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Beyond exposure: a feasibility and validity study of virtual reality-based cognitive therapy for social anxiety disorder

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Background: Social Anxiety Disorder (SAD) is maintained by maladaptive cognitive patterns, yet most virtual reality (VR) interventions focus on exposure-based strategies, neglecting cognitive restructuring. To address this gap, we developed VR CHANGE, a mobile-based virtual reality cognitive therapy (VRCT) program targeting cognitive distortions in SAD. The program guides users through structured training tasks, including identifying automatic thoughts, recognizing cognitive distortions, and modifying maladaptive thinking. This study examined the program's feasibility and validity.

Methods: Twenty-four individuals with SAD completed the VRCT program, consisting of Theoretical Learning, Basic Training (beginner, intermediate, and advanced), and Applied Training, in two sessions spaced 1 week apart. Data collected for analysis included automatically recorded performance on behavioral tasks within the program, measures of social anxiety symptoms and cognitive distortions before and after the program, and a post-program user experience evaluation.

Results: Participants showed significant reductions in social anxiety and cognitive distortion scores post-intervention. Treatment satisfaction and content comprehension were high, and user experience ratings fell within an acceptable range. Behavioral data supported the program's construct, content, and convergent validity. In detail, error rates in cognitive distortion identification decreased with progression through training levels, and thought modification ability was associated with baseline cognitive distortion levels. Social anxiety-related scenario-induced distress increased appropriately across stages and correlated with social anxiety scales. Content validity was supported by differentiated task difficulty across cognitive distortion types.

Conclusion: VR CHANGE demonstrated strong feasibility and validity as a cognitive therapy intervention for SAD, suggesting that its structured, multimedia-supported format reduced cognitive load and facilitated therapeutic learning. The findings support its value as a subject for a large-scale randomized controlled trial to determine whether VRCT can be effectively used to treat SAD.

KEYWORDS
cognitive therapy, feasibility, social anxiety disorder, validity, virtual reality

1 Introduction

Social anxiety disorder (SAD) is characterized by a persistent and intense fear of being observed or negatively evaluated in social or performance situations, leading individuals to experience significant anxiety or avoid such situations altogether (American Psychiatric Association, 2013). SAD is associated with a higher risk of maladaptive outcomes, including impaired occupational performance, lower income, academic difficulties, and challenges in forming and maintaining relationships (Davila and Beck, 2002; Stein and Kean, 2000; Stein et al., 2000; Wittchen et al., 2000). With a lifetime prevalence of 7%–13%, SAD is one of the most common psychological disorders, contributing to substantial functional impairments and societal costs (Antony and Rowa, 2008; Ruscio et al., 2008).

The cognitive model of SAD, as refined by Hofmann (2007) based on Wells' et al. (1995) framework, highlights the role of cognitive biases in maintaining social anxiety symptoms. According to this model, individuals with SAD set unrealistically high social standards and engage in excessive self-monitoring, reinforcing negative expectations and anticipatory anxiety. This, in turn, leads to avoidance behaviors and post-event rumination, perpetuating the disorder. In this process, cognitive biases play a key role in maintaining the disorder (Rapee and Heimberg, 1997). Hofmann (2007) further identified four key maladaptive cognitive patterns in SAD: (a) underestimation of one's own social skills, (b) belief that anxiety symptoms are uncontrollable and visible to others, (c) overestimation of the severity and likelihood of negative consequences in social situations, and (d) an excessively critical self-view. These pathological patterns can be characterized as perceived poor social skills, low perceived emotional control, high estimated social cost, and negative self-perception, respectively. These biases contribute to a cycle of fear, avoidance, and negative self-appraisal, which sustains social anxiety symptoms.

