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Dynamic Interactive Social Cognition Training in Virtual Reality (DiSCoVR) for adults with Autism Spectrum Disorder: A feasibility study☆

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ABSTRACT

Background: Social cognitive difficulties in Autism Spectrum Disorder (ASD) can affect the daily lives of people with ASD profoundly, impacting the development and maintenance of meaningful social relations. Social cognition training (SCT) is commonly used for improving social functioning, but lacks ecological validity and the ability to effectively mimic social situations. Development of virtual reality (VR) interventions, focusing on enhancing social cognition, could add to the effectiveness of SCT within ASD care, by offering a safe, interactive and practical training setting, where generalization of knowledge and skills to the real-world are promoted. In this paper, our primary aim is to evaluate the feasibility and acceptance by participants and therapists of the Dynamic Interactive Social Cognition

Method: Training in Virtual Reality (DiSCoVR) protocol as developed for adults with schizophrenic spectrum disorder (SSD), adapted for ASD (DiSCoVR-A). 26 participants, aged 18–63, took part in a pilot study. 22 participants completed baseline and post-assessment, including primary outcome evaluation assessment through a semi-structured interview. Secondary measures focused on social cognition, emotion recognition, mental flexibility, social anxiety, empathy and social responsiveness and were assessed at baseline (T_0), post-treatment (T_1), and at follow-up (T_2) sixteen weeks after completion of the intervention.

Results: Our results show that the majority of participant and therapists found the VR intervention acceptable and feasible, as reported in evaluation questionnaires and interviews.

Conclusion: These preliminary findings are promising; however, controlled research is needed to further investigate the effectiveness of VR within social cognition training for adults with ASD.

☆ Trial registration: This trial was registered prospectively in the Dutch Trial Register, NL8069.

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1. Introduction

Social communicative difficulties and problems in social-emotional reciprocity largely define Autism Spectrum Disorder (ASD) (American Psychiatric Association, 2013). These problems can affect the daily lives of people with ASD profoundly, impacting development and maintenance of meaningful social relations. Furthermore, they can affect academic and vocational success (Turner-Brown, Perry, Dichter, Bodfish, & Penn, 2008). Problems in social functioning arise, in part, from underlying difficulties in social cognition (Baron-Cohen, 1989; Pinkham et al., 2014; Sasson, Nowlin, & Pinkham, 2013). Social cognition refers to the way we perceive and process social information, and determines how we respond to this information with our social skills (Henry, von Hippel, Molenberghs, Lee, & Sachdev, 2016; Velikonja et al., 2019). Indeed, social cognition is an important predictor of social competency and is related to general and social functioning (Bishop-Fitzpatrick, Mazefsky, Eack, & Minshew, 2017).

In this paper we use *person-first* language to refer to people with ASD, in line with Dutch research and and international reccomendations (Vivanti, 2020; Wevers, 2020).

To have purposeful, effective and meaningful social interactions (Greaves-Lord et al., 2022), one has to be capable of integrating information from multiple domains of social cognition (Fernández, Mollinedo-Gajate, & Peñagarikano, 2018). These social-cognitive processes interact and build upon one another. At a fundamental level, facial affect perception, or facial emotion recognition, refers to the ability to detect emotional expressions from faces. Facial expressions provide valuable information about the emotional state of other people, that one needs to consider to communicate effectively (Pavlova et al., 2017). People with ASD generally have detail-focused perception and therefore do not always focus their attention on (all) available socially relevant details, increasing the chance of misperceiving and misinterpreting the social situation. At an intermediate level, building upon facial emotion recognition, social perception refers to the ability to perceive information from the social context, such as other non-verbal communication (e.g., body language), tone of voice and accounting for social circumstances (Bishop-Fitzpatrick et al., 2017). Not adequately detecting, recognizing and accounting for these cues can lead to incorrect interpretation. At a higher-order level, Theory of mind (ToM) enables a person to understand the affective state, beliefs, intentions, thoughts and mental states of others (Couture, Penn, & Roberts, 2006) and based upon this, make predictions about their future actions (Pellicano & Burr, 2012). Information from past experiences is integrated with current information and used to analyze social situations. The inability to relate adequately to feelings and thoughts of others (i.e., having less effective ToM) can have negative consequences for social functioning (Baron-Cohen, 2001). Taken together, difficulties in social cognitive domains like facial emotion recognition, social perception and ToM can cause misjudgement or misinterpretation of.

other people's thoughts and actions (Couture et al., 2006), and are salient in ASD (Pelphrey, Adolphs, & Morris, 2004; Sasson, Pinkham, Carpenter, & Belger, 2011).

If social reception (i.e., perceiving input) is erroneous, subsequent preparation ('programming') of social behavior (i.e., producing output) can be maladaptive and may lead to inadequate behavior in the social context. Problems in emotion recognition, social perception and mentalising in ASD are also described in predictive coding theories within ASD (Pellicano & Burr, 2012; Van de Cruys et al., 2014). The predictive coding theory proposes that the brain makes predictions about, amongst other things, the social behavior of others and uses these predictions to interact effectively with other people. In individuals with ASD, erroneous prediction models (too specific or not sufficiently accurate) result in problems during social interaction, such as slow responses, detail focussed responses or mismatches of their responses to their conversational partner.

1.1. Training social cognition

Social cognition training (SCT in autism; (Bishop-Fitzpatrick, Minshew, & Eack, 2013; Gevers, Clifford, Mager, & Boer, 2006)) in individuals with ASD is commonly used to improve social functioning. SCT uses repeated practical training, to automate newly acquired (social) skills based on knowledge, strategies and insights that have been taught through repeated practice and role-play exercises. To promote consolidation and generalization of social cognitive skills, it is crucial that training takes place in a setting that encompasses the dynamic, complex and interactive nature of real, day-to-day social situations without the possible habituation effect of physical role play exercises (Kandalaft, Didehbani, Krawczyk, Allen, & Chapman, 2013). This way, the application of social knowledge and skills to a broad range of specific situations is strengthened through generalization. Homework assignments are used to allow the patient to train in his/her own social environment the newly learned skills and knowledge (Tseng, Biagianti, Francis, Conelea, & Jacob, 2020). Such as: observe emotions during the day and completing ABC schemes to determine the thoughts and feelings of their conversational partner. But to optimally provide performance feedback, a therapist (or coach) should accompany the patient in daily real-world interactions. This is time-consuming, however, and when a situation does occur, it becomes unnaturally charged due to the presence and potential interference of the therapist. Moreover, in real-world exercises, the situation can usually not be fully controlled or repeated to practice and reflect. Practicing social cognition and skills in a daily life context might therefore be impractical, or even unfeasible.

