The detailed list of technological devices used in each intervention can be found in *table 3.* Furthermore, the length of the interventions varied from one single session to a total of 40 sessions per intervention (see *Table 3* for the length of each intervention). More detailed information about the characteristics of the interventions can be found in *table 2* and *3*.

Figure 2

Virtual environment in form of a birthday party (Lorenzo et al., 2016)

Figure 3

Underwater fantasy world in the DEEP study (Bossenbroek et al., 2020)

Figure 4

Emotion control and relaxation scenario in half-Cave environment (Ip et al., 2018)

Advantages of the Interventions

Safe and Controlled Exposure

A number of advantages were found across interventions. The most frequently-mentioned advantage that was mentioned in all five articles was the ability to practice skills in a safe and controlled environment. This argument was mentioned in all papers and appears to be a major advantage of virtual reality across literature. More specifically, since multiple studies worked with social situations in which children with ASD usually feel uncomfortable, they were able to control the environment and not worry about any unpredictable events. For instance, the number of people present as well as the noise level could be controlled for to fit the children's individual needs. Thus, the children knew exactly what to expect during the interventions and could practice skills in a safe environment.

Ip et al. (2018) mentioned how this is especially beneficial if the environment represents a potentially dangerous situation, such as crossing a road, which can result in severe sensory overload for the children. Furthermore, since the situation can be practiced repeatedly in the same way, the children can learn to feel more comfortable over time since they know what to expect. Even though the AR intervention did not provide this level of control since it worked with real-life settings that are rather unpredictable, the authors argued that there was still some level of safety provided. More specifically, the children were provided with gamified cues on when to engage in eye contact with another person as well as on their emotional state. These cues were presented in form of cartoons or emojis and could help children with ASD to navigate anxiety-inducing social situations. This potentially provided the children with a sense of security and a feeling of being able to practice their social and emotional skills in a somewhat safe environment.

Generalizability to Real-Life Situations

Next, the generalizability of acquired skills to real-life situations is another advantage of using VR or AR in this population. In fact, most of the included interventions specifically paid attention to ensure the ability of transferring the skills they taught during the interventions to real-life situations. For instance, Bossenbroek et al. (2020) taught their participants diaphragmatic breathing, which once learned, could be practiced by the children in any given stressful situation. One participant mentioned that she learned to "...pay attention to my breathing more often, for example when I stress about an exam. It happened once, for an English exam. I tried to breathe in and out more deeply." (Bossenbroek et al., 2020, p. 13).

Additionally, Ip et al. (2018) developed a VR intervention where the last two scenarios were entirely constructed to test the transfer of previously-learned social and emotional skills in a different setting. These skills included for example waiting in line for one's turn or entering a full elevator. Furthermore, the post-intervention assessment was conducted in a real-life setting without using VR, to test if the children could use the skills in real-life settings. Significant improvements were found in the children's emotion expression, emotion regulation, and social-emotional reciprocity two weeks after the intervention. Similar set-ups were used in the other studies, where for instance, the researchers followed up with the children's teachers to see if the learned skills also improved in the classroom, or did a follow-up session with the participants to talk about how to transfer the acquired skills. All five studies reported that the generalizability of skills was achieved, and improvements were found in all studies on the learned skills in real-life settings.

High Motivation to Participate

Another advantage that was mentioned frequently was high levels of engagement and motivation to participate in the interventions. While there was no specific data available on the reactions of the children in two of the papers, the other three interventions received solely positive feedback from the children. In Liu et al.'s (2017) study, participants rated both the 'level of engagement with the technology' as well as the 'level of enjoyment' as "very high" (p. 4). Similar reactions were reported by Ip et al. (2018), where "a lot of positive feedback were received" and no children dropped out because they did not feel comfortable with the used technology (Ip et al., 2018, p. 11). Bossenbroek et al. (2020) and Romero-Ayuso et al. (2020) both mentioned how VR environments significantly increase children with ASD's willingness to participate since they can be programmed to take their sensory preferences into account. Furthermore, the environments could be adjusted to fit the children's needs better if necessary. In addition, none of the studies reported any dropouts due to the children's unwillingness or fear to participate. Lastly, positive feedback was also received from parents, caregivers, and teachers in some of the studies. Thus, overall, VR and AR interventions seem to be well-accepted by the ASD population.

