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A systematic scoping review of virtual environments and tasks usable for therapist or self-guided assessment and intervention for Social Anxiety in children, adolescents, and adults

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Background: Virtual reality (VR) is a promising tool for diagnostics and treatment in Social Anxiety Disorder (SAD) and its subtypes. In VR, controlled environments for the activation of social fears and anxiety can be provided, making them valuable to measure and modify SAD. While research on both is expanding, the range of VR environments currently in use remains unclear. Therefore, this work systematically examines virtual environments and tasks for self or therapist-guided assessment and intervention of Social Anxiety in children, adolescents, and adults, focusing on technical implementation, feasibility, usability, and effectiveness in anxiety activation.

Methods: We conducted a preregistered systematic scoping review of original research published until January 2025 in English or German targeting interactive, immersive VR systems for the assessment and/or intervention in Social Anxiety. Included studies cover children, adolescents, or adults samples with a DSM/ICD diagnosis of SAD, or high Social Anxiety based on validated instruments. We extracted and summarized qualitative data on study and sample characteristics, VR environment design, technical realization, feasibility, usability, and presence. Furthermore, we descriptively summarized quantitative data on presence and anxiety activation during VR sessions.

Results: A total of 31 studies were included, eleven providing quantitative data for summary. Public speaking tasks dominated VR scenarios, while other subtypes, such as fear of blushing, were not addressed. VR scenarios for children and adolescents remained a substantial research gap. Immersive systems typically involved HMDs with head-tracking, and in part, motion- or eye-tracking. Effect sizes for anxiety activation were lacking; among the few studies reporting them, moderate to high effects were observed. Presence was sufficient to elicit anxiety responses, although social presence was underreported. Feasibility was assessed via dropout and adherence rates; usability reporting focused primarily on cybersickness, supplemented by user-friendliness, time- and cost-efficiency, and user satisfaction.

Conclusion: This review presents the wide range of VR environments and tasks for assessment and intervention in Social Anxiety, with promising anxiety-activating effects. However, improvements in technical features, usability, and presence are

needed. Future research should focus on expanding VR scenarios to address individual fears, enhance dialogues and social interactions, and provide applications targeting children and adolescents.

KEYWORDS

assessment, public speaking anxiety, scoping review, social anxiety, virtual reality, virtual reality exposure therapy, virtual social environments

1 Introduction

Social Anxiety Disorder (SAD) is one of the most common mental illnesses in the general population and is associated with a lifetime prevalence of 7%–13% (Fehm et al., 2008; Kessler et al., 2005). SAD is defined as an intense fear of social or performance situations with the possibility of being scrutinized by others or of embarrassment (American Psychiatric Association, 2018). Pronounced avoidance behavior (e.g., no visits to anxiety-provoking social situations), safety behavior (e.g., strategies to protect against feared social situations or their negative consequences), and inadequate social behavior (e.g., awkward, distanced, or insecure behavior, less eye contact) are typically associated with SAD (Clark and Wells, 1995; Heerey and Kring, 2007).

Social Anxiety can occur in various forms, with specific subtypes being distinguished. A prominent subtype involves performance situations, including public speaking anxiety (PSA) and test anxiety (Blöte et al., 2009). PSA is considered the most common manifestation of Social Anxiety and can severely affect individuals, as it plays a crucial role in professional, academic, and everyday contexts (Leigh and Clark, 2018). Test anxiety, on the other hand, predominantly affects children and adolescents, potentially impairing academic performance and leading to long-term consequences for educational trajectories (Rapee and Spence, 2004). If left untreated in childhood or youth, Social Anxiety increases the risk of chronic courses into adulthood (Weeks et al., 2009). Beyond these specific impairments, SAD is frequently associated with comorbidities such as depression, other anxiety disorders, or substance use disorders, all of which contribute to substantial suffering (Buckner et al., 2008).

Cognitive Behavioral Therapy (CBT) is a highly recommended treatment for SAD according to both the German S3 guideline (Bandelow et al., 2021) and the British NICE guideline (National Institute for Health and Care Excellence, 2017). Evidence-based CBT approaches for SAD treatment commonly involve psychoeducation, attention and social skills training, exposure, and behavioral experiments (Mayo-Wilson et al., 2014; Steinman et al., 2016). Among these, exposure is one of the most effective interventions for anxiety disorders (Powers et al., 2008; Steinman et al., 2016). During exposure, patients are confronted with a feared object or situation until distress has decreased and/or until a violation of dysfunctional expectancies about the feared object or situation is reached (Craske et al., 2008). However, a challenge in treating SAD with exposure therapy is that certain feared situations are often scarce and difficult to recreate (e.g., speaking in front of a large audience, having a job interview), or some patients do not consent to *in vivo* exposure due to high levels of distress or avoidance (Deacon and Abramowitz, 2004; Garcia-Palacios et al., 2007).

In recent years, virtual reality (VR) technology has emerged as a promising tool for facilitating exposure therapy (Kampmann et al., 2016a). VR enables confrontation with feared situations or objects in a controlled, flexible, and immersive virtual environment, thereby improving acceptability and reducing logistical barriers (Freeman et al., 2017). In addition to therapeutic applications, VR is also increasingly used to assess Social Anxiety using standardized, ecologically valid social-evaluative tasks (e.g., public speaking, participating in group interactions), with studies demonstrating reliable elicitation of anxiety and emerging psychometric validation (e.g., Pan and Hamilton, 2018; Reichenberger et al., 2022). Critically, consistent with fear activation accounts (Craske et al., 2008; Foa and Kozak, 1986), valid assessment requires sufficiently threatening, social-evaluative contexts that reliably elicit the behavioral, physiological, and cognitive response patterns distinguishing Social Anxiety severity; evidence from social stress paradigms and VR shows that task features enhancing social evaluation, contingency, and presence amplify and stabilize these responses (e.g., Dickerson and Kemeny, 2004; Freeman et al., 2017; Pan and Hamilton, 2018). However, several factors can influence the elicitation of anxiety, including individual differences in immersion and presence, limited realism of virtual agents, or the use of preformatted interactions that may not match participants' spontaneous behavior (Arnfred et al., 2023; Freeman et al., 2017).

Anxiety activation is crucial for therapeutic processes, as exposure relies on mechanisms such as habituation, expectancy violation, and inhibitory learning (Craske et al., 2008; Foa and Kozak, 1986). Empirical evidence indicates that VR scenarios eliciting moderate but manageable levels of fear promote learning and reduce avoidance, whereas insufficient or excessive anxiety may weaken therapeutic effects or increase dropout rates (Arnfred et al., 2023; Freeman et al., 2017). Hence, anxiety activation constitutes a key mechanism that links assessment and intervention in VR applications for Social Anxiety.

Virtual reality exposure therapy (VRET) has therefore become an important therapeutic instrument for the assessment and treatment of Social Anxiety or subtypes of Social Anxiety (Kampmann et al., 2016a; National Institute for Health and Care Excellence, 2017). Although VR scenarios reliably induce social distress and yield encouraging treatment outcomes (Anderson et al., 2005; Bouchard et al., 2017; Klinger et al., 2005), a meta-analysis by Wechsler et al. (2019) found that *in vivo* exposure therapy (IVET) remains moderately more effective than VRET when compared in the same amount. At the same time, the meta-analyses showed a high heterogeneity between studies, ranging from inferiority to even superiority of VRET over IVET.

These findings raise questions about factors influencing VRET efficacy in SAD. Beyond the complexity of the disorder (e.g., high comorbidity, chronicity, and impairment), creating realistic and

interactive social scenarios in VR that also address patients' dysfunctional beliefs remains a major challenge. Conversations with virtual interaction partners are difficult to implement and often rely on preformatted answers, which may not fully match participants' contributions (Bouchard et al., 2017). Patients' experiences of VR environments also vary depending on hardware and software quality, which can influence immersion, presence, and anxiety responses (Arnfred et al., 2023).

Previous reviews have provided valuable insights but remain limited in scope. Arnfred et al. (2023) placed primary emphasis on technical characteristics and reporting (e.g., hardware/software variability, interaction realism), with comparatively less attention to the magnitude of elicited anxiety responses. Emmelkamp et al. (2020) and Caponnetto et al. (2021) focused on clinical efficacy and intervention outcomes and only partially addressed technical and methodological features, the breadth of SAD subtypes, and age-specific considerations. Notably, prior reviews rarely synthesized the degree of anxiety activation elicited by VR scenarios - a central mechanism for both assessment and therapy.

The present scoping review aims to provide a comprehensive overview that bridges these gaps. We include studies across children, adolescents, and adults, covering multiple SAD subtypes, and systematically examine technical features, virtual environments, task characteristics, and reported user experiences (usability, feasibility, presence). Where possible, we adopt a descriptive summary of quantitative data on anxiety levels to clarify the extent of anxiety activation induced by VR scenarios. By integrating these perspectives, our review not only identifies methodological and clinical research gaps but also provides guidance for the development of more effective and individually tailored VR scenarios for both assessment and intervention of Social Anxiety. Given the heterogeneity of VR applications and reported outcomes, a scoping review approach is particularly suited to map the evidence, highlight gaps, and inform future research and clinical practice.

2 Objectives and research questions

This scoping review provides a systematic qualitative overview of available virtual environments and tasks applicable to assessment and intervention in Social Anxiety or its specific subtypes (e.g., public speaking anxiety, test anxiety, fear of blushing) in children, adolescents, and adults. In addition, we descriptively report the quantitative outcome data regarding anxiety levels reached during VR sessions to evaluate whether virtual social environments reliably elicit symptoms to serve as effective assessment and therapeutic tools. Also, quantitative data on feasibility, usability and presence will be descriptively summarized. The particular research questions are described in Table 1.

3 Methods

We conducted a scoping review to provide a comprehensive qualitative synthesis of eligible studies. The review followed the methodological framework proposed by Arksey and O'Malley (2005) and refined by Levac et al. (2010) and Peters et al. (2020), in accordance with the PRISMA-ScR guidelines (Tricco et al., 2018). Within the review, we also descriptively summarized available quantitative outcome measures on anxiety levels, anxiety activation, feasibility, usability and presence reported in regard to the VR sessions, to evaluate whether virtual social environments reliably elicit sufficient anxiety, show adequate feasibility and usability, and induce a satisfactory experience of presence to serve as valid assessment and therapeutic tools. Where possible, effect sizes (Cohen's *d*) were descriptively reported; no quantitative data syntheses or respectively meta-analytic computations were performed.

3.1 Protocol

We followed the Preferred Reporting Items for Systematic reviews and Meta-analyses extension for Scoping Reviews (PRISMA-ScR) checklist and protocol, provided by the PRISMA group (Tricco et al., 2018). Our review protocol was preregistered on the Open Science Framework OSF (https://doi.org/10.17605/OSF.IO/ZMR8A).

3.2 Eligibility criteria

We set no time limit for the period the studies were conducted. Only (1) original studies (no review articles, meta-analyses, study protocols), (2) written in English or German were included. The population inclusion criterion was (3) an ICD or DSM diagnosis for SAD, or high Social Anxiety in general or in a specific subtype of Social Anxiety like public speaking anxiety, exam anxiety or others, indicated by participants meeting the cut-off for high Social Anxiety on a validated social phobia, public speaking, or other subtype specific diagnostic instrument (questionnaire or interview). Studies were also eligible if participants had a previously established clinical diagnosis of SAD confirmed in earlier clinical assessment or treatment, even if no renewed diagnostic interview was conducted within the respective study. In addition to our preregistration, SAD should be the primary diagnosis (e.g., Social Anxiety not as comorbidity) to ensure that the design and intended function of the virtual environments were specifically aligned with social anxiety-related fears and behaviours and not confounded by anxiety mechanisms associated with other primary disorders. Further inclusion criteria covered an VR application characterized by using (4) immersive (e.g., HMD, CAVE) and (5) interactive (e.g., head-tracking, motion-tracking, eye-tracking) systems. Moreover, (6) a minimum number of 10 participants to ensure validity was required. For additional quantitative summary, eligibility criteria covered (7) the measurement of primary outcome before (pre) and/or during (peri) the application with a symptom specific, standardized questionnaire or interview, or an anxiety or stress one-item scale (e.g., SUD), and (8) sufficient statistical values (for the primary outcome parameter/s at pre, and/or peri-assessment). Studies not fulfilling the criteria for quantitative summary could be included in the qualitative synthesis, though, if eligibility criteria 1-6 were fulfilled.

3.3 Information sources

A systematic literature search was conducted in PubMed, PsycINFO, and Web of Science in October 2023 and updated in

TABLE 1 Qualitative research questions of this scoping review and additional quantitative research questions.

Research questions	Qualitative synthesis	
1. Description of the virtual environment a) Intervention b) Assessment	A) Which was the content of the virtual social situation used for assessment/treatment? (e.g., virtual agents, classroom, actions, stories) B) How was the non-social VR environment designed? (e.g., setting/context, rooms, background sound) C) How was the social environment (virtual agents) designed? (e.g., sexes, number, age, behavior)	
2. Technical realization a) Intervention b) Assessment	A) Which kind of VR output devices were used? (e.g., HMD, loudspeakers, headphones) B) Which kind of VR input devices were used? (e.g., tracking devices like mouse, controller, hand-tracking, microphone, eye-tracking) C) How was movement realized in VR? (e.g., via head-tracking, joystick, controller, keyboard) D) How was interaction with virtual agents realized in VR? (e.g., controlled by therapist; preformatted answers, eye contact via eye-tracking)	
3. Description of the social task a) Intervention b) Assessment	A) Which task/s or challenge/s were defined for the participants? (e.g., speaking in front of a group, asserting one's right) B) Which was the theoretical, empirical, and/or therapeutical background/rationale and the underlying method for the task? (e.g., CBT, VRET) C) For which specific age group was the application intended? (e.g., children and adolescents, adults, seniors) D) For which target group was the application intended? (e.g., socially anxious students, adolescents with PSA, patients with SAD) E) Was the task manual-based? (e.g., CBT-manual, social skills training by Hinsch and Pfingsten) F) How many sessions did the application consist of? (number of VR sessions) G) How long did the whole VR task take? (duration of the VR task in minutes) H) How long did one VR session last? (duration of one VR session in minutes) I) How many non-VR sessions were additionally applied within the intervention/assessment procedure? J) Was the task self-guided or therapist-guided? K) Was the task composed of different levels? (e.g., difficulty levels)	
	4.1 Qualitative synthesis	4.2 Descriptive summary of quantitative measures
4. Experiences and results from the usage	A) What were the main results regarding the individual research questions? B) Which experiences on feasibility of the VR application have been made by the authors? (e.g., acceptability, suitability, and engagement) C) Which experiences on usability of the VR application have been made by the authors? (e.g., efficiency, cybersickness, few errors, and satisfaction) D) Which advantages of the VR application are mentioned by the authors? E) Which limitations are mentioned by the authors? F) Which indications are mentioned by the authors? G) Which experiences on presence in the VR application have been made by the authors? (e.g., social and physical presence) H) Which conclusions for future use in clinical settings or research and further developments are drawn by the authors? (e.g., ideas for changes for future studies)	A) What level of experienced presence in VR did the VR task induces? (if mean and standard deviation data are available) B) What absolute level of anxiety was reached during (peri) VR session? (mean and standard deviation for level/intensity of primary outcome variable during, e.g., BAT, assessment) – also compared to control group (e.g., *in vivo* exposure) C) How effective was the VR application concerning anxiety activation? (means and standard deviations of anxiety level/intensity on primary outcome variable before (pre) and during (peri) the VR session, and if available Cohen's d effect size) D) Which quantitative outcome regarding the feasibility of the VR application has been measured? (e.g., acceptability, and engagement assessed via ratings/SUD-scales, adherence rates, quantitative data of participant responses to the application) E) Which quantitative outcome regarding the usability of the VR application has been measured? (e.g., quantitative data of efficiency, cybersickness, few errors, and satisfaction)

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December 2023, and January 2025. In addition, experts in VR therapy were contacted to identify further eligible studies.

3.4 Search

The query strings were based on our inclusion criterion "only original studies" written in English and German. No time limit was set for the period the studies were conducted. We searched for the keywords "virtual" AND "social phobia", "virtual" AND "social anxiety", "virtual" AND "social anxious", "virtual" AND "public speaking anxiety", "virtual" AND "exam anxiety", "virtual" AND "fear of blushing" and "virtual" AND "social fear" in the PubMed, PsycINFO and Web of Science databases. Depending on the different search template structure of the databases, we used slightly different search strategies. In PubMed the connector 'AND' was used to search for "Virtual AND social phobia" as well as "Virtual AND social anxious", "Virtual AND public speaking anxiety", "Virtual AND exam anxiety", "Virtual AND fear of blushing" and "Virtual AND social fear" in titles and abstracts. In PsycINFO we searched for "virtual" in title and "social anxiety", "social anxious", "public speaking anxiety", "exam anxiety", "fear of blushing" and "social fear" in abstracts. In Web of Science, we searched for "virtual" in title and "social phobia", "social anxious", "public speaking anxiety", "exam anxiety" as well as "fear of blushing" and "social fear" in the topic.