Virtual Reality (VR) is a promising tool for delivering social cognition training in a more effective, dynamic, interactive and ecologically valid way. VR offers an ecologically valid environment where one can experiment with social behavior in a safe, controlled setting that offers the possibility of providing direct feedback by the therapist. VR could facilitate an effective treatment, helping to develop and improve skills needed to function in a complex social world (Lawson, Rees, & Friston, 2014).

VR is widely used in clinical practice for exposure treatment and has been found effective for specific phobias, anxiety disorders and post-traumatic stress disorder(Rizzo, Thomas Koenig, & Talbot, 2019) and aggression regulation training within forensic psychiatry settings (Klein Tuente et al., 2020). The availability of these treatment options demonstrates the feasibility and acceptance of offering

therapy through VR for both patients and therapists. The use of VR in treatment of people with ASD is also not entirely new. The first manuscripts were published in the mid-1990 s (e.g. (Strickland, 1996)), acknowledging the advantages of using VR in the treatment of children with autism. Several recent pilot studies also suggest that VR in patients with autism care is effective, employable and acceptable (Didehbani, Allen, Kandalaft, Krawczyk, & Chapman, 2016; Genova et al., 2021; Kandalaft et al., 2013; Maskey et al., 2019; Wainer & Ingersoll, 2011).

In this paper, we focus on a specific VR social cognition training (VR-SCT) that was originally developed for people with psychotic disorders, 'Dynamic Interactive Social Cognition Training in Virtual Reality', or DiSCoVR (Nijman et al., 2020). DiSCoVR uses both strategy training and repeated practice in VR to enhance social cognition, and addresses facial affect recognition, ToM, and social perception (for a description of the intervention please see Fig. 1 and methods section). In a recent pilot study (Nijman et al., 2020), 22 participants with psychotic disorder received DiSCoVR. The results showed that DiSCoVR was well-tolerated, and that participants particularly enjoyed the opportunity to practice with (personally relevant) situations in VR. A significant, moderate improvement in emotion perception (measured by Ekman 60 Faces, a picture task) was found, although no change was observed in other domains of social cognition.

Given the suitability of VR treatment for ASD and the fact that social cognitive difficulties are a shared characteristic between ASD and psychotic disorders (Abdi & Sharma, 2004; Chisholm, Lin, Abu-Akel, & Wood, 2015), suggests that the DiSCoVR treatment protocol might also be applicable for people with ASD. A focus group with volunteers with ASD first evaluated DiSCoVR before DiSCoVR was used in this pilot study. In this study, we investigated the feasibility and acceptance of DiSCoVR for adults with ASD (DiSCoVR-A). In addition, we explore the effect of the VR training on cognitive domains (social cognition, cognitive flexibility) and other clinically relevant outcome measures, such as social anxiety and autistic traits.

2. Methods

2.1. Design and procedures

This study is a dual center pilot study (uncontrolled single group), in which all participants received the DiSCoVR-A intervention in addition to treatment as usual (i.e. psycho-education, individual cognitive therapy). Participants completed three assessments: before the intervention (baseline, T_0), post assessment (12–16 weeks post-treatment, T_1) and twelve weeks after completing the intervention (follow-up, T_2).

After referral from a clinician or after self-enrollment, patients who expressed interest were contacted by phone by the research team and provided with information about the study. Interested potential participants were invited to an intake, during which a member of the study team explained the study in detail, answered participants' questions and performed a final eligibility check. Informed consent was also obtained during this appointment. After signing the informed consent, a baseline assessment was planned (duration: 60 min) and the participant received questionnaires to complete at home (duration: 45 min).

Upon completion of the intervention, post-assessment was planned (duration: 75 min). Before the post-assessment, participants

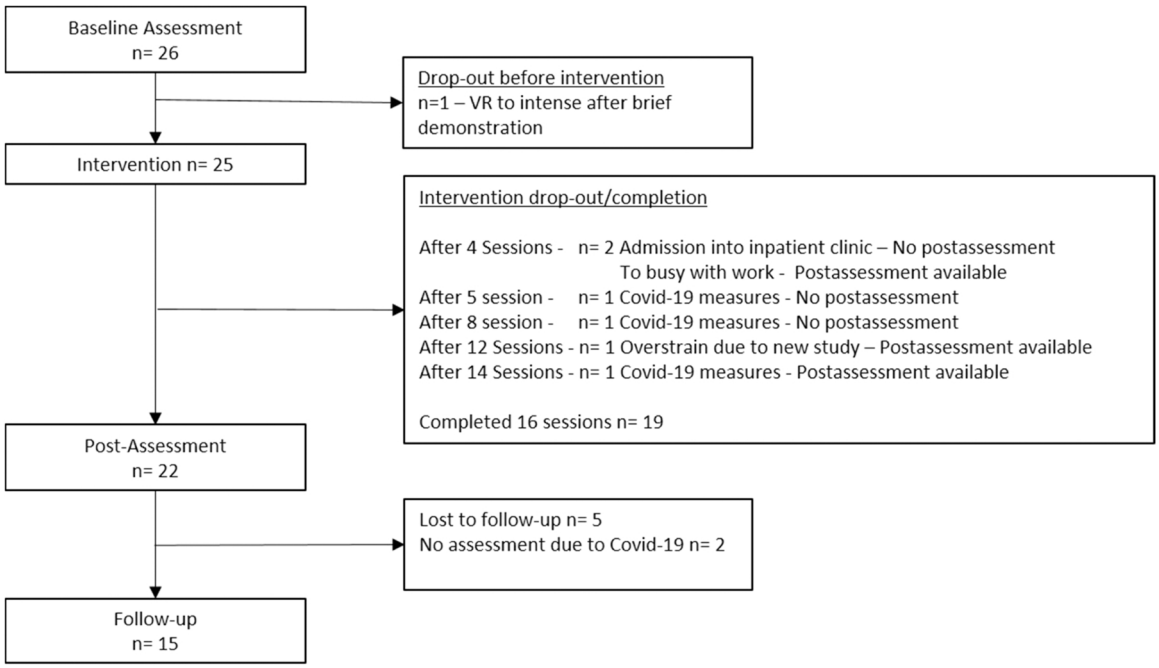

Fig. 1. Flow-diagram DiSCoVR-A.

again received questionnaires and an additional evaluation form to complete at home (duration: 60 min).