Cognitive behavioral therapy (CBT) is widely recognized as the gold-standard treatment for SAD, combining cognitive restructuring and exposure therapy to target both maladaptive thoughts and avoidance behaviors (Heimberg, 2002). Extensive meta-analyses have validated its effectiveness, demonstrating moderate to large effect sizes (David et al., 2018; Heimberg, 2002; Rodebaugh et al., 2004). However, despite its efficacy, many individuals with SAD avoid seeking traditional face-to-face treatment due to logistical barriers, such as time, cost, and fear of interpersonal interactions (Acarturk et al., 2008). Moreover, self-monitoring and verbalizing cognitive distortions during therapy can be particularly challenging for individuals with SAD, potentially limiting their engagement in treatment.

To overcome these barriers, digital and remote treatment approaches have been developed, including internet-based CBT, mobile applications, and virtual reality (VR) therapy (Anderson et al., 2013; Firth et al., 2017; Hedman et al., 2012). Among these, VR-based therapy has emerged as a promising alternative, offering an immersive environment that closely replicates real-life social situations through controlled auditory and visual stimuli. Additionally, VR enables controlled exposure to stimuli in a structured setting and offers a distinct research advantage. For example, it allows real-time monitoring of users' cognitive, emotional, and behavioral responses during treatment (Han et al., 2009; Polak et al., 2022; Ouellet et al., 2018).

VR-based therapy for individuals with SAD has primarily focused on exposure techniques. They expose participants to various virtual social situations, such as giving presentations in a conference room or classroom, attending job interviews, participating in house parties, and using cafés or public transportation. Multiple studies have demonstrated that virtual reality exposure therapy (VRET) can elicit anxiety responses comparable to real-life experiences and effectively facilitate gradual desensitization to social anxiety (Emmelkamp et al., 2020; Felnhofer et al., 2019; Herbelin et al., 2002). Additionally, VRET allows for controlled manipulation of interpersonal distance, audience reactions, and social dynamics, providing structured exposure tailored to each individual (Geraets et al., 2019). Importantly, VRET has been shown to yield effect sizes comparable to *in vivo* exposure therapy, suggesting its clinical applicability and effectiveness (Anderson et al., 2013; Carl et al., 2019; Chesham et al., 2018; Parrish et al., 2016). Furthermore, our research team suggests that mobile-based VRET for SAD may be a treatment option that patients can perform independently at home (Kim et al., 2017).

While VRET effectively reduces social anxiety symptoms through exposure-based techniques, it does not directly target the maladaptive cognitive biases that sustain SAD. Recent efforts have sought to integrate cognitive therapy with VRET, incorporating psychoeducation, cognitive restructuring exercises and support, and behavioral experiments (Bouchard et al., 2017; Geraets et al., 2019; Klinger et al., 2005; Robillard et al., 2010; Safir et al., 2012). In particular, cognitive restructuring involves modifying irrational beliefs and fostering adaptive thinking, is a core component of this cognitive therapy. However, a dedicated VR-based cognitive therapy specifically designed to modify SAD-related cognitive distortions has not yet been fully developed. Given that the integration of cognitive and behavioral therapy within a VR framework enhances intervention consistency and completeness, there is a pressing need for the development of VR-based cognitive therapy (VRCT).

To address this need, our research team developed a mobile-based VRCT program to enable individuals with SAD address the maladaptive cognitive patterns. Our program integrates cognitive therapy techniques, such as the downward arrow technique and Socratic questioning to systematically challenge and modify dysfunctional beliefs, ultimately aiming to reduce social anxiety symptoms. This program follows a structured learning progression, incorporating theoretical instruction, basic training (beginner, intermediate, and advanced), and applied training, allowing for gradual skill acquisition and adaptation. Unlike traditional CBT, which relies on therapist-delivered cognitive restructuring in face-to-face sessions, the VRCT program integrates therapeutic procedures into an immersive environment on a mobile device, allowing users independently complete the process through interaction with virtual characters. By using virtual agents to model adaptive responses and scaffold step-by-step cognitive restructuring, VRCT can preserve the core mechanisms of CBT while enabling a more scalable and self-guided mode of delivery.