3.5 Study selection

A PRISMA flow-chart diagram (Moher et al., 2009) illustrates the number of studies screened and excluded during the screening process (see Figure 1). The numbers from the initial search in October 2023 and the updates in December 2023, and January 2025 were summed up. First, obvious duplicates (n = 362) were removed from all records identified through database searching (n = 1,320). The titles and abstracts of the remaining reports (n = 958) were then screened against the eligibility criteria. Records were excluded as soon as one criterion was not fulfilled (n = 888).

For articles we did not have access to the full-text (n = 4), the corresponding authors were contacted, and half of them (n = 2) sent the full-text. All remaining records with no evidence for a violation in eligibility criteria within the abstract were passed on for full-text screening (n = 66). During this process, all eligibility criteria (1–6) for qualitative analysis were assessed. Reports not fitting every eligibility criterion (n = 35) were finally excluded. The remaining 31 studies were found eligible for qualitative synthesis and were additionally checked regarding the eligibility criteria for quantitative data summary (eligibility criteria 7–8). Since n = 14 of the 31 publications (assessment and intervention) did not measure anxiety level during VR session, and n = 6 studies did not present mean and standard deviation of anxiety measure, and/or Cohen's *d* effect size, they were excluded from the additional analysis.

A total of four researchers (TS, TW, PB, AM) were involved in the screening process. One researcher (TS) screened all titles, abstracts, and full-texts. These were re-screened by two researchers (TW, PB). Disagreements or uncertainties about inclusion after full-text screening were resolved through discussion with a fourth researcher (AM). We performed the exclusion process based on the information provided in the published articles and to the best of our knowledge.

4 Data

4.1 Collection process

Using a data collection form following the Cochrane Handbook guidelines (Chapter V: Collecting data; Li et al., 2019), we extracted data regarding our research questions (see Supplementary Table S1 for all domains and extracted entities).

1. *Study characteristics:* year of publication, name of the author/s, title, language, aim of the application, research question(s).
2. *Measurement of outcome variables:* primary and secondary outcome variables, time points of measurement, types of standardized measurement instrument used to assess outcome variables.
3. *Sample characteristics:* number of participants, mean age, number and distribution between genders, diagnostic instrument and cut-off used for inclusion of participants.
4. *Hardware features:* HMD or other VR output device specifications (model, field of view in degrees, resolution per eye, refresh rate), further output devices (e.g., motion platform).
5. *Software features:* software name/version/type, interaction elements, live-controllable elements for the therapist.
6. *Software-hardware-interaction:* average framerate or frametime, degrees of freedom for head movements, interaction and movement method, live-viewing for the therapist.
7. *Description of the virtual environment and technical realization:* content of the virtual environment, non-social environment, design of agents, VR input devices.
8. *Description of the social task:* content of the task/challenge, theoretical/empirical and/or therapeutical background and rational, name of used manual, therapist-guided or self-guided, manipulated variables, number of VR sessions.
9. *Experiences and results from the usage (feasibility and usability):* main results (qualitative), experiences of the study authors concerning feasibility and usability of the VR application, advantages and limitations concerning VR application, suggestions for future clinical use and research.
10. *Experiences and results on presence:* reported experiences, measurement instrument for presence, means and standard deviations for presence measures.
11. *Experiences and results on anxiety levels and activation*: means and standard deviations of the anxiety level reached during VR session, Cohen's *d* for pre vs. peri measurement (for intervention and assessment studies).

Means and standard deviations (as well as Cohen's *d*) were collected from the intent-to-treat sample, if not available, data from the completer sample was used.

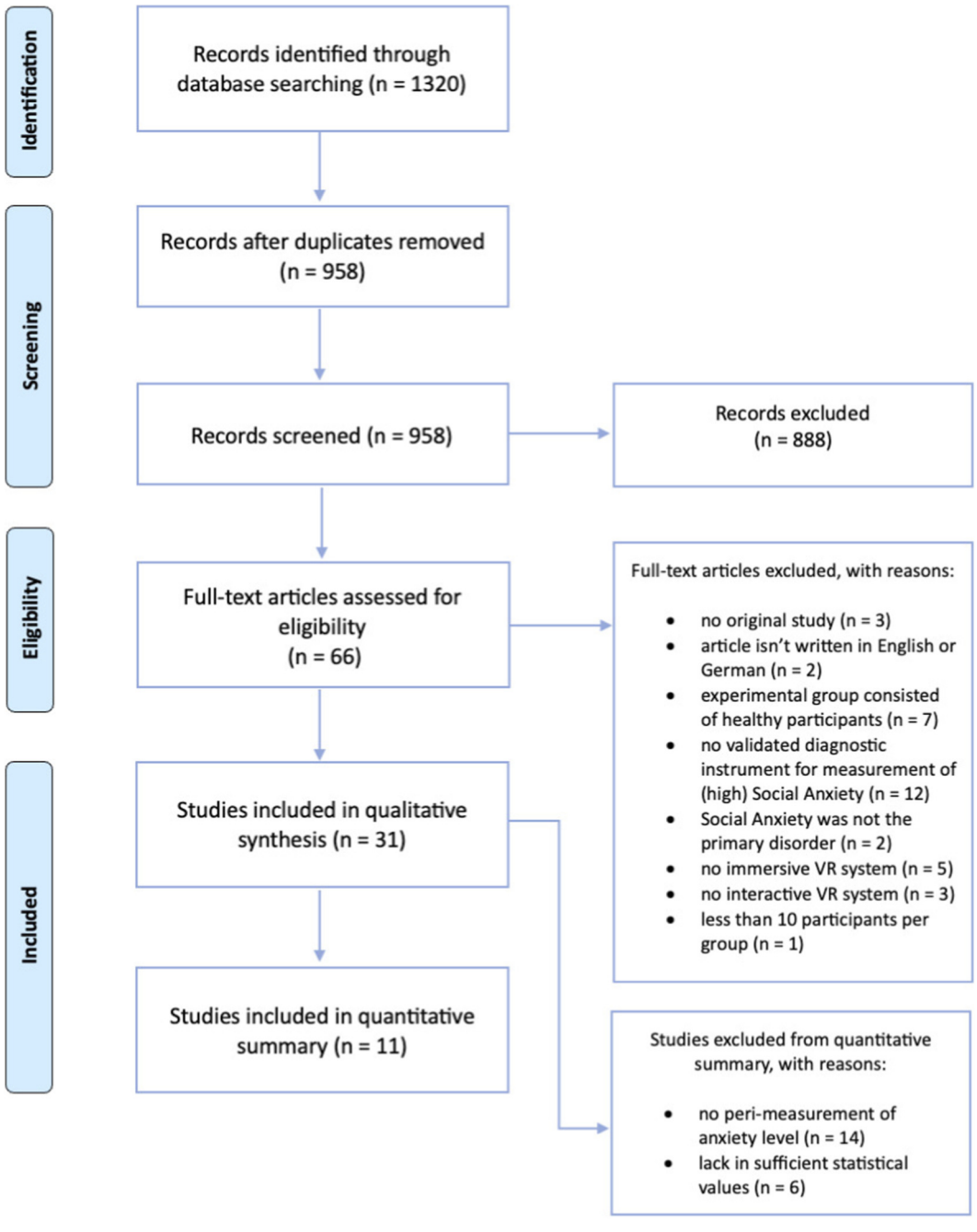

FIGURE 1
PRISMA flow diagram reporting the number of screened studies and the number of studies excluded during the screening process.

4.2 Qualitative synthesis

As qualitative synthesis of information from all included studies, we conducted a scoping review that provides a structured presentation and assessment of central characteristics of the included studies and their extracted entities, to be able to answer the research questions. For this purpose, we examined and summarized the main features of each study in regard of their *contents of the virtual world,* (e.g., content of the virtual social situation, design of the virtual environment), *technical realization* (hardware and software features; e.g., type of HMD, software name, interaction elements), *social tasks* (social task or "challenge" for the participants for the purpose of assessment or treatment), and *experiences as well as results on the usage* (e.g., experiences of the study author's concerning feasibility, usability, and presence). Also, we summarized the study *characteristics* (e.g., publication year, study design, population, intervention or assessment, outcome variables). To provide an overview, and to identify and highlight similarities and differences between the studies, we tabulated the most important information.

4.3 Descriptive summary of quantitative data

Furthermore, we wanted to give a descriptive summary of quantitative results on anxiety levels and activation as well as on presence during virtual sessions in socially anxious individuals for both assessment and intervention studies. For this purpose, we reported the anxiety level reached by the experimental group (VR group) during VR session, and if applicable the anxiety values reached of the control group (e.g., *in vivo* exposure group). Additionally, for the included assessment and intervention studies, the pre- and peri-values of their primary outcome variable, and if applicable Cohen's *d* effect size for pre vs. peri measurement, were also reported to show anxiety activation. Finally, for the descriptive summary of quantitative presence results, we reported the means and standard deviations achieved in the respective measuring instruments for assessment and intervention studies. Also, we descriptively summarized quantitative outcomes on usability and feasibility, e.g., cybersickness data or data on dropout or adherence.

5 Results

In the following section, data charted from the 31 included studies will be presented. The whole extracted information on every data point (Supplementary Table S1) for all included studies is displayed either in the tables of the manuscript or in Supplementary Table S5, Supplementary Table S6, and Supplementary Table S7.

5.1 Study characteristics

Overall, 31 studies fulfilled all eligibility criteria for the qualitative synthesis and eleven studies for the descriptive summary of quantitative data of the extracted entities for our systematic scoping review of virtual environments and tasks usable for therapist or self-guided assessment and intervention in Social Anxiety or subtypes of Social Anxiety.

Of these, 22 studies included participants diagnosed with SAD (e.g., Anderson et al., 2017; Bouchard et al., 2017). Two of these specifically addressed SAD participants with PSA as their primary fear (Anderson et al., 2013; Burton et al., 2013). Seven studies included highly socially anxious individuals (e.g., Ma et al., 2019; Wechsler et al., 2021), and two studies focused on individuals with high PSA (Nazligul et al., 2019; Reeves et al., 2021). For diagnostic instruments used to assess SAD or high social or public speaking anxiety see Table 2.

Eight studies aimed at assessment for Social Anxiety or subtypes of Social Anxiety (e.g., Holmberg et al., 2020; Kishimoto and Ding, 2019), 19 studies involved interventions (e.g., Geraets et al., 2019; Jeong et al., 2021) (see Table 2). Four studies aimed at both (e.g., Felnhofer et al., 2019; Hur et al., 2021) (see Table 2), and are therefore considered in the information synthesis for assessment. Across all studies, primary outcomes were comparable (they all consisted of Social Anxiety), with most studies assessing Social Anxiety symptoms through self-report questionnaires (e.g., BFNE, SIAS, SPS, PSAS, PRCS, LSAS) and/or subjective units of distress (SUDs) (see Table 2).

As presented in Table 2, the 31 studies were published between 2009 and 2022 and included data from 1,511 participants overall, with sample sizes ranging from 14 to 115 participants. The age of the included participants ranged from 16 to 42 years–referring to those studies providing information on this sample characteristic (n = 27). Within most of the studies that gave information on the distribution of sexes (biological sex), there were descriptively more female than male participants. Five studies did not give information on the distribution of the sexes of participants (e.g., Jeong et al., 2021; Kim et al., 2022) (see Table 2).

Information on participants' medication and/or actual psychotherapy treatment (beside VR assessment/intervention) was missing in 14 studies (see Table 2). In the study by Geraets et al. (2019) six participants used medication (SSRI, SNRI, benzodiazepine) and 12 participants have already received treatment. In other studies, a current medication or an ongoing treatment was an exclusion criterion (e.g., Kim et al., 2020; Reichenberger et al., 2017). Three studies allowed psychoactive medication if it was stable for several months, but did not give further details (Bouchard et al., 2017; Burton et al., 2013). A detailed overview of study characteristics is displayed in Table 2.

5.2 VR applications for intervention

Table 3 provides a detailed overview of virtual environments, their technical realization, and the VR tasks of the 19 VR intervention studies.

5.2.1 Description of virtual environments for VR-intervention in SAD

The virtual social situations (see RQ 1A) used in the intervention studies encompassed a wide range of social performance situations [presentations (e.g., Jeong et al., 2021; Lindner et al., 2019), speeches (e.g., Anderson et al., 2013; Donahue et al., 2009), talks (e.g., Kampmann et al., 2016a; Stupar-Rutenfrans et al., 2017), job interviews (e.g., Kampmann et al., 2016b; Zainal et al., 2021), and self-introductions (e.g., Kim et al., 2020; Zainal et al., 2021)], public social interactions [café (e.g., Bouchard et al., 2017; Geraets et al., 2019), restaurant (Kampmann et al., 2016a; Kim et al., 2022), bus (Geraets et al., 2019; Kampmann et al., 2016b), supermarket (Geraets et al., 2019), cafeteria (Zainal et al., 2021), and train (Kim et al., 2017)], and informal social interactions [dinner party (Kim et al., 2018; Zainal et al., 2021), talking with relatives in an apartment (Bouchard et al., 2017)]. Accordingly, all included intervention studies involved exposure to anxiety-provoking virtual social situations.

Table 3 displays an overview of virtual environments including the content of the environments, design of non-social (e.g., rooms, background sound), and social environments (e.g., design of virtual agents).

As context (see RQ 1B) for studies focusing on social performance situations, virtual rooms of varying sizes were used, including conference rooms (e.g., Reeves et al., 2021; Rubin et al., 2022), classrooms (e.g., Burton et al., 2013; Lindner et al., 2021), auditoriums (Nazligul et al., 2019; Jeong et al., 2021), lecture halls (e.g., Rubin et al., 2022; Wechsler et al., 2021), and meeting rooms (e.g., Jeong et al., 2021; Kampmann et al., 2016b). In addition to basic furniture such as tables and windows, some settings included a

TABLE 2 Study, and participants' characteristics and descriptions.

References	Study design	Participants					Aim of VR application and study aim	Primary outcome variable(s)
		N	Inclusion criterion social anxiety/ subtype (with measurement instrument)	Age in years M (SD)	Gender n or %	Ongoing medication or treatment (beside VR assessment/ intervention)		
Anderson et al. (2013)	Randomized controlled trial	97	Diagnosis of SAD (DSM-IV) with public speaking as the primary fear (SCID)	39.03 (11.26)	62% female 38% male	Medication had to be stable, concurrent psychotherapy as exclusion criterion	*VR Intervention* Comparing VR therapy and *in vivo* exposure to wait list in SAD.	Self-report anxiety (PRCS, FNE-B)
Anderson et al. (2017)	long-term follow-up study, randomized clinical trial	28	Diagnosis of SAD including public speaking fears (SCID)	42 (13.17)	71% female 29% male	VRE or EGT Therapy (parent study)	*VR Intervention* To evaluate the durability of VR exposure therapy for SAD over the long-term (6 years) using multimodal assessment	Self-report symptom severity (PRCS, FNE)
Bouchard et al. (2017)	3-arm randomized controlled trial	59	Diagnosis of SAD (DSM-5, SCID) for at least the past 2 years	36.2 (14.9)	73% female 27% male	Medication had to be stable for at least 6 months and remain unchanged throughout the study	*VR Intervention* To show that conducting VR exposure in CBT for SAD is effective and more practical for therapist than conducting exposure *in vivo*	Self-report social anxiety (LSAS-SR-score)
Burton et al. (2013)	Secondary report from a randomized controlled trial	65	Diagnosis of SAD (DSM-IV) with public speaking anxiety as most feared situation (SCID)	40 (12)	40 females 25 males	Participants on psychoactive medication were required to have been stable for at least 3 months	*VR Intervention* To examine the relation between self-report mindfulness and fear of negative evaluation over the course of non-mindfulness based cognitive-behavioral therapy (CBT) for SAD	Self-report of Fear of negative evaluation (FNE)
Donahue et al. (2009)	Clinical trial (double blind)	20	Diagnosis of SAD (DSM-IV, SCID)	21.2 (1.7)	N/A	N/A	*VR Intervention* To provide a rigorous test of the acute impact of a single dose of Quetiapine (25 mg) on SAD symptoms	Self-report of Public Speaking fears (SUDS, PRCS, LSAS)
Felnhofer et al. (2019)	Randomized controlled trial	24	Diagnosis of SAD (DSM-IV, SCID-I)	N/A	9 females, 3 males	N/A	*VR Intervention/assessment* To examine the link between social presence, physical presence, and emotional responses to photogenic virtual social stimuli	Self-report of physical and social presence (NMMSP, IPQ), state anxiety (SIAS, STAI-S), heart rate

(*Continued*)