Disadvantages of the Interventions

None of the authors mentioned any disadvantages related to their specific intervention. While they did elaborate on the benefits of their interventions and general limitations of their study designs, they did not mention any disadvantages that were specific to the interventions. Thus, no explicit disadvantages of XR interventions to increase emotion regulation in children with ASD were directly extracted from the given literature.

Discussion

This scoping review aimed to map out the existing literature on extended reality interventions to increase emotion regulation in children with autism spectrum disorder. After conducting a systematic literature search, five studies were included in the final review. Results indicate that overall, advantages were similar across interventions even though the interventions' specific characteristics varied quite substantially. For instance, all interventions named safe and controlled exposure as well as generalizability to real-life situations as their main advantages. On the contrary, each intervention used different technological equipment as well as varied in their level of immersion. Furthermore, the length of the interventions varied strongly, suggesting that the interventions were quite heterogenous. Lastly, no disadvantages were extracted from any of the five interventions.

Overall, it should be mentioned that there was a large discrepancy between the abundance of available literature on emotion regulation in children with ASD and limited number of interventions developed to tackle this mechanism. More specifically, a vast amount of research covers the importance of increasing emotion regulation in children with ASD, due to its potential to target the underlying mechanism of multiple comorbid disorders (Beck et al., 2020; Cai et al., 2018; Conner et al., 2022; Mazefsky et al., 2013). Furthermore, many studies outlined the benefits VR and AR have in treating children with autism (Lara et al., 2023). For instance, Ip et al. (2018) mentioned how they "facilitate the psychoeducational needs of people with ASD" and that the "computer-generated graphics attract the attention and interest of people with ASD because many of them primarily rely on visual thinking" (Ip et al., 2018, p. 2). Thus, a substantial amount of research outlined the importance of increasing ER in children with ASD and the potential XR interventions have to achieve this.

However, surprisingly, only five interventions were found that used XR technology to increase emotion regulation in children with ASD. Thus, the question arises why there is such a discrepancy between theory and practice. One reason for this discrepancy might be that XR research has mainly focused on developing VR exposure therapy (VRET) interventions to reduce symptoms of anxiety. Chung et al. (2022) explained that due to its established effectiveness, VRET for anxiety disorders has been the main research focus and that other areas have received much less attention and exploration. Consequently, research has been aimed at improving the field of VRET instead of expanding VR to different settings.

This is consistent with the findings of this research which showed that four out of five studies used exposure as their main underlying mechanism. While exposure is an important mechanism used to increase emotion regulation, research in the past has been mainly focused on using VRET to reduce anxiety symptoms instead of teaching self-regulation skills. This might explain why there are not many VR interventions aimed at increasing emotion regulation specifically. Another reason for the low number of interventions available could be that this research field is still relatively new (Mazefsky et al., 2013). Thus, research in this field has just begun and interventions still need to be developed.

The strong focus on exposure is likely related to the main advantage of VR interventions, namely providing a safe and controlled environment to practice exposure. More specifically, most children with ASD fear social situations and are easily overwhelmed by sensory stimuli. This fear is increased by the unpredictability of social situations, such as not knowing how other children might react to them or not being able to predict what happens next (Neil et al., 2016). This is where virtual reality provides a major advantage. Children can undergo exposure and practice new skills in a virtual environment that can be adapted to the child's specific needs and can be left instantly if the child feels uncomfortable (Zhang et al., 2022). For instance, the number of virtual people present can be adapted or the specific setting can be chosen based on the child's needs. Thus, VR exposure might be less fear-inducing than in-vivo exposure to situations that require the child to regulate intense emotions.

This finding was not surprising, since safe exposure is a well-known advantage of virtual reality interventions. This is in line with the general literature on using virtual reality in the health care sector, suggesting that VRET is as effective as traditional treatment (Chung et al., 2022). On the other hand, it was surprising to find that researchers in this field seem to almost exclusively focus on exposure and that other mechanisms are not considered as much. While the potential reasons for this were discussed earlier, there are currently some developments that explore other mechanisms.