The follow-up assessment was planned 12 weeks after the post-assessment. Participants received questionnaires at home by mail to complete (duration: 45 min) and were invited to the follow-up assessment (duration: 60 min). Participants who dropped out of the intervention were asked to complete the evaluation form.

Pre-, post- and follow-up assessments contained identical instruments, where post-intervention assessment was supplemented with the evaluation interview and questionnaire (see Table 4. for instruments used).

This study was approved by the Medical Ethical Committee of the Erasmus University Medical Center (NL65384.078.18) and the research committees of the participating center.

2.1.1. COVID-19 impact

Due to the COVID-19 pandemic, the study was temporarily paused between March and July 2020. All active participants had the possibility to continue their therapy after July 2020. Two participants resumed the training, and continued the training on the session where they stopped prior to the pandemic.

Standard hygienic precautions were taken to ensure a safe therapy environment such as: ventilation, disinfection of VR goggles, social distancing and health checks before every appointment.

2.2. Participants

Participants were recruited from two Dutch mental healthcare facilities, through clinician referral of eligible, interested candidates, as well as through advertisement of the study and consequent self-enrollment.

Inclusion criteria:

- DSM-5 diagnosis of Autism Spectrum Disorder
- Difficulties in social cognition, as indicated by their primary clinician.
- 18–65 years old.

Exclusion criteria:

- Epilepsy.
- An estimated IQ below 70.
- Insufficient proficiency in the Dutch language.

2.3. Intervention

2.3.1. DiSCoVR ASD patient focus group

The original treatment protocol (as used in the RCT on DiSCoVR for SSD; Nijman et al., 2019), was first presented to a panel of three individuals with ASD (mean age 30.3 years, range 21 – 48, 2 male, 1 female) who volunteered to evaluate the intervention, and were recruited through flyers at one of the institutions. They evaluated VR worlds and practiced multiple modules and sessions of the training. Evaluation of DiSCoVR was done through a short, 6-item, questionnaire with 10 point Likert scale questions about the VR. All volunteers were positive about the VR and the protocol. They rated the VR with a mean grade of 8.0 and would recommend other people with ASD the training (mean 8.9).

2.3.2. DiSCoVR-A - Intervention

DiSCoVR-A is a 16-session individual protocolized VR-SCT, provided over a period of twelve to sixteen weeks (1–2 weekly sessions, depending on participants' preferences) (van Pelt et al., 2021). The intervention was provided by a therapist who had (at minimum) a bachelor's degree in psychology/pedagogy and at least 5 years of experience in ASD care, and who had received a one-day VR training, including education on the content and vision behind the protocol.

Practice in VR was the main focus of every treatment session. In the first sessions, time in VR was gradually increased, building up to taking up approximately half of each treatment session. The difficulty level of the VR exercises was gradually increased, to ensure errorless learning. The training was designed with a gradual build-up, starting with emotion recognition (or facial affect recognition) without context. Followed by emotion recognition within context and Theory of Mind, with integration of all learned skills and knowledge in the final sessions.

Two important principles used in the DiSCoVR intervention were mass practice (i.e., repeated practice with social materials in VR) and compensatory strategy training (e.g., verbalizing salient emotional characteristics in the face, listening to an avatar's tone of voice). To increase the relevance of the intervention and to promote generalization of training content to daily life, participants chose personally relevant social goals. Some examples of goals formulated by participants in our study were: "Learning how to accurately detect and use social signals in conversations", "Enhancing my emotion recognition to avoid conflicts with my partner" and "Being able to chit chat with colleagues". Finally, to further facilitate generalization of skills homework was assigned. These assignments generally consisted of using strategies or techniques from the sessions in daily life. For example, in one assignment, participants noted emotions they spotted in daily life, the context, and the strategy they had used to identify them. An overview of the DiSCoVR modules, sessions and exercises is presented in Table 1.

The VR software was developed by CleVR BV (http://clevr.net). The immersive VR worlds included a shopping street, a supermarket, an office and a bar setting. An Oculus Rift S head-mounted display was used to display the VR worlds. Participants explored and interacted with the environment using a Microsoft Xbox One joystick controller. Voice transformation (using the program MorphVox) was used in the role-play exercises to alter the therapist's voice. During the role play exercises, therapists used a user interface to trigger facial emotion displays and/or gestures (e.g., shrugging, pointing) of their virtual character.

2.4. Measures

During intake, after signing informed consent, demographical data were collected as well as a questionnaire to assess motivation to participate. Motivation was assessed on a 10 point-Likert scale, ranging from 1 = not motivated at all to 10 = completely motivated.

2.4.1. Evaluation and feasibility

The feasibility and acceptability of the intervention was assessed by a questionnaire, generating both qualitative and quantitative data. Questions were answered on ten-point Likert scales (1 = very bad to 10 =very good) with room for elaboration of the answers by the participants. We considered grades of 5.9 and below unsatisfactory, and grades from 6 to 8 satisfactory and 9–10 good.

The outcome of the questionnaire was later discussed in an interview with DiSCoVR-A therapist and the participant to further elucidate participants' responses. The interview was semi-structured and was specifically designed to evaluate multiple aspects of the DiSCoVR-A intervention (e.g. added value of VR for the participant, usability of VR hardware and software, satisfaction with intervention). To further evaluate feasibility, data were also collected on the number of completed sessions and the drop-out rate. Furthermore, protocol fidelity was assessed by evaluating forms completed by the therapists, which included issues (technical or otherwise) that interfered with carrying out the protocol. All DiSCoVR-A therapists also completed a separate but similar evaluation questionnaire concerning their experiences with the intervention.