Our mobile-based VRCT offers several potential advantages. First, it enhances accessibility and cost-effectiveness, making cognitive therapy available to more individuals with SAD. Second, VR allows for repetitive learning in a structured

environment, reinforcing therapeutic skills. Third, unlike face-to-face cognitive therapy, VR-based therapy minimizes emotional discomfort by modeling adaptive responses through avatars. This feature creates a more comfortable therapeutic environment for individuals with SAD. Fourth, VR simulations provide a highly immersive setting, enhancing the retention and application of learned cognitive strategies in real-life social situations. Fifth, cognitive restructuring inherently involves elements of exposure therapy (Heimberg, 2002), allowing participants to assess their anxiety responses before actual exposure. With its heightened realism, VRCT enables a more precise evaluation of social anxiety severity, aiding in the customization of exposure-based interventions. Finally, VRCT allows for objective, real-time observation and measurement of social anxiety symptoms, offering valuable insights for both treatment and research.

This exploratory study aimed to evaluate the feasibility and validity of our mobile-based VRCT program by assessing its therapeutic effectiveness, user experience, and overall implementation. To achieve these objectives, the study tested the following five hypotheses for the program. 1) It would significantly reduce social anxiety symptoms and cognitive distortions in individuals with SAD. 2) Participants would report high levels of satisfaction, engagement, and comprehension regarding its therapeutic content. 3) Its user experience would be at an acceptable level. 4) Its structure and difficulty level would be appropriately designed, and learning effects would emerge as the program progresses, providing preliminary evidence of construct validity. 5) Participant responses to the scenarios and questions within it would accurately reflect the psychological characteristics of individuals with SAD, supporting the program's potential content and convergent validity.

2 Materials and methods

2.1 Participants

Individuals with neurological disorders and other major psychiatric conditions, including neurodevelopmental disorders, schizophrenia, bipolar disorder, and substance use disorders, were excluded. Eligibility and psychiatric diagnoses were assessed using the Mini-International Neuropsychiatric Interview (Sheehan et al., 1998), conducted by a certified clinical psychologist. A total of 31 patients with SAD were initially enrolled in the study. Of the initial participants, five withdrew from the study for personal reasons, and two completed only one of the two intervention sessions. As a result, complete data from 24 participants were included in the final analyses. These participants consisted of 11 males and 13 females, and had a mean age of 27.8 years (SD = 6.94) and an average education level of 14 years (SD = 2.41). Among the 24 participants, 13 were diagnosed with pure SAD. Comorbid conditions included major depressive disorder or persistent depressive disorder in four participants, obsessive-compulsive disorder in two participants, panic disorder in one participant, generalized anxiety disorder in one participant, major depressive disorder and panic disorder in two participants, and major depressive disorder and bulimia nervosa in one participant. None of the participants were engaged in any other form of psychological treatment during the study period. All participants received a detailed explanation of the study procedures and voluntarily signed an informed consent form before participation. This study was approved by the Institutional Review Board of Yonsei University Gangnam Severance Hospital, South Korea.

2.2 Experimental procedures

All participants took part in the implementation of a newly developed VRCT program called 'VR CHANGE.' Each participant visited the lab twice, 1 week apart, to complete the program, which lasted approximately three and a half hours in total. The entire procedure was conducted in a quiet, private room, where participants remained seated. No prior instruction or training was required for participants to use the program, as it was designed to be self-guided. An investigator did not participate in the therapeutic process, but only provided technical support.

The tasks were conducted using the Meta Quest 2 (Meta Platforms Inc. Menlo Park, CA, United States), a standalone VR headset equipped with a single LCD screen and built-in speakers. Participants wore the headset and could freely move their heads to align with the display. All questions were presented both through the virtual person's speech and as on-screen text, while response options were displayed as tables or graphs. Using hand-tracking-enabled touch controllers, participants interacted with virtual environments, selecting treatment options and responding to questions. If a participant spoke within a set time after hearing a question, their response was automatically recorded. Within the program, the therapist and all virtual characters were portrayed by professional actors following a pre-scripted scenario. The entire program content, including scenarios, questions, and response options, was designed by a research team of psychiatrists and clinical psychologists. The VR tasks were implemented by engineers from a specialized company and then revised and finalized based on the research team's review.