For instance, Harwood (2020) developed a virtual Calm Room which focused on the reduction of sensory stimulation and relaxation in form of breathing exercises. The environment was designed to help children to remove themselves from stressful situations and find a place to calm down. Since the Calm Room is still in its prototype stage and has only conducted preliminary testing so far, it was not included in this review. However, this study demonstrates that exposure is not the only mechanism VR interventions can target and some interventions are now being developed to focus on different mechanisms, such as relaxation or sensory reduction.

Another major advantage of extended reality interventions is the generalizability of learned skills to real-life situations. As mentioned in the introduction, traditional treatment has been struggling to teach children with ASD skills that they can apply in real-life. A common reason is that they practice the skills in settings that are not familiar to the children and thus, they struggle to transfer what they learned (Bossenbroek et al., 2020). This is in line with research on the psychology of learning and skill transfer. According to Thorndike and Woodworth’s (1901) ‘identical elements’ theory, finding similarity between multiple tasks is crucial to be able to transfer skills to from one context to another. For instance, for a child to successfully use breathing techniques in a busy supermarket and within the classroom, a common denominator needs to be found. This could be that both places are too loud for the child. Thus, the child can learn that whenever they feel sensorily overstimulated, they can make use of the skill of slow breathing to help them calm down. Furthermore, Perkins and Salomon (1999) identified practicing a skill in multiple contexts and reflecting on the skill to be crucial practices that enhance transfer.

Since existing literature laid out that traditional treatments have struggled with skill transfer, all five interventions incorporated elements to increase generalizability of skills. This was achieved by actively discussing with participants how they can use what they learned in real-life situations. For instance, children were asked to reflect on how their newly-acquired skills during the VRI can help them in real-life situations. Furthermore, some studies let children practice the same skill in different social settings, such as at a birthday party or in a classroom. While the researchers of the included studies did not explicitly state that they used the 'identical elements' or similar theories, it might help in understanding why and how the children were able to learn and apply new skills.

Lastly, the motivation to participate in the interventions was overall high. Even though two interventions did not report children's feedback, all other interventions received solely positive feedback. Furthermore, no child dropped out of the study because they felt uncomfortable or did not want to participate anymore. Since motivating children with ASD to participate in psychological interventions has been an ongoing challenge, this provides a major advantage of XR interventions (Bossenbroek et al., 2020). The reason for why children might enjoy participating in XR interventions could be related to the intervention characteristics. More specifically, all interventions incorporated gamified elements as well as provided a high level of interactivity (see *Table 3*). According to Dehkordi and Rias (2013), digital games have a special effect on children with ASD. Due to their visual properties, they capture the children’s attention and consequently, increase their attention span. Furthermore, their playful elements are considered to be more fun and engaging compared to traditional talk therapy (Dehkordi & Rias, 2013). Furthermore, due to the fact that the children are fully immersed in the games, they tend to be more present and focused. This finding was not surprising, since children are known to respond better to tasks that they intrinsically enjoy compared to highly theoretical tasks (Bossenbroek et al., 2020). In summary, the intervention characteristics seem to play a major role in increasing children’s motivation to participate in treatment.

Besides demonstrating major advantages, the disadvantages of XR interventions in this context need to be discussed as well. Most importantly, it should be noted that no disadvantages were directly extracted from the reviewed articles. While the advantages of XR interventions in this context were elaborated upon by all authors, the disadvantages were not. However, this does not imply that there are no disadvantages to these interventions. In fact, based on the information and facts provided in the articles, a number of disadvantages could be inferred in the current research paper. It should be noted that these disadvantages were interpreted as such by the researcher of the current study and not by the original authors of the reviewed papers.

A major disadvantage of these interventions seems to be their inaccessibility. This includes both the low access to high-end technological equipment as well as access to the interventions themselves. More explicitly, even though new technologies are on the rise and are becoming more common, they are still not accessible to all parts of the world (Chung et al., 2022). Since all five studies worked with highly new technologies, such as half-CAVEs, augmented smart glasses, or private computer vision systems, they might only be available to a very small niche of individuals. Furthermore, most of the technologies used are costly, since they require multiple high-end devices, such as the breathing belt, head-mounted display, and other gadgets in the *DEEP* study (Bossenbroek et al., 2020). Since affordability is a major contributor to accessibility, the high price of technological equipment compromises the accessibility even further.