We defined feasibility as how well the intervention suited the participant, and how easy it was for the therapists to provide the intervention. This was operationalized by investigating relevant parameters such as protocol adherence, drop-out rates, information about technical issues during the intervention and evaluation interview data.

Acceptability was defined as how effective and appropriate participants and therapists found the intervention, and whether participants would recommend the intervention to other people with ASD. For this, we investigated mean evaluation scores of participants and therapists from the evaluation interviews.

These criteria of feasibility and acceptability are also described by (Davis, 1989) and the technological acceptance model (Bowen et al., 2009) in assessing feasibility of technological interventions.

2.4.2. Social cognition

Movie for the Assessment of Social Cognition (MASC; Dziobek et al., 2006).

Table 1
DiSCoVR module and session overview.

Module*	Session	Session content	VR	
1. Emotion perception	1	Getting to know the therapist, determining training goals, learning to use the VR hard- and software.	Getting used to VR headset, practicing walking around in VR shopping street and using the multiple choice menus.	12–16 weeks, 1–2 sessions per week
	2	Further address treatment goals and start with training emotion recognition in VR.	Walking around in a shopping street and identifying emotions of various avatars, with increasing difficulty (i.e., shortened time to react, decreased intensity of emotions).	
	3–5	Participants learn about the visual characteristics and interpretation of emotions, how to recognize emotions (strategy training) and practice this in a VR environment.		
2. Social Perception & Theory of Mind	6 – 9	Participants learn to understand emotions of others in a social context by observing interactions between avatars.	Observe interactions between avatars and assess how they feel in the situations and answer open-ended/Socratic questions about the interaction (i.e., about behavior, emotions and thoughts of avatars). Observing interactions between avatars to assess their intentions, emotions and thoughts Participants continue to apply social strategies to understand situations (e.g., remembering how you felt in a similar situation). Participants learn about the connection between thoughts, emotions and behavior, and practice with recognizing them in VR scenarios, themselves, and others around them.	
3. Social interaction	10–16	Participants use the knowledge and cognitive skills acquired so far by actively participating in VR-interactions/role-plays with avatars (controlled by therapist).	Interactive role-plays with therapist through an avatar mediated system, using voice transformation. Exercises are tailored to the (social) needs of the participant and can include past social interactions, present-day social barriers or anticipating future interactions such as job interviews.	

The MASC is a video-based test to assess social cognition, the primary focus of DISCoVR-A. The MASC requires the subject to watch a video about four characters getting together for a dinner party. The video lasts 15 min and is paused 46 times to ask questions about characters' feelings, thoughts, and intentions. The questions are displayed on the screen (e.g. *"what is person X thinking?" "What is person X's intention?").* The actors in the video set out on a social get-together with various emotions, intentions and thoughts, gestures, and facial expressions during the social interactions of the actors. Other social cognition concepts as false belief, faux pas, metaphors, and sarcasm are also displayed. The videos depict different situations that elicit emotions and mental states such as anger, affection, jealousy, fear, embarrassment and disgust. Subjects respond to the questions by choosing one out of four answer options on a multiple-choice scoring sheet. This format allows differentiation of the answers: one answer is correct, and the three wrong answers differentiate between different types of mistakes: hypomentalization, hypermentalization and physical causation, and non-mental state inferences. The MASC has a high test-retest reliability (ICC=0.97) and internal consistency (Cronbach's alpha=0.84; (Dziobek et al., 2006)).

2.4.3. Emotion perception

Facial Expression of Emotion: Stimuli and Tests (FEEST) – Ekman 60 faces test (Young, Perret, Calder, Sprengelmeyer, & Ekman, 2002), Dutch translation and validation by (Voncken, Timmerman, Spikman, & Huitema, 2018)):

A computerized test which consists of 60 pictures portraying basic emotions (anger, disgust, fear, happiness, sadness or surprise), which the participant has to identify. The Ekman 60 faces uses a range of photographs from the Ekman and Friesen (Ekman & Friesen, 1976) series to test recognition of facial expressions of basic emotions. The test yields a score of correctly recognized emotions, with a total score ranging between 0 and 60 for all emotions. The stimuli are presented in random order for 5 s each.

2.4.4. Cognitive flexibility

Trail making Test (A and B) (TMT-A&TMT-B) (Delis, Kaplan, & Kramer, 2001).

To assess processing speed (TMT-A) and mental flexibility (switching between two mindsets; TMT-B). In this task, numbers (TMT-A) or numbers and letters (TMT-B) are printed in circles, scattered across a page. Participants connect these numbers in correct order (TMT-A). In TMT-B, participants also have to concurrently connect letters and digits (i.e., 1-A-2-B-3-C-4-D etc). The time (in seconds) taken to complete the exercise is recorded. Cognitive flexibility has been shown to be a strong predictor of adequate social skills (Parsons & Mitchell, 2002).

2.4.5. Social anxiety

Social Interaction Anxiety Scale (SIAS) (Mattick & Clarke, 1998), Dutch version and validation for Dutch population by: (de Beurs, Tielen, & Wollmann, 2014).

This self-report questionnaire consists of 20 items with 5-point scale from 0 (not at all) to 4 (completely true) with a total score ranging from 0 to 80 (with higher scores indicating more discomfort or anxiety), and is suitable for adults with autism (Maddox & White, 2015; Spain, Sin, Linder, McMahon, & Happé, 2018). A score of 43 or more indicates traditional social anxiety (generalized irrational fears across numerous social situations with avoidance and impairment). A score of 34–42 indicates social phobia in the English scales. Dutch cut-offs were $\geq$ 23 for men and $\geq$ 27 for women (de Beurs et al., 2014). The SIAS has been shown to have high levels of internal consistency, and test-retest reliability. The SIAS is sensitive to change in symptoms due to treatment.

The Brief Fear of Negative Evaluation scale-II (BFNE-II)(Carleton, McCreary, Norton, & Asmundson, 2006) is a revised version of the Brief Fear of Negative Evaluation scale (BFNE; Leary, 1983).