2.3 Composition and experimental experience of the VRCT program

The VRCT program consists of three sequential stages: Theoretical Learning, Basic Training, and Applied Training. It is recommended that each stage is completed in order. The overall structure of the program is illustrated in Figure 1.

2.3.1 Theoretical learning

The theoretical learning stage aims to introduce core principles of cognitive therapy through structured psychoeducation. Guided by a virtual person named Dr. Change, this stage consists of five structured steps (see the first row of Figure 2). First, participants are introduced to the three components of social anxiety—emotional, cognitive, and behavioral—and how these elements interact to produce symptoms. Second, automatic thought is explained as spontaneous, negative interpretation of social situation that contribute to anxiety. Third, participants learn about cognitive distortions, defined as biased thinking patterns that reinforce anxiety. The program introduces 12 common SAD-related

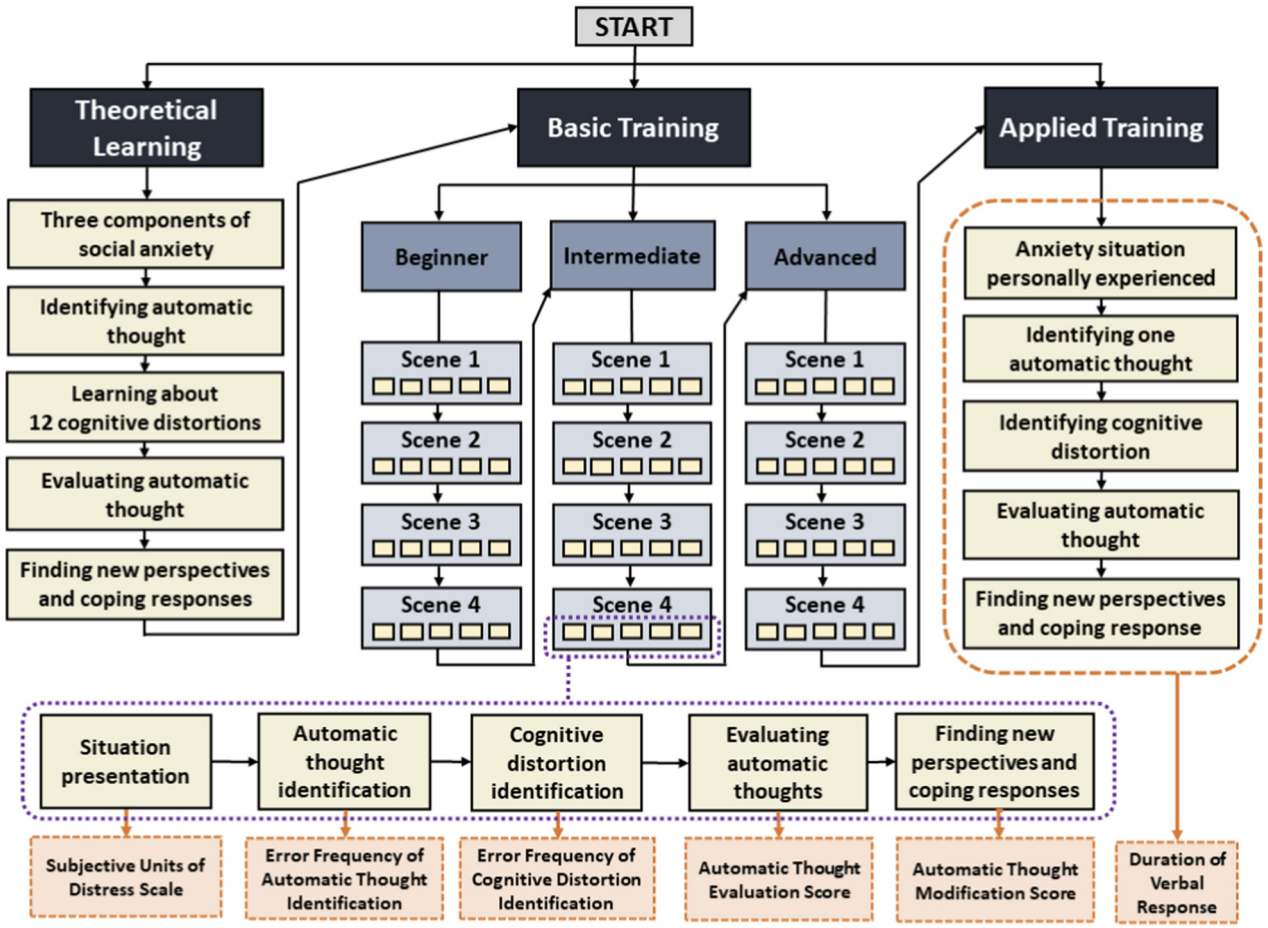

FIGURE 1
Overall structure of the virtial reality-based cognitive therapy program: VR CHANGE. The program consists of three sequential stages: Theoretical Learning, Basic Training (with beginner to advanced levels), and Applied Training.

cognitive distortions: 1) Fortune Telling, 2) Mind Reading, 3) Compulsive Responsibility, 4) Arbitrary Inference, 5) Overgeneralization, 6) Selective Abstraction, 7) Catastrophizing, 8) Personalization, 9) Magnification, 10) Minimization, 11) Dichotomous Thinking, and 12) Mislabeling (see Supplementary Material S1 for definitions of each). Fourth, participants learn to evaluate automatic thought using Socratic questioning, supported by structured examples. Finally, the program demonstrates how rational thought from a new perspective can replace automatic thought through a guided monologue.

2.3.2 Basic training

The basic training stage aims to help participants apply cognitive therapy principles to structured, socially anxious scenarios. The main characters include a virtual person representing a social anxiety patient and Dr. Change, who guides the therapeutic process by providing instructions, questions, and feedback. Unique virtual persons (e.g., Heemang, Kyujin) are introduced at each level, depicting different social anxiety scenarios. Additional characters, such as interviewers or club members, appear in the background without direct interaction.