Another point that decreases accessibility is the rigorous technological set up that is required for most interventions. Even though this is not the case for the AR intervention, the other four interventions required at least an entire room as well as heavy technological devices to be set up. For instance, for Ip et al.'s (2018) half-CAVE study, a whole room needed to be built for the intervention to be carried out. This imposes logistical challenges, which makes the interventions less accessible as well.

Besides low access to technological equipment, accessibility to the interventions themselves seems to be low as well. More specifically, all five interventions were designed to be carried out within a therapeutic setting, suggesting they are carried out within therapy and require an expert to be present. This means that they include psychological testing as well as short therapy sessions to discuss what the child learned and felt during the intervention. For instance, in Ip et al.'s intervention (2018), short sessions are included for the children to reflect on their emotions and experiences during the intervention. In addition, children engaged in briefing and debriefing for each session. Similar formats were found for the other four studies, suggesting that these interventions are not stand-alone formats. They require either a clinician or another expert to be present who is trained in using the respective technology. While none of the studies mentioned this to be a disadvantage of the interventions, it should be considered to affect the accessibility to these interventions.

Furthermore, children do not only need to be in treatment, but also be supported by a therapist who provides these services. Since this requires the therapist to be technologically-trained, this poses another barrier to the accessibility of these interventions. To be more specific, the reviewed interventions were only developed in the last seven years and are still fairly new. Thus, the likelihood that therapists already learned how to offer these services is quite low. This is in line with Chung et al. (2022), who stated that it can be difficult to find therapists that offer VRIs or ARIs since the majority of therapists are not trained in using new technological interventions.

This disadvantage is reinforced by the general rather negative attitude of clinicians towards implementing technology into clinical practice. More explicitly, van Lotringen et al. (2023) found that overall, many psychologists think that there are more barriers than advantages to using technology within therapy settings. Chung et al. (2022) found similar trends when they interviewed clinicians on their attitudes towards incorporating VR interventions into clinical practice. The researchers found that some of the biggest barriers were missing knowledge and skills as well as the attitude of clinicians towards technology. According to the researchers, many clinicians are not educated on the current state of technological interventions, leading to critical misconceptions. These are for example that technology will replace therapists or that devices are too heavy and complicated for them to use. Overall, it seems that clinicians do not receive adequate education on the newest technological advances, which maintains the negative attitude towards these interventions.

Despite these disadvantages being major barriers to implementation at the moment, they can be expected to subside in the future. Given that XR technology is becoming more commercialized and available to the public, their accessibility and affordability is expected to increase (Chung et al., 2022). In addition, younger generations are used to technology being part of their everyday life and thus, their acceptance towards technological interventions is likely higher than of older generations (Chung et al., 2022). Consequently, the accessibility to XR interventions might increase in the future.

Recommendations for Future Research

Based on the findings of this review, several recommendations can be made for future research. Firstly, research in this field should take a more critical look at the disadvantages of XR interventions in the given context. Only by identifying the key barriers that keep these interventions from being developed and implemented, they can be tackled. This way, if deemed effective, implementation of these interventions into clinical practice can be facilitated. Since the existing literature focuses mainly on acceptance by the end-user, namely children with ASD, future research should also consider other stakeholders that are crucial for implementation, such as clinicians (Chung et al., 2022). In other words, even if the interventions take all the needs of children with ASD into account, therapists have to be convinced as well. Since they are the ones who offer and carry out the treatment, their attitudes are just as critical for implementation.

Another recommendation can be made on a more general level. For children with autism, most of the interventions focus on treating the symptoms, including anxiety-related symptoms, such as obsessions or phobias (Chung et al., 2022). This focus is likely due to the strain these symptoms put on social interactions and the child's environment. However, this way, only the symptoms are being treated and not the underlying mechanisms (Cai et al., 2018). This means that the child might experience fewer distressing symptoms but does not learn how to regulate distressing situations themselves. Even though the shift towards taking a transdiagnostic approach is taking place, this shift should also be addressed in the development of XR interventions. Thus, future researchers should aim to broaden the range of mechanisms that can be targeted with XR interventions, such as to sensory reduction or relaxation. This way, children with ASD can learn self-regulation skills which can help them to feel more autonomous and in control of their emotions.