Self-report questionnaire consisting of 12 items reflecting fear of negative evaluation, which is central to social anxiety. In contrast with SIAS, which focuses on interaction anxiety, BFNE-II assesses fear of negative evaluation.

Respondents indicate how much each item applies to them on a Likert Scale ranging from 0 (''Not at all characteristic of me'') to 4 (''Extremely characteristic of me''). In past research, the BFNE-II has demonstrated good psychometric properties with an alpha of 0.95 (Carleton, Collimore, & Asmundson, 2007).

2.4.6. Social skills

SRS-A: Social Responsiveness Scale-Adult (Dutch version (Roeyers, Thys, Druart, De Schryver, & Schittekate, 2011)).

The SRS-A is a 64-item self-report questionnaire with 4-point scale from 0 (not true) to 3 (almost always true). Total scores range from 0 to 192. The SRS-A measures the severity of autistic social impairment across the entire range of the autism spectrum, from nonexistent to severe (Constantino & Gruber, 2012). Reliability and validity using the German version of the SRS-A was examined in 20 adults with Autism Spectrum Disorder (ASD), 62 with other mental disorders (CLIN) and 163 typically developing (TD) participants. Cronbach's alpha ranged from.71 (TD) to.89 (ASD). A SRS-A total score of 67 had a sensitivity of.85, and a specificity of.83 for ASD versus CLIN/TD. Correlations with established autism scales (ADOS, AQ, SCQ) were moderate to high ($r = 0.25–0.83$). In the Dutch version, the SRS produces a total score and subscales on social communication, social consciousness, social motivation, and autistic mannerisms.

EQ - Empathy quotient (EQ) (Baron-Cohen & Wheelwright, 2004); validation for Dutch population (Groen, Fuermaier, Den Heijer, Tucha, & Althaus, 2015).

The EQ is a self-report measure of empathy. The EQ consists of 60 items, with 40 items relating to empathy (statements regarding cognitive empathy, Statements regarding emotional/affective empathy) and 20 control/filler items. Each item is a first-person statement which is rated (Likert-scale 1–4) as either "strongly agree", "slightly agree", "slightly disagree", or "strongly disagree". The instrument is scored on a scale of 0 (being the least empathetic possible) to 80 (being the most empathetic possible). A cut-off score of < 30 was established when screening for autism spectrum disorders (Baron-Cohen & Wheelwright, 2004).

2.4.7. Analyses

To investigate the feasibility and acceptability of the intervention, we primarily attended to the evaluation of the intervention by participants and therapists. The qualitative data was analyzed using a thematic analysis (Braun & Clarke, 2006). A thematic analysis is a relatively simple way to gain insight into the qualitative data and to find common topics and overarching themes, by coding and structuring the answers into these common themes. Our qualitative data was collected on paper and imported into an excel worksheet. We used the answers on open-ended questions from the evaluation questionnaire to collect the evaluative data from participants and therapists. These kind of qualitative data are suitable for a thematic analysis approach (Joffe, 2011).

For the comparison of baseline, post-assessment and follow-up assessments (MASC, FEEST, TMT, EQ, SRS, BFNE and SIAS), we used paired-samples t-tests to test for immediate intervention effects (T_0 vs T_1) and consolidation effects (T_1 vs T_2 and T_0 vs T_2). Wilcoxon tests were used if the assumption of normality was violated. Significance level was set at $\alpha = 0.05$.

3. Results

Participants were recruited between October 2018 and March 2020. Baseline descriptive characteristics of all enrolled participants are displayed in Table 2. Fig. 1 shows the flow of participants and drop-outs. 24% of the participants (n = 6) dropped out of the intervention, because of reasons unrelated to the intervention (Fig. 1). 88% of participants completed at least baseline and post assessment measures, including evaluation of the intervention.

3.1. Feasibility and acceptance: participants

The results of the evaluation are shown in Table 3.

In the evaluation, participants scored the overall enjoyment of the intervention with a mean of 7.7. Mean satisfaction with the intervention was 7.4, and the usability of learned skills and knowledge for their daily social activities 7.4. Of the 22 participants with a post-assessment, 21 participants would also recommend the DiSCoVR-A training to other people with ASD, and gave a mean score of 8.5. Furthermore, the contents of the modules and exercises were satisfactory (M=6.6). Participants gave relatively low ratings to the realism of the appearance of the avatars (M=6.0), but ratings for the virtual environments (M=6.4) and sounds (M=7.3) were higher. Overall, participants indicated that the VR was realistic enough to practice social situations (M=6.9).

When considering the qualitative data, the following themes were identified: 'Practicing concrete social situations' in VR was mentioned as one of the important benefits of the intervention. Participants also mentioned as benefits of DiSCoVR-A being its 'realism' (emotions on the faces of avatars, real-life scenarios in the role play exercises), the 'safe practice environment' in VR (no real people involved, so no worries about potentially interfering with existing relationship), and the 'personalization' of the intervention (i.e., targeting specific personal goals and practicing in tailor-made situations/scenarios). Most participants (63.6%) reported that the intervention had a 'close fit to their personal needs'. The most often reported subjective effects of DiSCoVR-A were 'improved emotion recognition' (i.e. facial expressions), 'improved assertiveness' (i.e. verbal and non-verbal communication) and 'better overall social skills' in real life (i.e. initiating social activities).

Participants mostly criticized technical aspects of DiSCoVR, particularly 'problems with sound regulation' in the interaction module, and the 'graphical quality'. Furthermore, two of the participants indicated that the VR training was quite 'intense due to sensory and cognitive overload'. This mainly concerned incorporation of learned skills in stressful VR role-play exercises. Additionally, four participants (18%) considered the facial expressions to be somewhat 'unnatural'. Twenty of the participants (90.9%) were satisfied with the number, intensity, and duration of sessions.

3.2. Feasibility and acceptance: therapists

Nine therapists took part in the DiSCoVR-A pilot study of which seven completed the evaluation questionnaire. When considering

Table 2
Demographic details and baseline data.