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TABLE 2 Continued

References	Study design	Participants					Aim of VR application and study aim	Primary outcome variable(s)
		N	Inclusion criterion social anxiety/ subtype (with measurement instrument)	Age in years M (SD)	Gender n or %	Ongoing medication or treatment (beside VR assessment/ intervention)		
Geraets et al. (2019)	Single-arm trial, pilot study	15	Diagnosis of generalized SAD, score in SIAS >25	34.9 (12.4)	8 females7 males	n = 6 on medication (SNRI, SSRI, benzodiazepine),n = 12 had received previous treatment	*VR Intervention*To assess the feasibility and potential effect of VR-based cognitive behavioral therapy (VR-CBT) for patients with severe SAD	Self-report of social anxiety (SIAS)
Holmberg et al. (2020)	Mixed-methods study	18	Diagnosis of SAD (patients)	27.4 (N/A)	1 female 8 males	N/A	*VR Assessment* To develop VR videos with real-life content from a shopping situation and to evaluate participants' anxiety responses and feelings of presence	Self-reported anxiety level (SUDS), presence, acceptability of the videos and cybersickness
Hur et al. (2021)	Comparative fMRI study	47	Diagnosis of SAD (DSM-IV) and a score >82 on the Korean version of the social avoidance and distress Scale	23.04 (3.35)	20 females 27 males	N/A	*VR Intervention/assessment* To investigate the effect of VR on pathological self-referential processes in individuals with SAD To determine changes in self-referential processing and their neural mechanisms following VR treatment	Personal relevance ratings and reaction time (behavior outcome), neural correlates
Jeong et al. (2021)	Controlled study, retrospectively classification of the patients	115	Diagnosis of SAD (patients)	34.3 (13.3) Early Termination Group 31.2 (15.5) Normal Termination Group 27.6 (10.7) Session Extension Group	24 females, 28 males 11 females, 32 males 5 females, 15 males	N/A	*VR-Intervention* To find out whether VR-based individual CBT with few treatment sessions is effective in improving SAD	Self-report of social anxiety (BFNE scores according to session progress)
Kampmann et al. (2016b)	Randomized controlled trial	60	Diagnosis of SAD (DSM-IV, SCID)	39.65 (11.77)	65% female,35% male	N/A	*VR Intervention*To investigate the efficacy of a stand-alone VR exposure intervention comprising verbal interaction with virtual humans	Self-report of social anxiety (LSAS-SR, FNE-B), and behavioral assessment)

(*Continued*)

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TABLE 2 Continued

References	Study design	Participants					Aim of VR application and study aim	Primary outcome variable(s)
		N	Inclusion criterion social anxiety/ subtype (with measurement instrument)	Age in years M (SD)	Gender n or %	Ongoing medication or treatment (beside VR assessment/ intervention)		
Kim et al. (2017)	Randomized controlled trial	55	Diagnosis of SAD (DSM-IV, MINI)	23.0 (2.3)	16 females 14 males	no medication	*VR Intervention* To investigate the efficacy of self-training using the newly developed mobile-based VR program for the cost-effective treatment of SAD	Self-report of social anxiety (LSAS-Score)
Kim et al. (2020)	Single-arm trial, longitudinal questionnaire study	65	Diagnosis of SAD (DSM-IV, MINI)	23.12 (3.12)	37 females 28 males	no current medication, not currently receiving psychotherapy	*VR Intervention* To create a participatory and interactive VR intervention for SAD	Self-reported social anxiety SPS, SIAS, BFNE, LSAS)
Kim et al. (2022)	Controlled trial	52	Diagnosis of SAD (DSM-V), Score on LSAS >30	23.18 (2.04)	10 females, 18 males (EG) 10 females, 14 males (CG)	N/A	*VR Intervention* To find neurobiological evidence for the therapeutic effect of VR self-training (VRS)	Self-reported social anxiety (LSAS, BFNE, RSES, SIAS), neuronal correlates
Kishimoto and Ding (2019)	Quasi-experimental study	52	Diagnosis of SAD (Chinese version of the MINI)	23.65 (4.32)	13 females 13 males (EG) 12 females 14 males (CG)	oncurrent psychotherapy for SAD was an exclusion criterion	*VR Assessment* To explore the influences of ambiguous and negative virtual social feedback on SAD patients and a health control group	*Self-report of social Anxiety (SIAS, SPS and FNE), self-reported anxiety levels (SUD)*
Lange and Pauli (2019)	Quasi-experimental study	52	Social anxiety questionnaires based on the criteria for social phobia from DSM. An average score of 3.2 or higher was used for cut-off (based on Reutter et al.)	23.9 (3.5)	19 females, 6 males (EG) 19 females, 16 males (CG)	N/A	*VR Assessment* To introduce a VR task, looking at avoidance parameters during whole body movements To examine whether highly socially anxious individuals differ in avoidance behavior when bypassing another person	Self-reported state measures of anxiety (STAI, Sam-Scale), objective measures: distance, movement, and gaze domain

(*Continued*)

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TABLE 2 Continued

References	Study design	Participants					Aim of VR application and study aim	Primary outcome variable(s)
		N	Inclusion criterion social anxiety/ subtype (with measurement instrument)	Age in years M (SD)	Gender n or %	Ongoing medication or treatment (beside VR assessment/ intervention)		
Lindner et al. (2021)	Single-subject design	23	Score >60 on the public speaking anxiety scale (PSAS)	40.61 (10.15)	57% female, 43% male	no active psychoactive medication, and no planned psychological treatment, but patients had already completed the standard digital clinical assessment battery	*VR Intervention* To examine the effectiveness of a VR-assisted treatment protocol for public speaking anxiety with demonstrated efficacy, this time in routine care, using affordable VR hardware	Self-reported social anxiety symptoms (PSAS, LSAS-SR, B-FNE, GAD-7, BBQ)
Ma et al. (2019)	Randomized controlled trial	100	A score of 30 or above on the LSAS-SR	2D mock: 40.70 (12.66) 2D active: 40.72 (13.56) 3D mock: 38.48 (13.45) 3D active: 43.29 (12.38)	74% female, 26% male 44% female, 56% male 57% female, 43% male 58% female, 42% male	no pharmacological medication change, no ongoing or recently concluded psychological counselling	*VR Intervention* To evaluate the effects of a VR-based ABM training on attentional bias and anxiety symptoms	Self-report of social anxiety (LSAS-SR), objective measure: attentional bias
Nazligul et al. (2019)	Quasi-experimental study	14	Public speaking anxiety symptoms (cut-off by 20 for both scales of LSAS)	21.36 (1.08)	10 females 4 males	N/A	*VR Intervention* To examine whether a three-dimensional virtual environment might decrease the anxiety levels of novice software engineers	Self-reported anxiety level (SUD-scores)
Owens and Beidel (2015)	Quasi-experimental study	45	Diagnosis of SAD (DSM-IV, SCID)	20.90 (2.19)	11 females 10 males (EG) 13 females 11 males (CG)	no	*VR Assessment* To examine the ability of a VR environment to elicit physiological and subjective arousal typically associated with public speaking	Self-reported anxiety (SSPS, SUDS), physiological measures: HR, EDA and RSA
Parrish et al. (2016)	Feasibility study	41	Score above the cutoff of 29.5 on the liebowitz social anxiety scale for children (LSAS-CA)	16 (1.65)	66% female, 34% male	no	*VR Assessment* To assess the feasibility of VR exposure as an assessment and treatment modality for youth with SAD	Self-reported anxiety (average SUDS score across each scenario)

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TABLE 2 Continued

References	Study design	Participants					Aim of VR application and study aim	Primary outcome variable(s)
		N	Inclusion criterion social anxiety/ subtype (with measurement instrument)	Age in years M (SD)	Gender n or %	Ongoing medication or treatment (beside VR assessment/ intervention)		
Price et al. (2011a)	(Randomized) controlled trial	41	Diagnosis of SAD (DSM-IV, SCID)	N/A	60% female, 40% male	N/A	*VR Intervention/assessment* To evaluate the relations between three theorized components of presence, fear ratings during VRE and treatment response for VRE for social phobia	Self-report of social anxiety (PRCS), self-reported anxiety level (SUD)
Reeves et al. (2021)	Randomized controlled trial	103	Score on the PSAS >/60	360° audience: 27.40 (9.25) 360° empty: 26.60 (6.79) CG: 24.17 (6.53)	94% female, 6% male 94% female, 6% male 95% female, 5% male	no actual therapy, no medication	*VR Intervention* To examine whether stand-alone 360° video VRET is an effective intervention for treating PSA and interrelated disorder relevant fears	Self-Report of PSA-Symptoms (PSAS, LSAS-SR)
Reichenberger et al. (2017)	Randomized controlled study	55	Using the SPIN cut-Off >/ 19 (HSA)	21.6 (3.23)	78.30% female 21.70% male	medication, and psychotherapy as exclusion criterion	*VR Intervention/assessment* Validation of selected VR scenarios for Social Skills Training	Self-reported anticipatory anxiety (via rating), physiological measures: HR, EDA
Reichenberger et al. (2019)	Quasi-experimental study	60	Using the SPIN cut-Off >/ 19 (HSA)	21.21 (3.21)	52% female, 48% male	no medication, no treatment	*VR Assessment* To investigate gender differences and the effect of male versus female agents in low and high socially anxious participants regarding acquisition and extinction of social fear in VR	Psychophysiology, behavior, and cognition (recognition task), Self-report of social anxiety (SPIN and SIAS)
Reichenberger et al. (2020)	Randomized controlled study	53	Using the SPIN cut-Off >/ 19 (HSA)	N/A	54% female, 46% male	medication, and actual psychotherapy as exclusion criterion	*VR Assessment* To investigate the effect of induced and extinguished social fear on physical behavior, hypervigilance and attentional avoidance toward female and male agents in HSA and LSA in the SFC in VR	Physical behavior (duration to approach, gaze behavior), self-reported anxiety

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TABLE 2 Continued

References	Study design	Participants					Aim of VR application and study aim	Primary outcome variable(s)
		N	Inclusion criterion social anxiety/ subtype (with measurement instrument)	Age in years M (SD)	Gender n or %	Ongoing medication or treatment (beside VR assessment/ intervention)		
Reichenberger et al. (2022)	Randomized controlled multicenter study	62	Diagnosis of SAD (DSM-V, SCID)	28.61 (8.32)	25 females, 16 males (EG) 14 females, 7 males (CG)	N/A	*VR Assessment* To investigate if it's possible to evoke feeling of anxiety with social interaction in VR and to compare the reactions of patient with SAD and health controls	Self-reported fear response to the scenarios (SUD), psychophysiological measures (EDA; HR)
Rubin et al. (2022)	2-arm randomized controlled trial	21	Diagnosis of SAD (DSM-V, SCID), score >98 in PSAS, >30 in LSAS, peak fear >/ 50 on the behavioral approach task	25.90 (15.42)	8 females (EG) 5 females (CG)	N/A	*VR Intervention* To investigate attentional avoidance as a potential mechanism for SAD To investigate whether individuals who received VRET augmented with attention guidance would show greater reduction in symptoms of social anxiety	Self-reported symptoms of social anxiety (PRCS, LSAS-SR) proportion of fixations to audience members
Stupar-Rutenfrans et al. (2017)	Longitudinal quasi-experimental study	35	A moderate or high anxiety level state (a score 55 or higher in the PRCA, Personal Report of Communication Apprehension scale)	N/A	25 females, 10 males	N/A	*VR Intervention* To increase the understanding how mobile VR exposure therapy can reduce speaking anxiety To examine the effect of a new VRET strategy (Public Speech Trainer, PST)	Self-reported Speaking Anxiety (PRCA-24), Anxiety state (STAI)
Wechsler et al. (2021)	Randomized controlled study	48	Using the SPIN cut-Off >/ 19 (HSA)	Social focus group: 21.09 (3.25) non-social focus group: 20.10 (1.52)	80% female 20% male 95% female 5% male	no	*VR-Intervention* To investigate the effects of an attention training during public speaking in VR and to examine differential effects of an external focus on nonsocial vs. social stimuli	Self-report of anxiety (SUD), proportion of looking time (via eye-tracking)

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TABLE 2 Continued

References	Study design	Participants				Aim of VR application and study aim	Primary outcome variable(s)
		N	Inclusion criterion social anxiety/ subtype (with measurement instrument)	Age in years M (SD)	Gender n or %	Ongoing medication or treatment (beside VR assessment/ intervention)	*VR Intervention* To investigate the efficacy of self-guided/self-directed VR exposure
Zainal et al. (2021)	Pilot randomized trial	44	Diagnosis of SAD (DSM-5, MINI)	23.30 (9.32)	77% female, 2 3% male	N/A	Self-report of SAD Symptom severity, Job Interview Anxiety Severity

The left side of this table presents the study design, and the number of participants included in the individual studies, their inclusion criterion regarding social anxiety or subtype of social anxiety, their age, the distribution of the sexes (biological sex) and the presence of medication or any treatment. Age is reported as means and standard deviations for the whole sample. The distribution of gender is presented as absolute numbers or as percentages of female and male participants and is reported either for the whole sample or separately for both conditions (treatment conditions, or control group CG). The right side of the table gives an overview of the aim of the VR, application (intervention or assessment) and the research question(s) of the individual studies. Primary outcome variable(s) are predominantly reported in form of self-reported questionnaires; PRCS, Personal Report of Confidence as a Speaker; FNE-B, Fear of Negative Evaluation–Brief Form; LSAS-SR, Liebowitz Social Anxiety Scale-Self Reported version; NMMSP, Networked Minds Measure of Social Presence; IPQ, iGroup Presence Questionnaire; SIAS, Social Interaction Anxiety Scale; STAI-S, State-Trait-Anxiety-Inventory; SUDS, Subjective Units of Distress Scale; N/A, information was not available. BFNE, Brief Form of Fear of Negative Evaluation; PSAS, Public Speaking Anxiety Scale; GAD-7, Generalized Anxiety Disorder 7-item; BBQ, Brunnsviken Brief Quality of Life scale; SSPS, Self-Statements During Public Speaking; SUD, Subjective Units of Distress Scale; HR, heart rate; EDA, electrodermal activity; RSA, respiratory sinus arrythmia; IPQ, iGroup Presence Questionnaire; PRCS, Personal Report of Confidence as a Speaker; PSAS, Public Speaking Anxiety Scale; LSAS-SR, Liebowitz Social Anxiety Scale Self-Report version; SPIN, Social Phobia Inventory; PRCA-24, Personal Report of Communication Apprehension scale; STAI, State-Trait Anxiety Inventory.

podium (e.g., Burton et al., 2013; Donahue et al., 2009) with a laptop (Stupar-Rutenfrans et al., 2017). Social interactions also took place in various contexts, for example in virtual cafés, restaurants or at a special party (e.g., Geraets et al., 2019; Kampmann et al., 2016a; Kim et al., 2017).

The social environment (see RQ 1C), represented by virtual agents, varied substantially across studies in terms of audience size, appearance, and behavioral features. Depending on the virtual situation, the number of agents ranged from single interaction partners [e.g., a waiter in a café (Kampmann et al., 2016b), a shop assistant (Kampmann et al., 2016a)] to large audiences of up to 117 individuals in auditoriums or lecture halls (Nazligul et al., 2019). Typical configurations included conference rooms with five virtual audience members (Anderson et al., 2013; Burton et al., 2013), classrooms with around 35 agents (Anderson et al., 2017; Burton et al., 2013), and auditoriums with approximately 100 audience members (Anderson et al., 2003; Stupar-Rutenfrans et al., 2017). Several VR applications allowed manipulation of the audience size and its behavioral characteristics, including eye contact, attentiveness, and feedback behaviors such as laughing, whispering, applauding, or disengagement (see Table 3 for a detailed overview).

It is important to note, that of the 19 intervention studies, two studies utilized 360-degree video environments (Rubin et al., 2022; Stupar-Rutenfrans et al., 2017), whereas the remaining studies applied rendered virtual environments (e.g., Lindner et al., 2021; Wechsler et al., 2021).

5.2.2 Technical realization of VR scenarios for SAD intervention

All intervention studies used head-mounted displays (HMDs) as the primary output device (see RQ 2A) to deliver immersive visual and auditory stimulation, often complemented by additional headphones (e.g., Anderson et al., 2017; Nazligul et al., 2019) or earphones (Kim et al., 2017; Jeong et al., 2021). Across these HMD studies, a total of seven distinct models were reported; however, two studies (Burton et al., 2013; Price et al., 2011a) did not specify the model used. Among the 13 studies using PC-tethered or standalone (Lindner et al., 2021) HMDs, the most frequently applied models were the HTC Vive Pro (e.g., Wechsler et al., 2021; Kim et al., 2020), the Oculus Rift DK2 (e.g., Ma et al., 2019; Rubin et al., 2022), followed by VFX3D (e.g., Anderson et al., 2013; Kampmann et al., 2016b), the eMagin z800 (Bouchard et al., 2017; Donahue et al., 2009), HMZ-T1 (Geraets et al., 2019), Pico Globulin (Zainal et al., 2021), and Oculus Go (Lindner et al., 2021). In five studies using smartphone-based HMDs, the Samsung Gear paired with a smartphone was the most commonly reported device (e.g., Jeong et al., 2021; Reeves et al., 2021). Supplementary Table S2 provides an overview of all HMDs used across studies including model, field of view, per-eye resolution, and refresh rate.

Regarding input devices (see RQ 2B), all setups employed head-tracking, with several studies additionally integrating motion (e.g., via Cube Motion Tracker, see Bouchard et al., 2017) or eye-tracking (e.g., Rubin et al., 2022; Wechsler et al., 2021) systems to capture participants' additional body movements (beside head-movements) or gaze behavior. A detailed overview of input and output modalities is provided in Table 3.