Lastly, the technological equipment varied significantly between interventions. While this might have multiple logistic and financial implications, another important consideration should be the effect it might have on the children. Research should be conducted to find out whether the level of immersion influences the children's willingness to participate as well as the effectiveness of the intervention. Since the ASD population is highly heterogenous, the reactions to different types of technology might vary as well (Romero-Ayuso et al., 2020). Thus, it is important to establish whether some children on the spectrum respond differently to certain types of technology than others. Furthermore, the reactions to the interventions should be reported more extensively. In the included papers, the reactions were only labeled as 'positive'. However, a critical look at different children's reactions and acceptance to the technologies is crucial. This way, specific factors contributing to the motivation to participate can be identified and used for future interventions.

Strengths and Limitations of the Current Study

A few limitations of this scoping review should be considered. Firstly, the total number of participants was quite low (N= 144). Even though this is sufficient to make some general statements about the interventions, it is not sufficient to draw conclusions about the whole ASD population. In fact, since autism is considered a spectrum and is highly heterogenous (Karami et al., 2021), it is difficult to generalize the findings to the whole population. For instance, children who are considered high-functioning might respond differently to the interventions and technologies used compared to children who are considered low-functioning. Furthermore, 86 percent of the participants were boys and only 14 percent were girls. Although autism is significantly more frequently diagnosed in boys than in girls, the low number of girls that participated poses another limitation (Napolitano et al., 2022). Consequently, more girls and non-binary children with autism should be recruited to be able to draw conclusions for all genders.

Besides the limitations, a few strengths should be considered as well. Firstly, to our knowledge, this is the first study that mapped out the existing literature on VR and AR interventions that aim to increase emotion regulation in children with ASD. Especially when considering the large discrepancy between the literature and interventions available, this review can aid in making researchers more aware of the gap between theory and practice.

Additionally, by synthesizing the disadvantages of the interventions that are currently available, this study can function as a basis for future research in the field. More explicitly, since the disadvantages of XR interventions in this setting are rarely identified in literature, this study demonstrates a first attempt to identify important barriers. This way, more tailored programs can be developed to fit the target group's and other stakeholders' needs. Lastly, the study mapped out the potential XR interventions have, which supports the shift towards successfully implementing XR interventions into clinical practice in the future.

Conclusion

In conclusion, extended reality-based interventions demonstrate several advantages that eliminate the disadvantages and limitations of traditional, non-technological treatment forms. This includes the ability to practice skills in a safe environment, the generalizability to real-life situations, and the motivation of children to participate in the interventions. However, there are still some disadvantages to these new interventions that need to be addressed in order for VRIs and ARIs to be more commonly implemented in clinical practice. These disadvantages consist mainly of low accessibility and few therapists that are trained and open to use these technologies. Furthermore, research in this field is still in its very early stages and a substantial amount of research needs to be conducted in order to be able to develop effective interventions. However, with this in mind, there seems to be a promising basis for a whole new area of treatment that can be tailored and developed to address the specific needs of this population.

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Appendices

Appendix 1a.

Search String Developed for IEEE Xplore.

("Abstract": virtual reality) OR ("Abstract": VR) AND ("Abstract": emotion regulation) AND ("Abstract": autism) OR ("Abstract": ASD) AND ("Abstract": children) AND ("Abstract": intervention)

Filters Applied:

Journals

2013 – 2023

Appendix 1b.

Search String Developed for SCOPUS.

(“virtual reality” OR VR OR “virtual reality environment” OR VRE OR “virtual immersive technology” OR “virtual reality exposure therapy” OR VRET OR “virtual reality therapy”) AND (children OR adolescents AND NOT adults) AND (“autism spectrum disorder” OR ASD OR “autism” OR “autistic children” OR “autistic disorder”) AND (“emotion regulation” OR “emotional regulation” OR “self-regulation” OR “emotion dysregulation” OR dysregulation OR co-regulation)

Appendix 1c.

Search String Developed for Web of Science.

(((((AB=(virtual reality)) OR AB=(VR)) AND AB=(children)) AND AB=(autism)) OR AB=(ASD)) AND AB=(emotion regulation)