	DiSCoVR (n = 26)[a] M (SD), Range
Age	27.62 (11.50), 18 – 62
Sex (male/female)	21/5
IQ	103.00 (14.39), 79–128
Motivation[b]	8.32 (1.07), 6–10
Number of sessions completed	13.50 (4.84), 4–16
Technical issues[c] (total number of issues during study)	14 minor – 3 critical

[a] In total 351 VR sessions were carried out

[b] Motivation was scored on a 1–10 scale 1 = not motivated at all-10 = completely motivated.

[c] Minor problems could be resolved during the session, critical problems forced the therapist to cease the session

Table 3
Evaluation of VR intervention (participants; n = 22)*.

Question	Mean (SD)	Median	Range
The VR training met my treatment needs (1–10)	7.55 (1.10)	8	5–9
What rating would you rate the entire treatment (1–10)	7.55 (1.14)	8	4 – 10
I enjoyed the VR training (1–10)	7.77 (1.74)	8	4–10
I have learned a lot from the VR training (1–10)	7.41 (1.26)	7	5–10
I thought the content of the exercises were fitting (1–10)	6.64 (1.22)	7	3 – 8
I would recommend the training to other people with ASD (1–10)	8.45 (1.37)	9	5 – 10
I thought the training fitted in well with my daily life (1–10)	7.43 (2.11)	8	2 – 10
The number of sessions (16) was enough (1–10)	6.76 (2.32)	7	2 – 10
I thought the virtual characters looked realistic (1–10)	6.00 (2.00)	7	1 – 9
I thought the virtual sounds sounded realistic (1–10)	7.27 (1.49)	7.5	3 – 9
I thought the virtual surroundings looked realistic (1–10)	6.36 (1.99)	7	1 – 9
I thought the VR was realistic enough to practice with (1–10)	6.91 (1.93)	7.5	1–9
Question	Answers	n (%)	
What were strengths of the intervention?	*Practice with social situations / interaction module*	7 (29,2%)	
	Tailoring of intervention to personal situation	5 (20,8%)	
	Emotion recognition module	2 (8,3%)	
	Realism	1 (4,2%)	
	Techniques and materials	1 (4,2%)	
	Safe training environment	3 (12,5%)	
What were weaknesses of the intervention?	*Technical / sound issues*	4 (18,2%)	
	Realism (appearance, movement)	3 (13,6%)	
	Modules (too long / unnecessary/ to short)	6 (27,3%)	
	Techniques/materials	1 (4,5%)	
	*Other (*i.e *cognitive load, possibility of digital homework)*	1 (4,5%)	
	None	8 (36,4%)	
What have you learned?	*Social skills (talking to others, how to react)*	9 (41%)	
	Being assertive/confident	7 (32%)	
	Recognize emotions	17 (77%)	
	Maintaining my boundaries in social contact	5 (23%)	
	Dealing with arguments	5 (23%)	
	Understanding thoughts and actions of others	9 (41%)	
	Nothing	0 (0%)	
Did the intervention meet your treatment needs?	*Yes*	14 (63,6%)	
	No	0 (0%)	
	Partly	8 (36,4%)	

* The interview was based on the questions used to evaluate DiSCoVR-P (Nijman et al., 2020)

the qualitative data, the following themes were identified: Therapists viewed the addition of VR as a 'valuable tool' for future treatment and training within ASD care. The 'engaging characteristic' of VR and its 'possibilities to tailor the training to the specific needs of patients' (module 3) were mentioned as advantages of working with DiSCoVR-A.

Overall, the therapists were positive about the treatment protocol, the provided exercises, and the number of sessions. They found the VR and the DiSCoVR treatment protocol pleasant to work with (Mean 7.80, SD.45, range 7–8). Furthermore, all therapists found it 'relatively intuitive to work with' the VR soft- and hardware. Therapists rated the entire DiSCoVR-A intervention with a mean score of 7.80 (SD.45, range 7–8), and would recommend the training for other patients with ASD (mean 8.33, SD.52, range 8–9).

Four therapists commented on the 'limited flexibility' of the protocol in the first two modules. They would have 'preferred a more modular approach' to best suit the intervention to the needs of the patients. Further points of critique were that 'preparation (i.e. hardware set-up, preparing the intervention) took too long' and that the 'voice modulation had frequent errors' (i.e. microphone not working, voice modulation not working properly). Six therapists suggested 'updates to the overall graphics and avatars' (mean ratings of virtual worlds 6.60, SD.55, range 6–7, and avatars mean 7.20, SD 1.10, range 6–9). They deemed this necessary, because many patients were accustomed to a high level of graphical realism in video games. However, they found the VR worlds 'realistic enough' to practice social situations (mean 7.80, SD.45, range 7–8). Three therapists recommended that 'adapted age-appropriate' VR worlds and avatars should also become available for adolescents.

The treatment adherence reports indicated the DiSCoVR-A sessions lasted 53.44 min (SD: 4.69, range: 43.31–62.06). In these sessions, participants spent an average of 255.43 min practicing in VR (SD: 46.11, range: 182–361), which is equivalent to an average of 15.96 min per session (SD: 2.88, range: 11.38–22.56).

Technical issues were divided into two categories: minor issues (session could be finished with use of VR), and critical issues (not being able to use VR or need to terminate session early due to technical issues). Minor technical issues were reported in 14 sessions (4%), whereas critical issues arose in 3 sessions (<1%) of all VR sessions.

3.3. Baseline vs. post treatment vs. follow-up

Baseline and post-treatment (T_0, T_1) means, standard deviations, and test statistics are shown in Table 4. Analyses were conducted in n = 22. Comparison of post-assessment and follow-up (T_1, T_2), and baseline and follow-up measures (T_0, T_2) were conducted at

Table 4
Means, standard deviations and test statistics of patients (baseline, post-treatment and follow-up).