TABLE 3 Description of virtual environments, technical realization, and social tasks of VR intervention applications.

References	Additional VR assessment	Virtual environments			Technical realization				VR social tasks				Self-guided/ therapist/ guided
		Content of the virtual social situations	Design of non-social environment	Design of social environment (virtual agents)	VR output devices	VR input devices	Realization of movement	Realization of interaction of the agents	Description of the task	Theoretical, empirical, and/ or therapeutical background	Specific age group	Target group	
Anderson et al. (2013)	Yes	Virtual conference room with 5 audience members, a virtual classroom with 35 audience members, and a virtual auditorium (+100 audience members)	Virtual conference room, virtual classroom, virtual auditorium with audience members of a different size	n = 5 audience members in a virtual conference room n = 35 audience members in a virtual classroom n = 100 audience members in a virtual auditorium avatars can pose questions	HMD, voiceover, headphones	Head-tracking	Head-movement	Controlled by the therapist	Participants were asked to give a speech in front of an audience. Individual treatment = exposure to feared situations according to a fear hierarchy	CBT, fear hierarchy for each person, graduated exposure therapy with the goal of habituation, cognitive restructuring, relaxation training	Middle aged adults	Well-educated, middle to upper class participants with public speaking as the main fear	Therapist-guided
Anderson et al. (2017)	Yes	Virtual conference room with 5 audience members, a virtual classroom with 35 audience members, and a virtual auditorium (+100 audience members)	Virtual conference room, virtual classroom, virtual auditorium with audience members of a different size	n = 5 audience members in a virtual conference room n = 35 audience members in a virtual classroom n = 100 audience members in a virtual auditorium, avatars can pose questions	HMD, voiceover, headphones	Head-tracking	Head-movement	Controlled by the therapist	Participants gave a speech in front of audience members	CBT + VR exposure therapy (VRET)	Middle aged adults	Individuals with public speaking anxiety, SAD	Therapist-guided
Bouchard et al. (2017)	Yes	Eight exposure scenarios including speaking in front of an audience in a virtual meeting room, having a job interview, having a talk with relatives in an apartment, coffee-shop and store; neutral scenario	A neutral environment, a job interview, talking with supposed relatives in an apartment, a coffee shop, meeting unfriendly neighbors, refusing to buy goods at a store	N/A	HMD, mouse	Motion-tracking	Movement with a wireless computer mouse while interacting and speaking aloud to the virtual agents	Preformatted answers triggered by the therapists	Exposure to eight scenarios with different tasks, e.g., speaking in front of an audience, introducing oneself, acting under the scrutiny of strangers	Social exposure in VR, individual CBT	N/A	Individuals with SAD	Therapist-guided
Burton et al. (2013)	No	Virtual environments including a podium, and a virtual audience. Scenario either consisted of a small group of individuals in a conference room setting, a classroom setting, or a large group in an auditorium	Virtual conference room, virtual classroom and virtual auditorium	n = 5 individuals (virtual audience made up of images of real individuals superimposed in a virtual scenario) n = 35+ individuals or n = 100+ individuals in the scenario	HMD	Head-tracking	Head-movement	Reactions of avatars can be controlled by therapist	Participants were exposed to different virtual scenarios related to public speaking (fear hierarchies were created for each participant based on the available virtual environments)	VR exposure therapy based on CBT; Individual fear hierarchies were created for each participant based on the available virtual environments	Adults (40)	Treatment seeking adults diagnosed with SAD and public speaking as primary fear	Therapist-guided

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TABLE 3 Continued

References	Additional VR assessment	Virtual environments			Technical realization				VR social tasks				Self-guided/ therapist/ guided
		Content of the virtual social situations	Design of non-social environment	Design of social environment (virtual agents)	VR output devices	VR input devices	Realization of movement	Realization of interaction of the agents	Description of the task	Theoretical, empirical, and/ or therapeutical background	Specific age group	Target group	
Donahue et al. (2009)	Yes	Participants viewed a virtual certain and podium and heard audience noise in the background; participants were given 4 min to prepare their speech (2 themes) story: "imagine that you are running for president of the university government, and you will now speak in front of a faculty board"	Virtual certain and podium, audience noise which coming from behind the curtain, after preparation time of 4 min the virtual certain was opened, disruptions = a cell phone ringing	Audience could be manipulated in regard of maintaining eye contact, audience disruptions (e.g., asking a question, one agent is leaving the room or falling asleep)	HMD	Head-tracking	Head-movement	Virtual agents were maintaining eye-contact with presenter, asking a standard question (prerecorded)	One of two speech tasks á 4 min 1) "Why you are a good candidate for this office" 2) "How you plan to make university a better place to go to school"	Exposure Treatment of SAD with medication (quetiapine)	N/A	Individuals with Social Phobia	Therapist-guided
Geraets et al. (2019)	No	A virtual street, bus, café, and supermarket were available. The environments could be manipulated by the therapists. During the VR exercises patients tested their beliefs, approach behaviors were elicited, and feedback was given	Virtual street, bus, café, and supermarket environment. Sounds such as sirens and laughing were also available	Virtual agents could be manipulated in their crowdedness (0–40 virtual humans), in their ethnicity (% Caucasian or North-African appearance), gender, intensity and frequency of hostile looks, interpersonal distance, and watching/ staring behavior. Prerecorded sentences	HMD, headphones	Head-tracking	Movement with joystick, head-movement	Answers were prerecorded; behavior could be manipulated by therapist	Exposure to virtual environments and testing own beliefs, eliciting approach behaviors	Individual VR-CBT	N/A	Patients with severe generalized SAD	Therapist-guided
Jeong et al. (2021)	No	Three environments in which 12 situations and 36 topics were provided: conversation with some people, presentation in front of a small, and moderate audience size, a large audience size, and in front of evaluators	12 situations, e.g. a conference room, auditorium, business life situations (e.g. job interview), restaurant (company lunch situation), team meeting	No numbers; small audience, moderate audience, large audience	HMD, earphones and headphones	Head-tracking, eye-tracking	Head-movement	Prerecorded sentences and answers	Public speaking, different situations and tasks, to give a presentation	VR-based CBT	N/A	SAD patients	Therapist-guided

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TABLE 3 Continued

References	Additional VR assessment	Virtual environments			Technical realization				VR social tasks				Self-guided/ therapist/ guided
		Content of the virtual social situations	Design of non-social environment	Design of social environment (virtual agents)	VR output devices	VR input devices	Realization of movement	Realization of interaction of the agents	Description of the task	Theoretical, empirical, and/ or therapeutical background	Specific age group	Target group	
Kampmann et al. (2016a)	No	Different virtual situations: classroom, bus stop, restaurant, shop, train platform, meeting room, neutral world, and café. With virtual agents in form of an audience, or shop assistant, or strangers at a bus stop	Virtual classroom, bus stop, restaurant, shop, train platform, meeting room, and virtual café	Depends on virtual situation: classroom with an audience of 12 attendees, one stranger at a bus stop, cloth shop with one shop assistant, train platform with two men, meeting room with a smaller audience, café with a waiter or a blind date	HMD	Head-tracking	Head-movement	Controlled by therapist, prerecorded sentences	To give a talk, talking to a stranger, practicing a job interview, meeting a friend for a dinner, conversation with a shop assistant, talking about the own opinion, to give a talk and answer questions, to have a blind date and talk about personal topics with the person	Cognitive behavioral treatment for SAD, Virtual reality exposure therapy (gradual)	Adults	Individuals with SAD, not only public speaking anxiety (generalized SAD)	Therapist-guided
Kim et al. (2017)	No	Three different social situation sets: school, business, everyday life; after the beginning of each topic, there was a listening phase (avatars introduced the topic)	Virtual environment offered three social situation sets: school (e.g., classroom, casual talk), business (e.g., company lunch, team meeting), everyday life (e.g., café, party, train)	One or two avatars introduced the topic, asking a question and giving introductory speeches; number of avatars, their gestures and distractions (e.g., nodding, yawning) varied	HMD, in-ear earphones	Head-tracking, eye-tracking	Head-movement	N/A	To speak as long as possible in response to the avatars' speaking phase (in each topic)	Cognitive behavioral therapy in treating Social Phobia	Young adults	SAD patients	Self-guided
Kim et al. (2020)	No	Participants engaged in social situations: entering a room, where meeting several other college students and to introduce themselves to each other; 7 to 8 nonplaying characters appeared and introduced themselves	Room where meeting several college students	7 to 8 nonplaying characters appeared and introduced themselves: they listened to the participants' self-introduction, level of difficulty determined character's attitude: they become more distracted and made small talk, they say "Please introduce yourself properly!"	HMD, headphones, pressing a button	Head-tracking, eye-tracking	Head-movement	Reactions depend on difficulty level, prerecorded	Self-introduction	Graduated exposure with the goal of habituation	Young adults	Adolescents with SAD	Unclear if the researchers present acted as supportive therapists or only assisted with technical issues
Kim et al. (2022)	No	VRs program consisted of 36 social topics, which could be grouped into 12 situations from three environments: daily life, school life, and business life	Virtual conference room, auditorium, business life situations (e.g. job interview), restaurant (company lunch situation), team meeting	The topics have different numbers of virtual avatars and various levels of difficulties	HMD	Head-tracking, eye-tracking	Head-movement	N/A	E.g., to give a talk, talking to a stranger, practicing a job interview, meeting a friend for a dinner, conversation with a shop assistant, talking about the own opinion, to give a talk and answer questions, to have a blind date	VR self-training (VRS) at home, mobile-based VR technique	N/A	SAD patients	Self-guided

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TABLE 3 Continued

References	Additional VR assessment	Virtual environments			Technical realization				VR social tasks				Self-guided/ therapist/ guided
		Content of the virtual social situations	Design of non-social environment	Design of social environment (virtual agents)	VR output devices	VR input devices	Realization of movement	Realization of interaction of the agents	Description of the task	Theoretical, empirical, and/ or therapeutical background	Specific age group	Target group	
Lindner et al. (2021)	No	Systematic exposure using a series of speech tasks in three different environments (board room, conference room, and classroom) which varied regarding audience size and proximity	Virtual board room, conference room, and classroom	Audience size varied, a selected set of audience behaviors (laughing, booing, and applauding)	HMD, headphones	Head-tracking	Head-movement	N/A	Participants have to give a speech in front of an audience	CBT + VRET	N/A	Patients with SAD and Public speaking anxiety	Therapist-guided
Ma et al. (2019)	No	Dot-Probe Task to measure and modify attentional bias: stimuli set with 32 individuals each showing a neutral or a disgusted expression, 2D or 3D images	Probes "E" or "F" appeared on top or bottom	32 individuals (50% female) ach showing a neutral or a disgusted expression (64 expressions), 2D or 3D images	HMD	Head-tracking, eye-tracking	Head-movement	N/A	Participants were instructed to identify the letter as quickly as possible by pushing the controller joystick left or right	Cognitive models of social anxiety disorder, attentional bias in social anxiety, criticism of traditional ABM training Dot-Probe-Task to measure and modify attentional bias	N/A	General population with social anxiety	N/S
Nazligul et al. (2019)	No	Virtual training environment consisting of three different venues with different physical dimensions and different audience capacities (standard classroom, blue auditorium, red auditorium). Participants had to make a presentation in front of an audience	Virtual standard classroom, blue auditorium, red auditorium	Capacity of the classroom is designed to be 32 virtual agents, the blue auditorium to be 70, and the red auditorium to be 117 people. The characteristics can be controlled by the therapist (eight different audience models were used)	HMD, headphones	Head-tracking	Movement using the keys on a keyboard and the mouse, head-movement	Reactions can be manipulated by the therapist, e.g., texting, yawning, predetermined asking questions	Participants have to make a presentation in front of an audience (topics: effects of social media, education system, or being vegetarian), preparation of the speech 3 min	Exposure Cognitive biases and distortions in the social-information processing resulting in social phobic effect and behaviors	Students (younger adults)	Novel software engineers with PSA	Therapist-guided
Reeves et al. (2021)	No	VR stimuli were real life audience members; they were briefed to act as they naturally would when listening to a speech	Small classroom, large classroom, medium conference room, large conference room	Real-life audience members who act as they naturally would when listening to a speech (3 audience members/6 audience members/24 audience members/60 audience members)	HMD	Head-tracking	Head-movement	Prerecorded reactions (videos)	Participants have to give a speech and were presented to five topics and have to speak for 4–15 min	Exposure therapy and CBT	N/A	Individuals with PSA	Therapist-guided

(*Continued*)

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TABLE 3 Continued

References	Additional VR assessment	Virtual environments			Technical realization				VR social tasks				Self-guided/ therapist/ guided
		Content of the virtual social situations	Design of non-social environment	Design of social environment (virtual agents)	VR output devices	VR input devices	Realization of movement	Realization of interaction of the agents	Description of the task	Theoretical, empirical, and/ or therapeutical background	Specific age group	Target group	
Rubin et al. (2022)	No	Participants have to give six speeches and have to focus on a different audience member's face in a conference room	Virtual conference room with chairs and a conference table, a lecture hall	An audience of 6 individuals acting as if they are listening to a speech with varying levels of interest (e.g., nodding, smiling, looking away, on the phone); were live recorded (actors were researchers)	HMD	Head-tracking, eye-tracking	Head-movement	Prerecorded behaviors	To give six 3-min speeches delivered while standing in front of an audience and modify attentional focus	Attentional bias in Social Anxiety disorder, attention bias modification trainings	Adults	Adults with SAD	Therapist-guided
Stupar-Rutenfrans et al. (2017)	Yes	VR stimuli were real life recordings that took place in a lecture hall with 100 students and 2 teachers. Participants had to give a speech	Recordings of a real-life lecture hall (empty room or room with audience, windows, tables, laptop and podium)	No audience, small audience (12 people), or a big audience	HMD	Head-tracking	Head-movement	N/A	Participants should train to talk in front of an audience	VRET	Students (young adults)	Students with high and moderate level of public speaking anxiety in the Netherlands	Self-guided
Wechsler et al. (2021)	No	Virtual environments consisting of two rooms (a hallway and a lecture room). Participants could see objects and people in their immediate field of view. Attentional training and giving a speech in front of an audience	Virtual hallway, participants could see objects, hear background noises (speaking noises and nonverbal noises). Lecture room with 4 rows	In the virtual lecture room, 16 virtual audience members were sitting in four rows, four in each row. Male, and female, showing a positive and a negative facial expression. They were scripted to direct their gaze towards the speaker during the whole talk	HMD, headphones	Head-tracking, eye-tracking	Head-movement	Gaze of agents was scripted - looking towards the participant during the whole talk	Attention focus exercise in the virtual hallway (describing noises, objects, peoples) and then shifting the attention from self-focus to external stimuli during giving a speech in front of a virtual audience	Attentional bias in Social Anxiety Disorder, Cognitive behavioral therapy, attentional trainings	N/A	Students with high social anxiety	Therapist-guided
Zainal et al. (2021)	No	Participants are coached by a virtual therapist. They could choose between informal dinner party or the formal interview scenes. Exposure to dinner party job interview	Dinner party setting and job interview setting (being in a waiting room, conference room, office cafeteria)	Host of the dinner party (virtual agent), multiple agents at the dinner party, an authority person. At the job interview with two other visible anxious interviewees, one-on-one format	HMD	Head-tracking, movement-tracking	Head-movement	bidirectional social interactions (recognition of verbal output, preprogrammed reactions)	Exposure to a dinner party or job interview. Within the two environments different tasks are obvious, e.g., introducing to the host of the party, ordering a drink in front of others	Virtual Reality Exposure therapy, emotional processing theory, inhibitory learning, therapist-guided VRE	Young to middle aged adults	Persons with SAD and diverse interpersonal fears	Self-guided

N/A, information was not available; N/S, information was not specified; HMD, head-mounted display; CBT, cognitive behavioral therapy; VRET, virtual reality exposure therapy.

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Among the five studies providing detailed information on movement methods (see RQ 2C), participants navigated within the virtual environments using a handheld-controller (Geraets et al., 2019), a wireless computer mouse (Bouchard et al., 2017), keyboard keys (Nazligul et al., 2019), or an active head-tracking system (Price et al., 2011b; Wechsler et al., 2021).

The realization of interaction between participants and virtual agents (see RQ 2D) varied across studies. In most cases, agents' reactions were prerecorded to ensure standardized responses (e.g., Anderson et al., 2013; Reeves et al., 2021). Typical agent behaviors included maintaining eye contact, nodding, yawning, or asking predefined questions. Several studies further provided live-controllable elements for the therapist allowing adjustments to parameters such as audience reactions (e.g., appearing interested, hostile, or distracted; asking prerecorded questions) (e.g., Anderson et al., 2013; Anderson et al., 2017), gaze behavior of agents (Donahue et al., 2009; Geraets et al., 2019), or dialogue style and speech topics (Kampmann et al., 2016b) (see Table 3).