		Mean (SD)			Dependent samples T-Test statistics								
		T_0 (n = 26)	T_1 (n = 22)	T_2 (n = 15)	T_0 - T_1			T_1 - T_2			T_0 - T_2		
					t	*P*	*d*	*t*	*p*	*d*	*t*	*p*	*d*
MASC	Total correct	31.19 (5.28)	34.14 (4.63)	34.38 (4.70)	3.00	.001**	-0.74	-1.06	.310	-0.29	-2.98	.01	-0.83
	Exceeding ToM	5.69 (3.52)	4.50 (1.68)	4.38 (2.76)	1.96	.063	.42	.923	.374	.26	2.26	.04	.63
	Less ToM	5.81 (3.14)	4.55 (3.19)	4.77 (2.86)	1.78	.089	.38	-0.89	.391	-0.25	2.10	.06	.58
	No ToM	2.11 (2.11)	1.82 (1.33)	1.46 (1.05)	1.23	.234	.26	1.95	.075	.54	1.49	.16	.41
FEEST	Total correct	47.23 (4.85)	49.43 (5.56)	51.36 (5.67)	-2.42	.025*	-0.53	-1.75	.074	-0.47	-2.60	.02	-0.69
TMT	A	21.50 (7.86)	18.46 (5.07)	17.66 (5.48)	3.25	.004**	.69	2.50	.028*	.69	3.85	.002	1.07
	B	44.60 (14.95)	38.22 (14.54)	40.19 (21.52)	2.65	.015*	.57	.27	.793	.07	2.06	.06	.57
SIAS	Total	39.92 (13.93)	35.29 (18.31)	36.64 (16.00)	2.39	.027*	.52	-0.70	.50	-0.19	1.68	.12	.45
BFNE	Total	29.64 (14.89)	25.81 (13.72)	29.33 (12.39)	1.51	.146	.33	-0.64	.53	-0.17	0.84	.42	.22
SRS	Total	81.08 (26.76)	66.48 (30.45)	72.76 (32.48)	3.55	.002**	.78	-1.36	.20	-0.35	1.76	.10	.46
	Soc. Consciousness	22.81 (8.06)	18.86 (9.01)	19.93 (7.55)	2.34	.030*	.51	-0.23	.82	-0.06	2.08	.06	.54
	Soc. Comm.	26.85 (10.07)	22.14 (10.69)	23.00 (12.85)	2.93	.008**	.64	-0.85	.41	-0.22	1.43	.20	-35
	Soc. Mot	17.54 (6.15)	15.38 (7.51)	17.13 (8.75)	3.11	.006**	.68	-1.44	.17	-0.37	0.38	.71	.10
	Mannerisms	13.88 (6.36)	10.10 (5.55)	12.60 (6.84)	3.77	.001**	.82	-3.15	.007	-0.81	1.48	.16	.38
EQ	Total	27.96 (13.45)	30.00 (12.51)	31.50 (12.41)	-0.79	.437	-0.18	-1.70	.11	-0.45	-1.37	.19	-0.37

*$p < .05$, ** $p < .01$

n = 15.

3.4. Social cognition - MASC

From pre- to post-treatment, a significant improvement in the total MASC score was observed ($p < .01$). This improvement was maintained at follow-up, as shown by the *t*-test from T0-T2, $t(12) = -2.98$, $p = .010$.

3.5. Emotion perception – FEEST

A significant improvement in emotion perception was observed from baseline to post assessment $t(19) = -2.42$, $p = .025$, mean difference 2.2. The results show that participants increased in the facial affect recognition on the FEEST total score over time, $t(13) = -2.60$, $p = .020$.

3.6. Cognitive flexibility – TMT

The mean post-assessment completion time for TMT-A was significantly lower than the baseline completion time (MD = 1.54 s, t (6), $p = .004$, $r = 0.49$). From post-assessment to follow-up, the mean time to complete TMT-A again significantly reduced (MD=1.82 s, t (12)= 2.50, $p = .028$). Post-assessment time to successfully complete TMT-B was significantly lower than at baseline (t (21)= 2.65, $p = .015$, MD= 6.7 s), indicating greater cognitive flexibility after the intervention, but was not maintained at follow-up.

3.7. Social anxiety – SIAS

The total SIAS score was significantly lower at post-assessment than at baseline ($p = .027$, MD=4.63). From post-assessment to follow-up, the SIAS total score did not change significantly, indicating that improvements were sustained.

3.8. Social anxiety – BFNE

No significant changes were observed in the total score of the BFNE from baseline to post-assessment ($p = .146$), nor from post-assessment to follow-up ($p = .530$).

3.9. Social skills and social responsiveness – SRS

The mean SRS-A Total score and the Communication, Motivation and Autistic Mannerisms subscales were significantly ($p < .01$) reduced from baseline to post-assessment, as well as the subscale 'Social Awareness' ($p = .030$). Self-reported autistic mannerisms decreased significantly from baseline to post-assessment ($p < .01$) but increased significantly to pre-treatment levels from post-assessment to follow-up ($p < .01$).

3.10. Social skills and autistic traits – EQ

No significant changes were found, neither at post-treatment, nor at follow-up.

4. Discussion

We set out to develop and test the feasibility of DiSCoVR-A, an immersive VR-SCT intervention for adults with ASD who experience difficulties in social communication. We demonstrated that overall, patients as well as therapists found the intervention acceptable. Therapists found the addition of VR to social cognition training feasible to deliver. Results of the secondary clinical outcomes gave a first indication that participants improved in social cognition, social responsiveness and facial affect perception, and declined in the experience of social anxiety.

4.1. Feasibility and acceptance

Overall, participants found the DiSCoVR intervention good and pleasant. Nearly all, but one, participants would recommend the intervention to other people with ASD. Participants indicated that they had learned a lot from the intervention and enjoyed the practical training in a virtual environment accompanied by a real-life therapist. Our findings are in line with a previous pilot study on DiSCoVR in patients with SSD (Nijman et al., 2020), which found that the opportunity to practice with interactive, dynamic, personalized social material was one of the most important strengths of VR-SCT. Additionally, the present pilot study suggests that the incorporation of a visual training setting helps to meet the treatment needs of adults with ASD.

A few participants dropped out of the intervention, mainly for reasons unrelated to the intervention, e.g. too busy at work and long commute due to starting new study. Most participants completed the intervention as intended in the treatment protocol.

Participants and therapists indicated that the intervention and the accompanying hardware and software could be further improved. Some participants found the number and frequency of sessions too high, whereas others deemed the number of sessions too

low. Participants who criticized the number of sessions would have liked a more modular approach in the training, making modules shorter or longer, depending on their needs. Indeed, due to the heterogeneity in patients with ASD, individual tailored interventions (e.g., a modular approach) are likely to be more efficacious (Wood et al., 2015).