5.2.3 Virtual social tasks for SAD intervention

In most intervention studies (15 of 19 studies), participants' primary task or challenge (see RQ 3A) was to perform anxiety-provoking social exercises, such as giving a speech or presentation in front of a virtual audience (see Table 3). The other tasks focused on everyday social interactions, including ordering a drink in front of others (Zainal et al., 2021), acting under the scrutiny of strangers (Bouchard et al., 2017), conversing with a shop assistant or stranger (Kampmann et al., 2016a), meeting friends for dinner (Zainal et al., 2021), going on a blind date (Kim et al., 2022), or going to a special party (Kim et al., 2017). No studies were found that implemented tasks or challenges addressing fear of blushing, eating in public or other subtypes of SAD.

The theoretical and therapeutic rationale (see RQ 3B) across studies was primarily grounded in CBT and VRET, often following graduated exposure principles based on individualized fear hierarchies, with the goal of habituation and corrective learning (see Table 3). Some interventions also integrated mindfulness-based CBT, or cognitive models of Social Anxiety (e.g., Clark and Wells, 1995; Rapee and Heimberg, 1997) to address attentional biases, avoidance behaviors, and self-focused attention. For example, the study by Wechsler et al. (2021) integrated an attention training task, instructing the participants to shift focus from self-focused attention toward social or non-social stimuli (see Figure 2).

Regarding the targeted age group (see RQ 3C), there was a range from young adults and students (e.g., Stupar-Rutenfrans et al., 2017; Zainal et al., 2021), to finally middle aged adults (e.g., Anderson et al., 2017; Kampmann et al., 2016b). Nine studies did not describe the specific age of participants (e.g., Price et al., 2011a; Reeves et al., 2021) (see Table 3 for the whole overview). Importantly, we could not identify studies in children and in adolescents below the age of 18 years. With regard to further target group characteristics (see RQ 3D) it can be noted that, overall, the studies predominantly aimed at individuals and patients with (generalized) SAD and highly socially anxious individuals with PSA (Table 3). Some studies have defined a highly specific target group: the intervention by Burton et al. (2013) specifically targeted at treatment seeking adults diagnosed with SAD and public speaking as the primary fear; Stupar-Rutenfrans et al. (2017) aimed at students with high and moderate level of public speaking anxiety in the Netherlands; Zainal et al. (2021) targeted at persons with SAD and diverse interpersonal fears, and Nazligul et al. (2019) focused on novice software engineers with PSA. In the other studies, a specialized target group was not clearly defined (e.g., Kim et al., 2022; Lindner et al., 2021).

Regarding manualization (see RQ 3E), eleven studies mentioned a specific treatment manual as background for their VR intervention task (e.g., manual based on Clark and Wells in Bouchard et al., 2017; manual based on related CBT protocols for SAD in Zainal et al., 2021), seven studies did not relate to such (see Supplementary Table S6).

The number and duration of VR sessions (see RQ 3F) and non-VR sessions (see RQ 3I), as well as the duration of the whole VR task and one VR session (see RQ 3G + RQ 3H) applied within the VR intervention studies varied from 1 (Lindner et al., 2021; Wechsler et al., 2021) to 14 (Geraets et al., 2019) VR sessions and 1 (e.g., Kampmann et al., 2016b; Lindner et al., 2021) to 4 (Anderson et al., 2013) non-VR-sessions. The duration of one VR session ranged from 30 min (Kampmann et al., 2016a; Zainal et al., 2021) to 180 min (Lindner et al., 2021), and the duration of the whole VR task from approximately 3 min (e.g., Rubin et al., 2022; Lindner et al., 2021) to 30 min (Bouchard et al., 2017). Some studies did not give information on the question of number and duration of sessions (e.g., Anderson et al., 2017; Kim et al., 2020) (for more details see Supplementary Table S6). Regarding the modus self-guided vs. therapist guided (see RQ 3J), four studies implemented the VR intervention as a self-led tool (Kim et al., 2017; Kim et al., 2022; Stupar-Rutenfrans et al., 2017; Zainal et al., 2021), while all other studies followed a therapist-guided approach (see Table 3). Regardless of the modus, individual studies used different levels of difficulty (see RQ 3K), which were determined by differences in the attitude and reactions of the virtual agents toward the participants (e.g., they become more distracted, e.g., Kim et al., 2020), or in the number of virtual agents present in the scenario (e.g., Reeves et al., 2021; Stupar-Rutenfrans et al., 2017) (see Supplementary Table S6).

5.3 VR assessment in SAD

Table 4 provides a detailed overview of the virtual environments, the technical realization, and the VR tasks in the eight VR assessment studies, as well as in the four studies conducting assessment and intervention.

5.3.1 Description of virtual environments used for SAD assessment

Similar to intervention studies, the virtual social situations (see RQ 1A) which the assessment studies used, included performance scenarios [speeches (Owens and Beidel, 2015; Parrish et al., 2016), self-introduction (Kishimoto and Ding, 2019)] and social interaction scenarios [house party (Parrish et al., 2016), train compartment (Reichenberger et al., 2017; 2022), travel agency (Reichenberger et al., 2017; 2022), shopping center (Holmberg et al., 2020), café (Felnhofer et al., 2019)]. Table 4 summarizes the design of both non-social and social environments (RQ 1B+ 1C). For public speaking assessments, the contexts (see RQ 1B) were

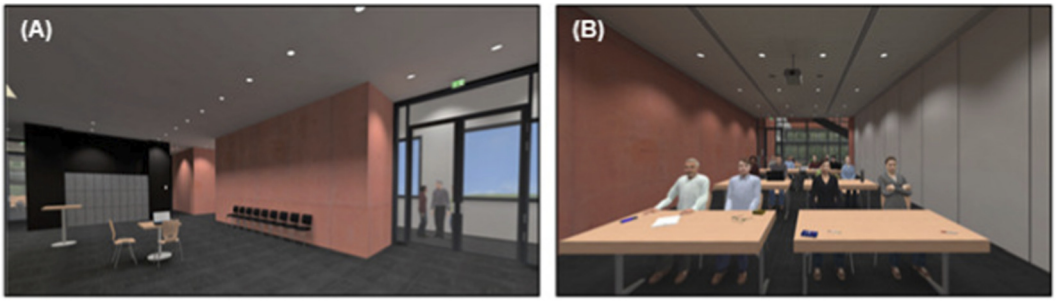

FIGURE 2
VR environments used in the study by Wechsler et al. (2021); used with permission by the authors and by courtesy of VT plus GmbH). **(A)** Virtual hallway with two agents in the corridor for VR attention training **(B)** Virtual lecture room with non-social objects (e.g., tables, windows, items on the tables, etc.) and social stimuli (a virtual audience sitting in rows) for a VR speech task with additional attention training. Audience members of different genders and with positive and negative emotional expressions were implemented.

virtual classrooms (e.g., Hur et al., 2021; Price et al., 2011b), conference rooms (e.g., Kishimoto and Ding, 2019; Owens and Beidel, 2015), or large auditoriums (Price et al., 2011a). While most studies provided only limited information regarding environmental design, some reported additional contextual details. For instance, Owens and Beidel (2015) included a virtual waiting room preceding the speech task, and Parrish et al. (2016) integrated background sounds such as cell phone ringing to increase ecological validity. In another setting by Parrish et al. (2016), participants attended a virtual house party accompanied by background music. In contrast, Reichenberger et al. (2017), Reichenberger et al. (2022) created social interaction contexts in a travel agency and a train compartment, while Holmberg et al. (2020) used 360-degree videos depicting real-life shopping scenarios filmed in an actual Danish shopping center (e.g., main entrance area, kitchen equipment store) (see Table 4).

The social environment (see RQ 1C) was realized in presenting virtual agents whose number, appearance, and behavioral responses varied substantially across studies (see Table 4). For instance, Hur et al. (2021) used a group of eight student agents who first introduced themselves; depending on task difficulty, the agents' behavior changed and included unkind reactions or mutual staring. In other paradigms, virtual audiences consisted of five to thirty agents (e.g., Owens and Beidel, 2015; Parrish et al., 2016), whereas in larger auditoriums up to 100 audience members were depicted (Owens and Beidel, 2015). Typical audience behaviors included displaying ambiguous or negative feedback such as folding arms, looking away, checking phones, taking pictures, or shaking their heads, while others showed supportive reactions such as nodding or clapping at the end of the task (see Table 4 for a detailed overview). In Reichenberger et al. (2017), Reichenberger et al. (2022), virtual agents acted as interaction partners with prerecorded verbal responses and synchronized lip movements - for instance, a passenger initially refused to release a train seat, or an employee denied a booking cancellation, requiring participants to assert themselves.

It is important to note, that of the twelve assessment studies, one study utilized 360-degree video environments (Holmberg et al., 2020), whereas the remaining studies applied rendered virtual environments (e.g., Reichenberger et al., 2020; Parrish et al., 2016) for presenting social stimuli and contexts.

5.3.2 Technical realization of VR scenarios for SAD assessment

As output device for visual immersion in VR, eleven out of twelve studies used HMDs as the primary output device (see RQ 2A), whereas one study (Lange and Pauli, 2019) employed a CAVE system (see Supplementary Table S2; Table 4). Across the HMD studies, a total of six distinct models were reported; however, one study (Owens and Beidel, 2015) did not specify the model used. Among the ten studies using PC-tethered HMDs, the most frequently applied models were the HTC Vive Pro (e.g., Reichenberger et al., 2019; Reichenberger et al., 2020), the Oculus Rift DK2 (e.g., Reichenberger et al., 2017; Reichenberger et al., 2022), followed by VFX3D (Parrish et al., 2016), HMZ-T1 (Felnhofer et al., 2019), and Adai-OTO-VR1-T1 (Kishimoto and Ding, 2019). Holmberg et al. (2020) used the mobile VR headset BOBO VR. Supplementary Table S2 provides an overview of all HMDs used across studies including model, field of view, per-eye resolution, and refresh rate. In contrast, Lange and Pauli (2019) employed a 3D multisensory CAVE system featuring four projection surfaces (resolution: 1920 × 1,200; one surface: 2016 × 1,486), with participants wearing 3D glasses.

Input modalities (see RQ 2B) included head-tracking (e.g., Felnhofer et al., 2019; Reichenberger et al., 2019) and partially additional eye-tracking (Reichenberger et al., 2019) to capture participants' gaze behavior. However, some studies did not provide detailed information regarding these technical specifications (e.g., Hur et al., 2021; Price et al., 2011b). Among the studies providing detailed information on movement methods (see RQ 2C), participants navigated within the virtual environments using a joystick (e.g., Reichenberger et al., 2017; Reichenberger et al., 2019), a smartphone device (Felnhofer et al., 2019), or an active head-tracking system (e.g., Lange and Pauli, 2019; Kishimoto and Ding, 2019) (see Table 4).

To ensure interaction between the virtual agent and participants (see RQ 2D), preprogrammed (Felnhofer et al., 2019) and prerecorded reactions and responses (Hur et al., 2021; Reichenberger et al., 2017) were predominantly used. These could be triggered and controlled live by the therapist in some studies (e.g., Parrish et al., 2016; Price et al., 2011a). Making eye contact was also part of the typical behavior of the virtual agents

TABLE 4 Description of virtual environments, technical realization, and social tasks of assessment and assessment/intervention applications.

References	Aim of application	Virtual environments			Technical realization				VR social task				Self-guided/ therapist/ guided
	Assessment or assessment/ intervention	Content of the virtual world	Design of non-social environment	Design of social environment (virtual agents)	VR output devices	VR input devices	Realization of movement	Realization of interaction of the agents	Description of the task	Theoretical, empirical, and/ or therapeutical background	Specific age group	Target group	
Felnhofer et al. (2019)	Assessment	Virtual cafe with three social tasks	Virtual café setting	N/A	HMD	Head-tracking	Movement and navigation with a smartphone device, Head-movement	Preprogrammed reactions	Ordering a drink from the waiter, responding to a stranger's request, and reacting to being offered a false drink	Relationship between presence and affective responses in SAD, causal model proposed by Robillard et al., exposure to phobic stimuli	Students (younger adults)	N/A	Therapist-guided
Holmberg et al. (2020)	Assessment	Three VR shopping videos (graduated in numbers of people present): e.g., being welcomed by the shop personal, bystanders with negative statements about the personnel and their service	The Main entrance of big Danish shopping center, inside the center: kitchen equipment store	VR-shopping videos which graduated in numbers of people present	HMD	Head-tracking	Head-movement	Videos with reactions were developed before (no direct interaction)	Participants had, e.g., to enter in a shopping center, stopping in front of a shop, standing in a short queue, waiting and receiving a gift card from the store clerk	VR exposure	N/A	SAD patients	Therapist-guided
Hur et al. (2021)	Assessment/ intervention	Scenario was a team meeting in class: a student group was meeting for the first time to discuss an assigned task and introduce themselves meditation in VR: gently shaking tree	Meditation-based warm-up virtual setting (core stage) 7 to 8 nonplayers introduced themselves (a college student group was meeting) finishing meditation	College student group was meeting for the first time (7–8 nonplayer characters introduced themselves) According to the level of difficulty reactions of the characters could differ, e.g., unfavorable reaction, staring intently at each other	HMD, headphones	Head-tracking	Head-movement	Prerecorded reactions (according to difficulty level)	TO discuss an assigned task and to introduce themselves	Graduated exposure	Adolescents/ adults	Individuals with high social anxiety	Unclear if the researchers acted as supportive therapists or only assisted with technical issues
Kishimoto and Ding (2019)	Assessment	Public speaking scenario in a conference room with virtual audience members, participants were asked to make a speech on one of the given topics	Virtual conference room	Six audience members comprising mild ambiguous feedback (randomly nodding, looking at the speaker, drinking water, folding their arms) and intense negative feedback (looking at a cell phone, taking pictures, shaking one's head)	HMD	Head-tracking	Head-movement	Looking at the participant, nodding (according to preprogrammed feedback condition)	Participants were asked to make a 3-min speech on one of the given topics (self-introduction, the most memorable trip, a funny thing, and a fable story)	Exposure in VR Role of social feedback	Undergraduate students (younger adults)	SAD individuals	Therapist-guided
Lange and Pauli (2019)	Assessment	Virtual environment consisted of a room of the CAVE's physical dimension (4 × 3 × 3 m). Participants had to pass a virtual agent to reach the target position. Virtual agent stood in one position showing random idle behavior	Background gave the feeling of being in a backyard ally: four walls had a reddish brick stone pattern; the floor had a white marble pattern. Temporary virtual elements marked the start position (red footsteps) and the target position (green circle)	Three different males. Virtual agent stood in one position showing random idle behavior and display different facial expressions and followed the participant with gaze and body orientation. The agent's facial expressions were either neutral or angry. Avatars had different hair color	CAVE, loudspeakers	Head- and position-tracking	Freely movement (active tracking system) without additional equipment	Fixation of eyes, gaze contact, facial expressions according to condition (preprogrammed)	Participants had to position themselves on the start location. When an agent appeared, participants had to name their hair color, and for the main task they were instructed to move to the target position as quickly and accurately as possible (by bypassing the agent without any explicit social interaction)	Approach-avoidance task in VR Avoidance of social stimuli as maintaining factor (Clark and Wells, 1995, Rapee and Heimberg, 1997)	N/A	Highly socially anxious individuals	Therapist-guided

(*Continued*)

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TABLE 4 Continued

References	Aim of application	Virtual environments			Technical realization				VR social task				Self-guided/ therapist/ guided
	Assessment or assessment/ intervention	Content of the virtual world	Design of non-social environment	Design of social environment (virtual agents)	VR output devices	VR input devices	Realization of movement	Realization of interaction of the agents	Description of the task	Theoretical, empirical, and/ or therapeutical background	Specific age group	Target group	
Owens and Beidel (2015)	Assessment	Participants have to give an impromptu speech in front of a five-person audience; They were provided with 5 topics	Waiting room, virtual conference room with conference table	5 audience members seated around the conference table, consisting of two men and three females of varying ethnicities (3 Caucasians, 1 African American, 1 Asian)	HMD	Head-tracking	Head-movement	N/S	To give an impromptu speech in front of a VR five-person audience to three of five topics (e.g., the legal drinking age, qualities of a good president)	Virtual reality exposure; emotional processing theory	Young adults	Adults with SAD	Therapist-guided
Parrish et al. (2016)	Assessment	Participants were exposed to a party and public speaking environment; they were asked to give a speech and to interact with others	VR neutral environment consisted of a virtual art gallery with fish and aquatic environments on the walls. VR public speaking environment: virtual classroom with background sounds (e.g., phone ringing). VR party environment: house party with music, and open front door	VR public speaking scenario: 30 audience members were prompted to look sleepy, distracted (person answering), disagreed, at the end clapping hands VR party scenario: several social interactions with individuals	HMD, headphones	Head-tracking	Head-movement	Prerecorded behaviors controlled by the therapist	To give a 4-min speech on a topic of choice and to engage in social interactions	Virtual reality exposure; lack of research for adolescents with SAD	Children, adolescents	Adolescents with SAD	Therapist-guided
Price et al. (2011a)	Assessment/ intervention	VR scenarios included a classroom, a conference room, and a large auditorium. Audience reactions and the difficulty of questions posed by audience members could be manipulated-	A virtual classroom, a conference room or a large auditorium	Conference room: approx. 35 audience members, and in the large auditorium: approx. 100 virtual audience members. They can pose prerecorded questions and could show different reactions (e.g., bored, interested)	HMD, headphones	Head-tracking	A tracker allowed the participant to move naturally, Head-movement	Prerecorded questions controlled by VRE therapist	Participants had to give a speech in front of an audience and answer different questions	Individual exposure in VR Emotional processing theory	N/A	Adults with SAD	Therapist-guided
Reichenberger et al. (2017)	Assessment/ intervention	Each scenario with a max. of one virtual agent, to assert one's right in a virtual train compartment and virtual travel agency	Train compartment, travel agency	Not explicitly mentioned (approx. 1 agent per scenario)	HMD, earphones, loudspeakers	Head-tracking, eye-tracking	Movement with joystick (Logitech Extreme 3D Pro Joystick), Head-movement	Answers of the agents were prerecorded, mimic was synchronized	To assert one's right (cancellation of a booked flight vs. to get one's reserved seat), training of assertiveness	Social skills Training in VR (Hinsch and Pfingsten, 2015)	Adults	People with high social anxiety, social skills deficits	Therapist-guided

(*Continued*)

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TABLE 4 Continued

References	Aim of application	Virtual environments			Technical realization				VR social task				Self-guided/ therapist/ guided
	Assessment or assessment/ intervention	Content of the virtual world	Design of non-social environment	Design of social environment (virtual agents)	VR output devices	VR input devices	Realization of movement	Realization of interaction of the agents	Description of the task	Theoretical, empirical, and/ or therapeutical background	Specific age group	Target group	
Reichenberger et al. (2019)	Assessment	VR environment consisted of one room, in which all three phases took place. Participant was positioned at one end of the room and could see each female or male agent at the opposite site. Either an aversive consequence (air blast to the right side of the participant's neck accompanied by a sound of spitting followed by a verbal rejection) or a positive consequence (startle sound) was reached	Virtual room, air blast (5 bar, 10 m) and a sound of spitting followed by a verbal rejection or a startle sound	Either a male or a female agent, gazed dynamically at the participant and moved their head and upper body slightly	HMD, headphones	Head-tracking, eye-tracking	Movement with joystick (Logitech Extreme 3D Pro Joystick), Head-movement	The agents gazed dynamically at the participant and moved their head and upper body slightly	Participants had to approach the agents actively using the joystick as soon as they reached a specific distance to the agents	Mechanisms of emotional learning, conceptual-theoretical model for SAD (Rapee and Heimberg, 1997) Social fear conditioning paradigm (SFC)	Young adults	Individuals with high social anxiety	Therapist/ experimenter-guided
Reichenberger et al. (2020)	Assessment	A female or male agent was at the opposite end of the room; agents moved their head and upper body slightly and gazed dynamically at the participant to appear alive; In 75% of the trials agents were paired with aversive stimulus existing of a sound of spitting attended by an air blast toward the right neck of the participant followed by a verbal rejection	Virtual room was modeled after a corridor of the University of Regensburg; Starting position of the participant was at one end of the room	Either a male or a female agent, gazed dynamically at the participant and moved their head and upper body slightly	HMD, headphones	Head-tracking, eye-tracking	Movement with joystick (Logitech Extreme 3D Pro Joystick), Head-movement	Dynamically gaze-contact, slightly movement of head and upper body of the agents	Participants had to actively approach the female and male agents until 30 m where movement stopped	Cognitive model from Clark and Wells (1995) and cognitive behavioral model from Rapee and Heimberg (1997); mixed empirical results of the vigilance-avoidance hypothesis of selective attention in SAD	Young adults	Individuals with high social anxiety	N/S - experimenter guided
Reichenberger et al. (2022)	Assessment	Participants find themselves in a train compartment and travel agency where they have to assert their right in both roleplays	Train compartment, and travel agency	*Train compartment:* Six people in the compartment *Travel agency:* one employee who tried to dissuade the participant. Facial expressions were neutral. The verbal responses were prerecorded, and the lip movements were synchronized accordingly	HMD, head phones	head-tracking, eye-tracking	Movement with joystick (Logitech Extreme 3D Pro Joystick), Head-movement	Reactions of the agents (prerecorded), situations, and amount of gaze contact (20% vs. 80% gaze; preprogrammed)	Participants had to assert their rights in two roleplays. In the train compartment: they should ask the passenger to release their reserved seat. In the travel agency they should cancel their already booked trip	Social skills training (Hinsch and Pfingsten, 2015); avoidance behavior in SAD	Adults	Individuals with SAD	N/S - experimenter guided

N/A, information was not available; N/S, information was not specified; HMD, head-mounted display; CBT, cognitive behavioral therapy; VRET, virtual reality exposure therapy.

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(e.g., Lange and Pauli, 2019; Reichenberger et al., 2019). However, eye contact was not dependent on the participants' gaze behavior, but was preprogrammed (e.g., amount of gaze contact 20% vs. 80%, see Reichenberger et al., 2022).

5.3.3 Virtual social tasks for SAD assessment

Typical assessment tasks (see RQ 3A) included impromptu speeches in front of virtual audiences (e.g., Owens and Beidel, 2015; Parrish et al., 2016), or social interaction tasks such as requesting a reserved seat or canceling a flight (Reichenberger et al., 2017; Reichenberger et al., 2022) (see Figure 3). Holmberg et al. (2020) presented participants with 360-degree shopping videos, where they faced everyday social challenges, such as accepting a gift card, waiting in line, or entering a crowded shop (see Table 4 for all tasks). No studies were found implementing tasks or challenges addressing fear of blushing, eating in public or other subtypes of SAD.

Beyond explicit social tasks, some assessment studies implemented implicit social paradigms. Lange and Pauli (2019) developed a social approach - avoidance task in which participants had to walk past a virtual agent displaying either an angry or neutral facial expression on their way to a target location. Agents followed the participant with gaze and body orientation, and participants saw their own body within a realistic virtual alley environment while using a handheld controller to register responses. A similar implicit approach was adopted in the social fear conditioning paradigms by Reichenberger et al. (2019), Reichenberger et al. (2020), where participants approached virtual agents paired with aversive stimuli (e.g., verbal rejection or simulated spitting sounds) (see Figure 4).

Across studies, the theoretical and empirical rationale (see RQ 3B) underlying the assessment paradigms was primarily grounded in VRET, often following graduated exposure principles to deliberately activate Social Anxiety and enable its systematic assessment (see Table 4). Several assessments further drew on cognitive models of Social Anxiety (Clark and Wells, 1995; Rapee and Heimberg, 1997) and elements of social skills training (Hinsch and Pfingsten, 2015), not as interventions, but to derive structured social tasks targeting attentional biases, avoidance behavior, and self-focused attention. Finally, the assessments by Reichenberger et al. (2019), Reichenberger et al. (2020) were explicitly based on the social fear conditioning paradigm underlying the hypervigilance-avoidance hypothesis (Bögels and Mansell, 2004), providing a theoretical framework for assessing attentional and behavioral responses to social threat.

Regarding the specific age group targeted in the assessment (see RQ 3C) there was a range from adolescents (Parrish et al., 2016) to young adults and students (e.g., Owens and Beidel, 2015; Reichenberger et al., 2019) to finally middle-aged adults (e.g., Hur et al., 2021; Reichenberger et al., 2017). Several studies did not describe the specific age of the participants (e.g., Holmberg et al., 2020; Lange and Pauli, 2019). Importantly, we could not identify studies in children and in adolescents below the mean age of 16 years. The further target group characteristics (see RQ 3D) were similar to intervention studies, overall, the studies mainly aimed at individuals and patients with SAD and highly socially anxious individuals with PSA (see Table 4). In contrast to Reichenberger et al. (2017) who aimed at individuals with high Social Anxiety and social skills deficits, in some studies, a specialized target group was not clearly specified (e.g., Lange and Pauli, 2019; Felnhofer et al., 2019).

Regarding manualization (see RQ 3E), four studies mentioned a specific treatment manual as background for their VR assessment task (e.g., SKT training of Hinsch and Pfingsten in Reichenberger et al., 2017; Reichenberger et al., 2022; standardized treatment protocol in Parrish et al., 2016), eight studies did not relate to such (see Supplementary Table S6).

The number and duration of VR sessions (see RQ 3F) and non-VR sessions (see RQ 3I), as well as the duration of the whole VR task and one VR session (see RQ 3G + RQ 3H) applied within the VR assessment studies varied from 1 (e.g., Felnhofer et al., 2019; Kishimoto and Ding, 2019) to 6 (Hur et al., 2021) VR sessions and 0 (e.g., Reichenberger et al., 2019; Reichenberger et al., 2020) to 4 (Price et al., 2011b) non-VR-sessions. The duration of one VR session ranged from approximately 15 min (Felnhofer et al., 2019; Hur et al., 2021) to 60 min (Parrish et al., 2016), and of the duration of the whole VR task from approximately 5 min (Felnhofer et al., 2019) to 8 min (Hur et al., 2021). Some studies did not give information on the question of number and duration of sessions (e.g., Holmberg et al., 2020; Kishimoto and Ding, 2019) (for more details see Supplementary Table S6). Finally, all applications were therapist-guided (see RQ 1J).

An examination of the participant tasks within the assessment studies described above indicates that most studies implemented multiple task iterations and/or task variations, rather than relying on a single exposure (see RQ 3K). Participants were often required to complete repeated trials, such as delivering speeches on different topics (Owens and Beidel, 2015) or experiencing multiple social scenarios, as in Reichenberger et al. (2017). In some studies, task difficulty was additionally manipulated in a systematic manner. For instance, Holmberg et al. (2020) increased task difficulty across levels by varying the number of present individuals, the amount of required verbal interaction, and the intensity of negative social feedback. A similar graded approach was employed by Hur et al. (2021), whose participatory VR intervention comprised three distinct difficulty levels.

5.4 Experiences and results from the usage

In this subsection, we specifically report on the feasibility and usability of the included VR assessment and intervention applications based on the authors' reports and corresponding quantitative outcome measures (e.g., adherence rates, cybersickness measures). Furthermore, we report on the participants' experience of presence as reported by the authors and measured using respective assessment instruments and describe the participants' quantitative level of anxiety during VR assessment and/or intervention, as well as the degree of anxiety activation from before to during the intervention. Finally, we report on authors' experiences regarding advantages and limitation, as well as possibly eligible indications and further implications for the usage of VR applications for the assessment and intervention in SAD.

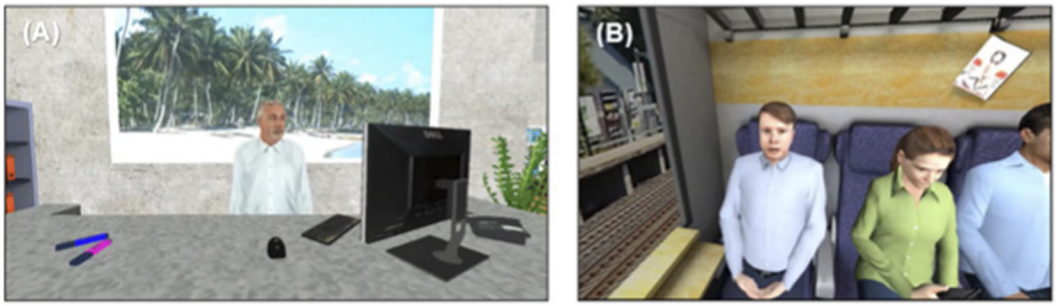

FIGURE 3
VR environments and roleplays used in the studies by Reichenberger et al. (2017), (2022). Used with permission by the authors. **(A)** Travel agency with interaction partner sitting at his desk. **(B)** Train compartment with virtual interaction partner on the left.

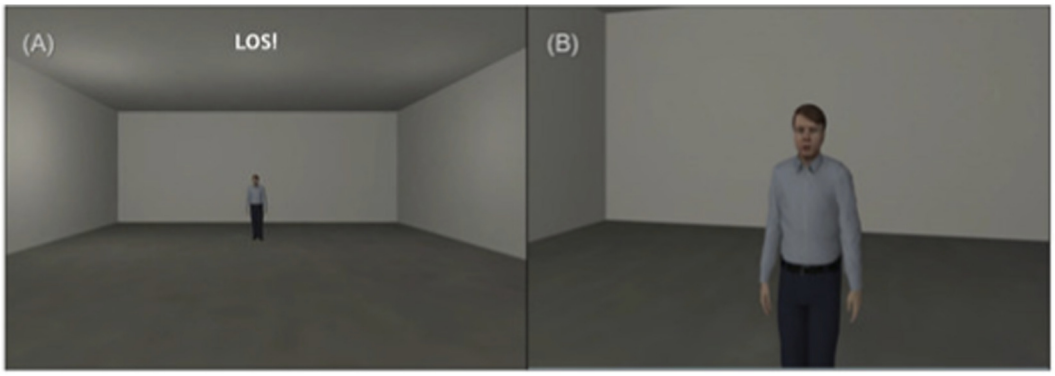

FIGURE 4
VR environments used in the studies by Reichenberger et al. (2019), (2020); used with permission by the authors). **(A)** Starting point in the room, in which learning phases, and behavioral avoidance task took place. **(B)** End point for approaching the virtual agent.

5.4.1 Results on individual research questions of assessment and intervention studies

Across intervention studies, the individual research questions primarily addressed the effectiveness of VR-based exposure approaches in reducing Social Anxiety symptoms, whereas assessment studies focused on the ability of VR environments to reliably elicit and measure anxiety-related responses (RQ 4.1A). Detailed results for all individual research questions are reported in Supplementary Table S7.

5.4.2 Feasibility of VR assessment and intervention applications for SAD

In line with our research questions, we report on the authors' experiences (see RQ 4.1B) regarding the feasibility of the VR application (e.g., acceptability, engagement, suitability, and safety), and on quantitative outcomes (e.g., adherence rates, dropout rates) regarding feasibility (see RQ 4.2D).

Except for two studies (Geraets et al., 2019; Zainal et al., 2021), feasibility was not quantitatively assessed in the other 29 of 31 included studies (see Supplementary Table S4, see RQ 4.2D). In their intervention study, Geraets et al. (2019) reported a dropout rate of 13.3%. Two participants discontinued treatment after session 7: one dropout was attributed to excessive anxiety during exposure, and the other to distraction caused by the VR equipment and a perceived lack of realism of the virtual agents, reflecting a tolerability-related feasibility issue. Among treatment completers, the mean number of completed VR-CBT sessions was 15 (range 13–16) from maximum 16 sessions. Zainal et al. (2021) operationalized feasibility quantitatively (RQ 4.2D) within their intervention study through completion rates and participant acceptance. They reported that participants completed between 3 and 55 scenes (M = 18, SD = 14), depending on self-guided use and individual choice of scenarios, with 58% reaching the highest difficulty level, and 85% reporting that they would recommend the VR application to others.

Qualitative indicators of feasibility (see RQ 4.1B), primarily in terms of acceptability, were reported by Parrish et al. (2016) regarding their VR assessment. Based on post-exposure debriefing interviews, adolescents generally perceived the VR environments as realistic, engaging, and tolerable. Neutral environments were predominantly described as calming, whereas socially demanding environments were reported to elicit anxiety-related reactions consistent with their social demands. Most participants perceived the social scenarios as authentic; a few

described them as unrealistic. Several adolescents suggested that increased levels of social interaction would further enhance the relevance of the scenarios. Overall, the authors conclude that these findings indicate good acceptability of VR exposure among youth.

Beyond acceptability, feasibility-related challenges concerning the implementation of social interaction were reported by Geraets et al. (2019). In this study, interaction scenarios relied on prerecorded sentences delivered by virtual agents. Therapists therefore occasionally supplemented the interaction with brief spontaneous verbal input to preserve conversational naturalness, which the authors described as a minor feasibility limitation.

In studies without direct feasibility analyses, feasibility was often inferred indirectly from descriptive quantitative indicators. Several assessment and intervention studies (e.g., Holmberg et al., 2020; Reeves et al., 2021) reported high compliance and low dropout rates, suggesting that participants were generally able to complete the VR procedures as intended. In addition, some intervention studies employed standardized or self-led protocols and adherence ratings (e.g., Anderson et al., 2013; Burton et al., 2013) to support consistent implementation of the VR procedures. For all results on qualitative data on feasibility see Supplementary Table S4.

5.4.3 Usability of VR assessment and intervention applications for SAD

In line with our research questions, we report on the authors' experiences (see RQ 4.1C) regarding the usability of VR application (e.g., user-friendliness, clarity, and ease of use) and on quantitative outcomes (e.g., satisfaction ratings, and measures of simulator or cybersickness) regarding usability (see RQ 4.2E).

Quantitative indicators of usability (see RQ 4.2E) were reported in ten from the included 31 studies, mostly targeting cybersickness (e.g., Bouchard et al., 2017; Kishimoto and Ding, 2019). Reichenberger et al. (2019), within their assessment study, found, e.g., that highly socially anxious individuals exhibited higher simulator sickness symptoms compared to healthy controls (M_{HSA} = 66.16 vs. M_{CG} = 44.40), likely reflecting an overlap between anxiety and simulator sickness or enhanced self-focused attention according to the authors. Other studies reported comparable (Holmberg et al., 2020, assessment) or lower levels of cybersickness relative to other VR applications (Zainal et al., 2021, intervention). Anderson et al. (2013), within their intervention study, assessed treatment satisfaction using the CSQ-8 (8 items, 4-point Likert scale, range 8–32). Participants reported high satisfaction with VR exposure (M = 27.25, SD = 2.09), comparable to *in vivo* exposure (M = 26.40, SD = 2.43), indicating generally positive evaluations of the VR application.