In general, the majority of participants were generally satisfied with the frequency and number of sessions. The reliability of the equipment and software was criticized by some participants and therapists; in some sessions, minor or major problems with hardware and/or software were encountered, with some errors leading to not being able to use VR in that session. While participants and therapist rated the intervention as sufficiently realistic for practice, they indicated the realism of the virtual environments needed improvement in the future, particularly the appearance of the avatars. Enhancing the realism of avatars and stability of hardware and software is a possible next step in enhancing the feasibility and acceptability of DiSCoVR-A. However, previous studies that used VR that were less realistic, were nonetheless effective. The question rises if heightened realism adds to the effectiveness of DiSCoVR-A, or whether other aspects could add to the effectiveness, such as a more modular approach or a higher intensity of training.

4.2. Observed changes following treatment

Our secondary clinical outcome measures indicated that DiSCoVR-A might improve social cognitive skills as measured with the MASC, by showing improvement on the total score, but not on particular subscales. Additionally, a significant improvement in facial affect recognition (FEEST) was observed, which was maintained through the follow-up period. Furthermore, an improvement in information processing and cognitive flexibility from baseline to post intervention was found; information processing time (TMT-A) was found to improve further from post-intervention to follow-up assessment, but cognitive flexibility (TMT-B) was not. Additionally, an overall improvement in self-reported social responsiveness (SRS-A), as well as improvement on all social responsiveness subscales from pre- to post intervention was observed. The ability to recognize and interpret social cues (social awareness), motivation to participate in social interaction (social motivation) and the ability to adequately respond to social cues (social communication) increased directly after the intervention, whereas stereotypical and repetitive behaviors (autistic mannerisms) declined after intervention, but increased again after a follow-up period. Self-reported empathy, EQ (cognitive or affective), was not found to change significantly. However, mean scores on the EQ approached levels within the normal range of scoring at follow-up.

Self-reported social anxiety, as measured with the SIAS, showed a significant decline between baseline and post-assessment, which was maintained at follow-up. Baseline scores indicated that mean scores were within the range of ‘social phobia’, while post intervention scores were close to the general population range of social anxiety. However, participants’ fear of negative evaluation did not specifically change following the intervention.

4.3. Limitations

Limitations do apply to this pilot-study. First and foremost, the pilot was uncontrolled (i.e., no waiting list or alternative treatment control group), so we cannot imply a causal relation between improvement in outcome and the intervention. Therefore, we cannot rule out learning effects due to spontaneous symptomatic remission and/or repeated administration of tasks. For the TMT, for example, practice effects have been found (Buck, Atkinson, & Ryan, 2008), but a Spanish study investigating test-retest reliability of the MASC found stable scores upon repetition after several months (Lahera et al., 2014).

Moreover, the small, selective sample limited statistical power and generalizability of the results on the secondary outcome variables. Our main goal was investigating the feasibility of the intervention. The feasibility shows that a larger, randomized controlled trial, should be performed to properly assess the effectiveness of DiSCoVR-A on social cognition in adults with ASD.

Finally, we only included adult participants with ASD. It could be worthwhile to extend the VR worlds for adolescents, given the engaging nature of the intervention, thereby likely promoting treatment motivation in this group.

4.4. Clinical and theoretical implications

Next to our findings that DiSCoVR-A could enhance social cognition in ASD, the advantage of adding VR to the treatment are in line with the predictive mind framework (Van de Cruys et al., 2014). Predictive coding theories state that people make unconscious predictions about the behavior of others and use these predictions to interact with each other effectively, instead of a stimulus-response approach. In the real social world, no two interactions are exactly the same, and a certain degree of error has to be tolerated and resolved during the interactions. Also, a more general abstract level of representation of social interaction (or social scripts) has to be readily available to utter social behavior. However, when prediction errors are not well tolerated, dealt with, or overly detailed predictions (scripts) about an interaction prevent the development of a more abstract level of social interaction, communicative difficulties as seen in ASD can arise (Van de Cruys et al., 2014). Addressing these problems in social prediction with VR interventions could contribute to enhancement of overall social cognition by promoting the use of social cognitive strategies. VR offers the ability of practicing in a safe, controllable and visually immersive setting that mimics real life experiences as truthfully as possible. Moreover, practise can take place as often as required to automate skills and access to knowledge in these situations, without the problems of infeasibility that practice in real life can entail. Finally, intensity of the interaction exercises and the environmental factors can be gradually adjusted to the progression and demand for help of the individual patient. In this way, dynamic, complex and interactive scenarios are rehearsed, without a possible habituation effect of physical role play exercises.

The costs of the delivery of VR interventions are still relatively high. The treatment remains to be guided by a professional, and cannot (yet) be replaced by VR alone. However, these costs are likely to decrease further in the future, as the hardware needed to run

VR already becomes more widely available. Also, a recent cost-effectiveness study was done on a VR-CBT intervention for psychosis patients, which showed promising results and economic viability (Pot-Kolder et al., 2020).

Our findings suggest that the DiSCoVR-A intervention is feasible and acceptable to deliver within adult ASD mental health care, and initial clinical outcome data show promising results. The intervention still needs to be evaluated on a larger scale, comparing it to a control condition, to assess its effectiveness. Implementing VR in daily clinical practice, or in a larger scale RCT would require some adjustments of the VR, primarily updating the graphical component (VR worlds and avatars).

CRediT authorship contribution statement

BvP: Methodology, Project administration, Data curation, Formal analysis, Investigation, Writing – original draft. **SN**: Conceptualization, Methodology, Writing – original draft, Formal analysis, Resources. **NvH**: Supervision, Writing – review & editing. **WV**: Conceptualization, Methodology, Writing – review & editing, Resources. **GP**: Conceptualization, Writing – review & editing. **IvB**: Methodology, Writing – review & editing. **AL**: Methodology, Writing – review & editing. **KGL**: Conceptualization, Methodology, Supervision, Investigation, Writing – review & editing, Formal analysis, Funding acquisition.

Declarations of interest

The authors have no competing interests to declare that are relevant to the content of this article.

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