Qualitative observations (see RQ 4.1C) reported in 13 from 31 included studies supported the usability of VR applications. Participants generally described VR systems as user-friendly, time- and cost-efficient, and associated with high satisfaction (e.g., Bouchard et al., 2017; Kim et al., 2020, interventions). Lindner et al. (2021), within their intervention study, emphasized that VRET could be delivered by therapists without prior VR experience and minimal training. Authors of all four intervention self-led training studies also reported no major usability issues (Kim et al., 2017; Kim et al., 2022; Stupar-Rutenfrans et al., 2017; Zainal et al., 2021). At the same time, both assessment and intervention studies (e.g., Ma et al., 2019; Reichenberger et al., 2017) highlighted the need for technical improvements, such as optimizing eye-tracking systems (Reichenberger et al., 2020; Wechsler et al., 2021) and making dialogues with virtual agents more flexible and realistic (e.g., Geraets et al., 2019; Kishimoto and Ding, 2019) (see Supplementary Table S4 for a comprehensive presentation of results on usability).

5.4.4 Presence within VR assessment and intervention applications for SAD

According to our research questions, we present quantitative (RQ 4.2A) and qualitative (RQ 4.1G) results on the participants' presence in VR during VR assessment and/or intervention for SAD. Of the 31 included studies, 14 studies explicitly measured presence (see RQ 4.2A) using questionnaires such as the *Igroup Presence Questionnaire* (IPQ; e.g., Felnhofer et al., 2019; Lange and Pauli, 2019), the *Presence Questionnaire* (PQ; Bouchard et al., 2017; Kishimoto and Ding, 2019), the *Gatineau Presence Questionnaire* (GPQ; Bouchard et al., 2017), and the *Networked Minds of Social Presence* (NMMSP; Felnhofer et al., 2019), or using semi-structured interviews (Holmberg et al., 2020) and visual analogue scales (Owens and Beidel, 2015). An overview of the measures used to assess presence as well as mean values and standard deviations for the presence measures can be found in Table 5. Notably, only the assessment study by Felnhofer et al. (2019) assessed social presence in addition to physical presence, using the NMMSP questionnaire. Their results indicated that participants with SAD experienced a sense of co-presence of 69.30 (SD = 8.12), psychological involvement of 44.30 (SD = 14.92), and behavioral engagement of 35.30 (SD = 9.59), with an overall social presence score (sum of all three NMMSP dimensions; range 36–252) of 148.90. The study furthermore found that social presence subscores were all higher in participants with SAD compared to healthy controls, while physical presence did only differ in the subscale "sense of being there" (with higher values in SADs). Besides Felnhofer et al. (2019), the three further studies by Reichenberger et al. (2017), Reichenberger et al. (2019), Reichenberger et al. (2022) compared presence values (physical presence) of Social Anxiety participants with healthy controls, showing no significant differences regarding IPQ subscales.

In 14 of 31 included studies (e.g., Price et al., 2011b; Reichenberger et al., 2022), authors reported experiences regarding presence (see RQ 4.1G; Supplementary Table S4). In the assessment studies by Owens and Beidel (2015), Parrish et al. (2016), and Reichenberger et al. (2019), the authors noted that the levels of presence and immersion were acceptable, moderate in intensity, and that the VR environments were perceived as sufficiently realistic. These observations are supported by Holmberg et al. (2020), who also reported that the scenarios within the VR assessment were perceived as realistic and elicited a high sense of presence, which was discussed by the authors as sufficient to elicit anxiety.

Conversely, some authors (e.g., Kim et al., 2020; Kishimoto and Ding, 2019) reported impairments in presence in both intervention and assessment studies. Kishimoto and Ding, 2019 noted that the sense of presence in their study was

TABLE 5 Measurement instruments for presence and corresponding means (M) and standard deviations (SD) of fourteen studies.

References	Aim of the application	Measurement instrument for presence	Presence *M (SD)*
Bouchard et al. (2017)	Intervention	PQ	78.31 (14.77)
		GPQ	51.41 (21.87)
Felnhofer et al. (2019)	Assessment/intervention	IPQ	
		Sense of being there	5.10 (1.38)
		Spatial Presence	23.70 (7.81)
		Realism	12.70 (2.64)
		Involvement	16.90 (3.03)
		NMMSP	
		Copresence	69.30 (8.12)
		Psychological involvement	44.30 (14.92)
		Behavioral engagement	35.30 (9.59)
Holmberg et al. (2020)	Assessment	Semi-structured interviews	N/S
Kim et al. (2017)	Intervention	N/A	N/A
Kishimoto and Ding (2019)	Assessment	PQ	12.77 (22.58)
Lange and Pauli (2019)	Assessment	IPQ	
		Spatial Presence	4.10 (1.0)
		Realism	2.80 (1.10)
		Involvement	3.70 (1.20)
Owens and Beidel (2015)	Assessment	Visual analogue scale	
		"Being there"	52.63 (25.52)
		"Engagement"	52.22 (25.94)
Parrish et al. (2016)	Assessment	Modified Version of the Imagery Realism PQ	89.61 (22.76)
Reeves et al. (2021)	Intervention	IPQ	N/S
Reichenberger et al. (2017)	Assessment/intervention	IPQ	3.91 (1.20)
Reichenberger et al. (2019)	Assessment	IPQ	2.72 (1.62)
Reichenberger et al. (2022)	Assessment	IPQ	N/S
Wechsler et al. (2021)	Intervention	IPQ	
		Spatial Presence	4.20 (0.74)
		Realism	2.86 (0.78)
		Involvement	3.63 (1.33)
		General Presence	4.30 (1.03)
Zainal et al. (2021)	Intervention	IPQ	
		Spatial Presence	3.49 (0.81)
		Realness	2.67 (0.75)
		Involvement	3.84 (1.05)

N/S, Not specified. Information was not available in the main manuscript, or in additional files. N/A, No data available. No measurement of presence. IPQ, Igroup Presence Questionnaire; PQ, Presence Questionnaire; PQ, Presence Questionnaire; GPQ, Gatineau Presence Questionnaire; NMMSP, networked minds of social presence.

reduced due to random virtual social feedback that did not correspond to participants' actual performance. Similarly, Geraets et al. (2019), within their intervention study, reported that presence was diminished when therapists provided live spoken sentences during the scenario instead of prerecorded sentences. For all experiences of the study authors regarding presence see Supplementary Table S4.

5.5 Anxiety levels and activation

To address the research question of whether virtual social environments and tasks can sufficiently elicit anxiety symptoms (see RQ 4.2C), and which absolute anxiety level was reached during participation (see RQ 4.2B), the following subsection and Table 6 provide an overview.

For the descriptive summary of quantitative data, eleven studies were included that measured the absolute level of anxiety during the VR session via SUD ratings (e.g., Anderson et al., 2013; Wechsler et al., 2021), heart rate (Reichenberger et al., 2017), arousal ratings (Lange and Pauli, 2019), and STAI-state scores (Reichenberger et al., 2022; Stupar-Rutenfrans et al., 2017). This allowed inclusion of both assessment and intervention studies that, for example, used Behavioral Avoidance Tasks (BATs) to determine the level of anxiety triggered. Except for three studies (Reichenberger et al., 2017; Reichenberger et al., 2022; Lange and Pauli, 2019), all tasks involved public speaking or similar social-evaluative situations (see Table 6).

Regarding absolute anxiety levels reported during the VR tasks (RQ 4.2B), SUD ratings during VR exposure (Anderson et al., 2013; 2017; Bouchard et al., 2017) ranged from approximately 6.9–8.4 on a 0–10 scale or 14.3 to 58.7 on a 0–100 scale (e.g., Reichenberger et al., 2022; Kishimoto and Ding, 2019) (see Table 6 for more details). This wide range reflects differences in scenario type and task demands, with lower anxiety levels observed in assertive interaction tasks such as the train compartment scenario, and higher levels in public speaking settings involving larger virtual audiences. However, in the studies by Anderson et al. (2013), Anderson et al. (2017), it was unclear which specific scenario primarily elicited the reported anxiety during the BAT, as details regarding the setting of the BAT (e.g., classroom vs. conference room, 5 vs. 35 audience members) were not provided. Physiological indicators of anxiety (heart rate; n = 1), as well as STAI-state scores (n = 2) and arousal ratings (n = 1) were only conducted in few studies (see Table 6 for results).

Some studies (5 out of 11, e.g., Donahue et al., 2009; Kishimoto and Ding, 2019) also reported baseline values prior to the VR scenario, therefore giving inside in anxiety activation from before to during the VR scenario. Anxiety increases (SUD) were, e.g., from $M = 29.80$, $SD = 22.10$ (total range 0–100) to $M = 53.40$, $SD = 29.10$ (Donahue et al., 2009; intervention), and from $M = 39.08$, $SD = 22.07$ (total range 0–100) to $M = 58.65$, $SD = 21.47$ (Kishimoto and Ding, 2019; assessment) (for comprehensive results see Table 6). While Donahue et al. (2009) reported a large effect size for the anxiety increase trough the task from pre-to peri-measurement ($d = 0.91$), (Reichenberger et al. (2019); assessment) found effect sizes of $d = 0.62$ for the train scenario and $d = 0.40$ for the travel agency scenario. However, for the remaining studies no effect sizes were reported by the authors.

Four studies (e.g., Bouchard et al., 2017; Owens and Beidel, 2015) provided comparative anxiety levels from control groups that underwent *in vivo* interventions. In addition, three studies (Kishimoto and Ding, 2019; Reichenberger et al., 2017; Reichenberger et al., 2022) included healthy or low-anxiety participants as control groups to examine whether the VR scenarios and tasks elicit differential anxiety responses between socially anxious and non-anxious individuals. Overall, the *in vivo* control groups showed comparable anxiety levels, and it became evident that socially anxious participants consistently exhibited stronger anxiety activation in response to the VR tasks (see Table 6).

5.5.1 Advantages and limitations of VR applications for SAD assessment and intervention

Across assessment and intervention studies, authors of 29 of the included 31 studies reported on advantages of VR applications (see RQ 4.1D) for the assessment and treatment of Social Anxiety. A central strength repeatedly highlighted was the high degree of experimental and therapeutic control, allowing therapists and researchers to manipulate social situations with respect to content, duration, difficulty, and social feedback. This controllability enables standardized yet adjustable exposure and assessment conditions, facilitating graduated exposure and reliable anxiety activation in a safe and confidential environment (e.g., Anderson et al., 2013; Ma et al., 2019). VR applications were further described as practical and cost-effective, offering a lower-threshold alternative to *in vivo* exposure, particularly for individuals unwilling or unable to engage in real-life social situations (e.g., Anderson et al., 2017; Lindner et al., 2021). In addition, VR was considered especially suitable for youth populations (Parrish et al., 2016) providing private and controlled opportunities to practice social skills in realistic scenarios (e.g., Reichenberger et al., 2017; 2022). For assessment purposes, VR was described as a promising and ecologically valid tool to evoke Social Anxiety under controlled conditions while approximating real-life social interactions (e.g., Holmberg et al., 2020; Felnhofer et al., 2019). A detailed overview of reported advantages is provided in Supplementary Table S7.

At the same time, authors identified several limitations of current VR applications (see RQ 4.1E). A frequently mentioned constraint concerned the limited flexibility of social interactions, including restricted verbal exchanges due to prerecorded dialogue, lack of real-time interaction with virtual agents, or absence of contingency between participant behavior (e.g., gaze) and avatar responses (e.g., Kishimoto and Ding, 2019; Reichenberger et al., 2022; Rubin et al., 2022). Several studies were further limited by the exclusive use of public speaking scenarios, restricting the assessment or treatment to a narrow subtype of Social Anxiety and limiting the coverage of idiosyncratic fears (e.g., Price et al., 2011a; Anderson et al., 2013; Holmberg et al., 2020). Moreover, some VR applications could only be administered in clinical settings, limiting opportunities for home-based exposure or homework assignments (e.g., Kim et al., 2017; Kampmann et al., 2016b). A detailed overview of reported limitations is provided in Supplementary Table S7.

TABLE 6 Means (M) and standard deviations (SD) of anxiety level reached during VR session for eleven assessment and intervention studies providing the respective values.

References	Aim of application	VR scenario and task	Outcome measure (range)/ if applicable: Diagnostic procedure	If applicable: anxiety level before VR task (pre measurement) *M (SD)*	Anxiety level during VR task (peri measurement) *M (SD)*	Anxiety increase through VR task (Cohen's d pre-peri, if applicable)	If applicable: Content of control group	If applicable: Anxiety level reached in control group *M (SD)*
Anderson et al. (2013)	Intervention	Public speaking scenario – giving a speech in front of a virtual audience[a]	SUD ratings (0–10; higher = more anxious) during BAT	N/S	6.93 (2.41)	N/S	*In vivo* exposure group – giving a videotaped speech in front of a group	7.42 (2.43)
Anderson et al. (2017)	Intervention	Public speaking scenario – giving a speech in front of a virtual audience[a]	SUD ratings (0–10; higher = more anxious) during BAT	N/S	7.69 (2.25)	N/S	*In vivo* exposure group – giving a videotaped speech in front of a group	7.60 (1.88)
Bouchard et al. (2017)	Intervention	Public speaking scenario – giving a videorecorded impromptu speech	SUD ratings (0–10; N/S) during BAT	N/S	8.40 (4.0)	N/S	*In vivo* exposure – giving an impromptu speech to an audience of staff members	8.50 (3.80)
Donahue et al. (2009)	Intervention	Public speaking scenario – giving a speech about one of two topics	SUD ratings (0–100; no distress – extreme distress)	29.80 (22.10)	53.40 (29.10)	0.91	Placebo group (without quetiapine) – giving a speech about one of two topics	N/S
Kishimoto and Ding (2019)	Assessment	Public speaking scenario – giving a speech in front of six audience members	SUD ratings (0–100; no distress – extreme distress)	39.08 (22.07)	*Ambiguous feedback* 58.65 (21.47) *Negative feedback* 52.31 (24.08)	N/S	Healthy control group – giving a speech in front of six audience members	*Ambiguous feedback* 35.85 (23.11) *Negative feedback* 39.62 (22.75)
Lange and Pauli (2019)	Assessment	Social approach-avoidance task	STAI state (20–80; higher = more anxious) Arousal ratings (1–7; very calm – very excited)	N/S	37.10 (7.40) 6.08 (1.60)	N/S	N/A	N/A
Owens and Beidel (2015)	Assessment	Public speaking scenario – giving an impromptu speech in front of a five-person audience	SUD ratings (0–8; no distress – extreme distress)	N/S	3.43 (1.99)	N/S	*In vivo* exposure – giving a speech in front of a real live audience	5.43 (1.57)
Reichenberger et al. (2017)	Assessment/ intervention	Social skills trainings – asserting one's right in a roleplay	Heart Rate (Δ bpm from 120s baseline)	*Train scenario* 17.39 (13.31) *Travel agency* 17.69 (10.19)	*Train scenario* 24.69 (15.15) *Travel agency* 18.13 (17.75)	N/S	Low socially anxious individuals – asserting one's right in a roleplay	*Train scenario* 24.78 (11.69) *Travel agency* 24.29 (11.58)
Reichenberger et al. (2022)	Assessment	Social skills trainings – asserting one's right in a roleplay	SUD ratings (0–100; no fear – very strong fear)	*Train scenario* 10.88 (11.07) *Travel agency* 8.83 (11.16)	*Train scenario* 20.54 (18.99) *Travel agency* 14.32 (15.81)	0.62 0.40	Healthy control group – asserting one's right in a roleplay	*Train scenario* 2.33 (10.23) *Travel agency* 3.10 (14.02)

(*Continued*)

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TABLE 6 Continued

References	Aim of application	VR scenario and task	Outcome measure (range)/ if applicable: Diagnostic procedure	If applicable: anxiety level before VR task (pre measurement) *M (SD)*	Anxiety level during VR task (peri measurement) *M (SD)*	Anxiety increase through VR task (Cohen's d pre-peri, if applicable)	If applicable: Content of control group	If applicable: Anxiety level reached in control group *M (SD)*
Stupar-Rutenfrans et al. (2017)	Intervention	Public speaking scenario – to talk in front of a virtual audience	STAI state (20–80; higher = more anxious)	*Moderate speaking anxiety:* 40.28 (8.81) *High speaking anxiety* 44.00 (5.14)	*Moderate speaking anxiety* 44.40 (10.22) *High speaking anxiety* 47.50 (13.95)	N/S	N/A	N/A
Wechsler et al. (2021)	Intervention	Public speaking scenario – giving a speech in front of a virtual audience and shifting attentional focus	SUD ratings (0–100; not at all anxious – extremely anxious) during BAT	N/S	*Social focus group* 45.93 (28.71) *Non-social focus group* 36.28 (22.91)	N/S	N/A	N/A

N/S, not specified, remains unclear. Information was not available in the main manuscript, or in additional files. N/A, No data available. No *in vivo* control group or other kind of comparative measures.
[a]Details of the scenario were not provided. BAT, behavioral avoidance test; STAI, State-Trait-Anxiety-Inventory; bpm, beats per minute. Interpretation of Cohen's d as effect size: d≥.20 as small, d≥.50 as medium, and d≥.80 as large effect.

5.5.2 Eligible indications and conclusions for usage in clinical settings and research

Across assessment and intervention studies, VR applications were described as a promising option for the assessment and treatment of Social Anxiety in clinical settings. Eligible indications (see RQ 4.1F) mentioned by the authors most consistently included (a) the routine treatment of SAD, particularly in individuals with generalized Social Anxiety and heterogeneous fear profiles (e.g., Bouchard et al., 2017; Geraets et al., 2019), (b) the use of VR within structured therapeutic contexts combining behavioral and cognitive elements, such as exposure and social skills training (e.g., Reichenberger et al., 2017; Wechsler et al., 2021), and (c) applications targeting adolescents and younger individuals, for whom VR offers controlled yet realistic opportunities to practice social skills (e.g., Parrish et al., 2016; Zainal et al., 2021). In addition, several studies identified self-guided or home-based VR applications as a low-threshold option for individuals with SAD, potentially facilitating treatment initiation and motivating subsequent help-seeking (e.g., Kim et al., 2017; Zainal et al., 2021). Supplementary Table S7 summarizes the eligible indications for VR applications as reported by the study authors.

Regarding future clinical use and research (see RQ 4.1H), authors consistently highlighted the need for further development of VR applications. Central suggestions included increasing the flexibility and complexity of virtual social interactions, particularly through more individualized and naturalistic verbal exchanges with virtual agents (e.g., Geraets et al., 2019; Kampmann et al., 2016a). Further recommendations comprised larger randomized controlled trials, direct comparisons with conventional treatments, transdiagnostic approaches, and the assessment of psychophysiological outcome measures (e.g., Jeong et al., 2021; Nazligul et al., 2019). An overview of conclusions for future clinical use and research is provided in Supplementary Table S7.

6 Discussion

6.1 Discussion of main results

The aim of this scoping review was to provide a systematic overview of available virtual environments and tasks usable for assessment and intervention of Social Anxiety or specific subtypes of Social Anxiety in children, adolescents, and adults. As the strength of a scoping review is to identify gaps in the literature and proposing suggestions for future research (Arksey and O'Malley, 2005), the following discussion is primarily intended to offer ideas for future research and clinical applications to optimize assessment and treatment tools for Social Anxiety in the long-term.

The 31 included studies encompassed adolescents (n = 1) and adults (n = 30) from clinical (n = 15) and subclinical (n = 16) populations, but did not target children (n = 0). Overall, the existing literature is heavily skewed toward young to middle-aged adults, with only one included study by Parrish et al. (2016) investigating a VR intervention for adolescents up from the age of 16 years (M = 16.15 years; range 13–18). The lack of studies conducted in children

and adolescents highlights a key research gap, as SAD typically has its onset in late childhood or early adolescence, with median ages in the early teens and most cases emerging before the age of 15 (Dalrymple et al., 2007; Kessler et al., 2005). Findings derived from adult samples therefore cannot be directly generalized to children and adolescents, given developmental differences in cognitive capacities, motivational factors, and social-emotional processing (Leigh and Clark, 2018). Notably, the study by Beidel et al. (2021), which examined *Pegasus VR* for children with SAD, was excluded from the present review because it did not meet the inclusion criteria of an immersive and interactive VR application. Nevertheless, this work represents an important initial step toward the development of VR-based interventions tailored to younger populations. Similarly, studies using gamified and eye-tracking based VR paradigms in other anxiety disorders (e.g., spider phobia; Wechsler et al., 2021; Wechsler et al., 2023) demonstrate the potential of age-appropriate VR designs to successfully engage younger users. Future research should therefore prioritize the systematic development and reporting of immersive, interactive, and developmentally appropriate VR assessments and interventions for children and adolescents with SAD, particularly given evidence that untreated Social Anxiety in youth often persists into adulthood (Weeks et al., 2009).

In addition to age distribution, sex and gender considerations remain underexplored in the current literature. Epidemiological evidence suggests that women tend to show higher prevalence and, in some cases, more severe clinical presentations of SAD compared with men (Asher and Aderka, 2018). Although most included studies reported the proportion of male and female participants, sex-specific analyses were rarely conducted in the VR literature. Furthermore, explicit reporting of gender identity beyond the binary classification, including non-binary or transgender identities, was absent. Research on gender minority populations indicates elevated levels of anxiety and psychological distress among transgender and gender-diverse individuals compared with cisgender peers, highlighting the need to better understand mental health disparities across gender identities (Li et al., 2025; Reisner et al., 2016). Future research on VR-based assessment and intervention should therefore more systematically examine sex- and gender-related effects and adopt inclusive reporting practices to enhance generalizability and clinical relevance. Altogether, this topic would be an interesting research question for future (scoping) reviews, which could explicitly examine questions of VR in social phobia related to sex and gender.

Regarding the targeted subareas of Social Anxiety, most studies focused on PSA (e.g., Anderson et al., 2017; Lindner et al., 2021; Reeves et al., 2021; Stupar-Rutenfrans et al., 2017), reflecting its high prevalence and clinical relevance. Consequently, many virtual environments were designed as classrooms, conference rooms, or auditoriums, often with adjustable audience sizes and observable reactions such as clapping, yawning, or neutral gazes. Therefore, we can conclude that VR assessment and intervention for SAD primarily addresses one subtype of Social Anxiety. Several studies broadened the focus by including interactive social situations, such as ordering a drink in a café (Supplementary Figure S1), canceling a flight, or engaging in small talk at a dinner party (Felnhofer et al., 2019; Holmberg et al., 2020; Kampmann et al., 2016b; Reichenberger et al., 2017). These tasks target other relevant fears, such as fear of rejection or embarrassment, covering additional relevant social fears. However, subtypes such as fear of blushing, eating in public, or using public restrooms remain largely underrepresented. Considering the heterogeneity of social fears, future research should develop more diverse, contextually rich VR scenarios that allow individualized adjustments.

A notable gap in current VR scenarios relates to the realism and contingency of social interactions. Many assessment and intervention studies relied on prerecorded or randomly triggered audience reactions (e.g., Bouchard et al., 2017; Reichenberger et al., 2017). Problems resulting from lacking contingency to the users' actions could cover a reduction in ecological validity and users' sense of social presence. Recent developments in artificial intelligence (AI) offer opportunities to address these limitations. AI-driven systems can generate context-sensitive verbal and nonverbal responses, enabling bidirectional and adaptive avatar interactions. By dynamically responding to users' behavior and anxiety cues, such systems can tailor scenarios to individuals' specific fears and anxiety hierarchies, enhancing the ecological validity of social interactions. This adaptive approach allows for personalized exposure, targeting the social situations most relevant to each participant, and may improve therapeutic learning and engagement (see Halkiopoulos and Gkintoni, 2025). Early implementations of adaptive avatars and gaze-contingent feedback (e.g., Kroczek et al., 2025; Schmidt-Peter et al., 2025), demonstrate promising avenues for improving interactivity and therapeutic engagement. While research directly comparing AI-enhanced VR to standard VR or human-facilitated interventions is still emerging, these developments demonstrate the potential for more realistic, responsive, and individualized VR-based Social Anxiety interventions. Future (scoping) reviews could specifically address the use of AI in the assessment and intervention in Social Anxiety to provide an overview of existing approaches.

Another gap highlighted by our review, consistent with Arnfred et al. (2023), is that hardware and software specifications were inconsistently reported across studies, limiting comparability and interpretability. Key technical aspects such as tracking precision, latency, and therapist control options were rarely described, despite their likely impact on presence and anxiety induction. Future studies should therefore emphasize transparent and detailed reporting of technical specifications to facilitate replication, systematic comparison, and optimization of VR applications.

Most VR interventions were embedded within a cognitive-behavioral framework, often combining exposure with cognitive restructuring, psychoeducation, or relaxation. Only a few studies incorporated attention bias modification (Ma et al., 2019; Wechsler et al., 2021) or social skills training (Zainal et al., 2021), despite evidence of their relevance in maintaining and reducing Social Anxiety (e.g., Clark and Wells, 1995). VR provides a controlled yet realistic environment to practice safely, suggesting that future interventions could further expand their cognitive and behavioral targets beyond current standard applications. In addition, some assessment studies implemented VR tasks based on the Social Competence Training of Reichenberger et al. (2017), Reichenberger et al. (2022), focusing on situations such as asserting one's rights. Importantly, these tasks were designed to measure anxiety activation across different VR environments, such as a train scenario or a travel agency, rather than to serve as interventions themselves. Overall, these studies highlight the potential of VR for safe

and ecologically valid assessment of Social Anxiety, but also reveal heterogeneity in the types of scenarios, measurement modalities, and reporting practices. Together, these findings indicate that future studies both intervention and assessment should aim to broaden the range of cognitive and behavioral targets, incorporate interactive and ecologically valid scenarios, and provide transparent and standardized reporting of task design, measurement procedures, and technical specifications to improve comparability, reproducibility, and the interpretation of anxiety activation in diverse social contexts.

As shown in our review, self-led or home-based VR approaches (e.g., Kim et al., 2017; Kim et al., 2022; Stupar-Rutenfrans et al., 2017; Zainal et al., 2021) offer promise for improving accessibility and scalability, as participants can complete VR exposure exercises without a human therapist. Across the included studies, adherence, feasibility, and usability were generally high, even though some interventions were conducted under controlled conditions (e.g., Kim et al., 2017; Zainal et al., 2021) with a researcher present to manage scenario transitions. Zainal et al. (2021) emphasized that future access to self-led programs should be facilitated in clinical or home settings as an adjunctive treatment. Stupar-Rutenfrans et al. (2017) reported promising symptom reduction but noted that it remains unclear whether self-led VR can fully replace therapist-guided exposure. Consequently, future research should evaluate these programs in real home environments to determine their standalone effectiveness versus their role as a complement to standard therapy.

Presence - particularly social presence - is a key determinant of anxiety activation (Felnhofer et al., 2019; Pfaller et al., 2021). While most included studies measured general (physical) presence, only Felnhofer et al. (2019) directly assessed social presence. This indicates a central research gap, especially since the respective study found that in SAD participants social presence was more closely associated with anxiety responses than physical presence. The bidirectional relation between social presence and anxiety activation was furthermore indicated by higher social presence values in SAD participants compared to healthy controls. This difference of higher presence values in SADs was not consistently found for physical presence, suggesting a specific relation between social presence and Social Anxiety. Future research should systematically measure both physical and social presence using validated instruments. In addition, the impact of specific VR features on social presence such as adaptive feedback, bidirectional interaction, avatar dynamics, and gaze behavior should be investigated to determine which elements most strongly influence anxiety responses and therapeutic outcomes. For example, Kishimoto and Ding, 2019 already showed that adaptive feedback and dynamic avatar behavior tended to elicit stronger presence and more authentic anxiety, whereas noncontingent or repetitive feedback could diminish both.

Only a few studies included in this review (n = 5) reported quantitative values (pre and peri assessment/intervention) that provide insight into anxiety activation, with only three of them explicitly reporting effect sizes. Mostly, subjective units of distress (SUD) ratings were assessed, only in one study also state anxiety and/or heart rate. This highlights a significant research gap since anxiety activation is a crucial aspect for both, assessment and intervention in SAD. Among the available data, the few effect sizes on SUD increase indicate moderate to high anxiety activation. Public speaking tasks tended to elicit higher anxiety than interactive everyday scenarios, although effects varied depending on scenario type, task structure, and audience behavior. However, the actual clinical significance of the activated anxiety level remains unclear in the included studies. Here, thresholds in regards to reliable change indices are desirable. In general, given the limited number of studies reporting these data, future research should systematically measure anxiety activation by collecting baseline (pre) and during-scenario (peri) values using standardized instruments. Moreover, studies should aim to disentangle which scenario components (e.g., audience behavior, task type, interaction complexity) primarily drive anxiety responses. Furthermore, a meta-analysis comparing VR-based assessment and intervention scenarios with *in vivo* situations, and quantifying anxiety activation using reported pre-peri values and effect sizes would provide critical evidence for the clinical applicability of VR-based interventions and assessments.

Feasibility and usability were predominantly described as positive by the study authors, with good compliance, low dropout rates, and positive participant feedback (e.g., Geraets et al., 2019; Zainal et al., 2021). However, our review revealed a lack of quantitative measures (e.g., reporting of dropout rates, absolute and relative frequencies for different reasons for dropout, systematic use of validated instruments for cybersickness assessment and other side effects of VR), which should be more systematically assessed in future studies.

Altogether, our review highlights an inconsistent level of reporting detail across the included studies, particularly regarding technical specifications and the design of social tasks. Many articles provided limited or incomplete information on hardware, software, or interaction capabilities, and several authors did not respond to requests for additional information (e.g., see Supplementary Table S3). While most studies reported the number of VR sessions, crucial details regarding the overall treatment or assessment structure were often missing, including the number and type of non-VR sessions, the duration of social tasks, and how tasks were distributed across sessions (see Supplementary Table S6). Such omissions limit reproducibility and complicate systematic comparison of task characteristics. We built our research questions regarding technical features in consideration of the reporting suggestions proposed by Arnfred et al. (2023). Beside this work, further reporting guidelines for VR studies exist, e.g., the international methodological recommendations for clinical VR trials, which emphasize transparent reporting of hardware, software, and interaction features to improve reproducibility and comparability (Birckhead et al., 2019). Following Arnfred et al. (2023) and Birckhead et al. (2019), we equally call for action regarding a standardized and comprehensive reporting of technical features in future VR studies, in clinical and subclinical populations. Importantly, studies should focus on reporting technical features that are salient for the research questions and the VR procedure (e.g., tracking, interaction capabilities, therapist control). Additionally, clear descriptions of procedural aspects - session structure, task parameters, and task sequencing - are crucial to ensure methodological transparency, enable replication, and support systematic comparisons across studies.

Finally, our review highlights that most studies included only small sample sizes (e.g., Donahue et al., 2009; Geraets et al., 2019; Holmberg et al., 2020), and frequently relied on subclinical samples (e.g., Stupar-Rutenfrans et al., 2017; Wechsler et al., 2021). These patterns limit the generalizability of findings to broader or clinically

severe populations, indicating a need for future studies to include larger and more representative clinical samples. Nevertheless, these studies provide valuable groundwork for subsequent research in VR-based assessment and intervention for Social Anxiety.

6.2 Strengths and limitations

Although study selection and data extraction were conducted carefully by experienced researchers and preregistered, unconscious bias cannot be entirely excluded. Since the authors of this review also contributed to some of the included studies, this could be a source of bias. To diminish this risk, we involved a neutral researcher for screening, who did not co-author any of the included studies.

As further limitation, immersive and interactive components were not explicitly described in a few studies; in such cases, information on the VR hardware, such as the HMD model and its tracking capabilities, was used to infer immersion and interactivity. Furthermore, the descriptive quantitative summary of anxiety activation, presence, feasibility, and usability was necessarily limited to the data reported in the included studies.

Furthermore, in conducting a scoping review, we did not statistically assess publication bias. To reduce the risk of it, we used a transparent search strategy. However, the search strategy was restricted to peer-reviewed publications, and grey literature such as dissertations, technical reports, and conference proceedings was not systematically searched. This decision may have introduced publication bias, as studies reporting null or non-significant findings are less likely to be published in academic journals. Consequently, the body of evidence mapped in this review may overrepresent positive or statistically significant results, and the current state of the field may be portrayed in a more favorable light than warranted. Future reviews addressing similar research questions may benefit from incorporating grey literature sources to mitigate this limitation.

Despite these limitations, this review provides a systematic and comprehensive overview of VR environments and tasks for Social Anxiety, covering both clinical and subclinical populations. By summarizing technical and procedural features alongside key outcome measures, it identifies research gaps and offers concrete directions for future studies. The inclusion of descriptive quantitative data adds structured insights beyond a purely narrative summary, and the pre-registration and careful dual screening enhance methodological transparency.

6.3 Conclusion

Current research on VR-based assessments and interventions for Social Anxiety is promising, highlighting the potential of virtual audiences, dialogues with agents, and interactive social tasks. However, challenges remain, including prerecorded or randomly triggered interactions, inconsistent technical reporting, and scarce research in children. Future studies should develop realistic, diverse, and developmentally appropriate scenarios, incorporate AI-driven and gaze-contingent feedback, address individual fears, and combine exposure with cognitive or social skills training. Self-led or home-based applications may increase accessibility, and meta-analytic evaluations could clarify intervention and assessment effectiveness and guide clinical implementation.

Author contributions

TS-P: Writing – review and editing, Writing – original draft. AM: Writing – review and editing, Writing – original draft. TW: Writing – original draft, Writing – review and editing.

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Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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