The training is divided into three levels: beginner, intermediate, and advanced, with each level presenting increasingly challenging scenarios. As participants progress, the task format shifts from multiple-choice to open-ended responses, and the number of response options expands. At the beginner level, participants can observe a situation in which a virtual person requests a refund for an incorrect café charge. The intermediate level involves attending a new club meeting with a friend, while the advanced level addresses workplace scenarios such as job interviews and formal presentations. A detailed description of these scenarios is provided in Supplementary Material S2. Each level is subdivided into four time-sequenced scenes (scene 1, scene 2, scene 3, and scene 4), forming a coherent narrative. Within each scene, participants can follow a five-step cognitive learning process, mirroring the theoretical learning stage: (1) situation presentation, (2) automatic thought identification, (3) cognitive error identification, (4) evaluating thoughts, and (5) finding new perspectives and coping strategies (see the second row of Figure 2). This structured, repetitive approach supports continuous learning.

At the beginning of each scene, participants can observe a virtual person with SAD experiencing anxiety-inducing situations in settings such as a bedroom, public transportation, or a

FIGURE 2
Screenshot illustrating the sequential three-stage and five-step components of VR CHANGE. **(A)** The first row for the Theoretical Learning stage consists of the following five steps: Three components of social anxiety, Identifying automatic thought, Learning about 12 cognitive distortions, Evaluating automatic thought, and Finding new perspectives and coping responses. **(B)** The second row for the Basic Learning stage consists of Situation presentation, Automatic thought identification, Cognitive distortion identification, Evaluating automatic thoughts, and Finding new perspective and coping responses. **(C)** The third row for the Applied Training stage consists of Anxiety situation personally experienced, Identify one automatic thought, Identify cognitive distortion, Evaluating automatic thought, and Finding new perspective and coping response.

conference room. Automatic thoughts are conveyed through the virtual person's internal monologue and Dr. Change's narration. After that, the assistant asks, "If you were in [virtual person's name]'s situation, how anxious would you feel?" Participants should rate their anxiety using the Subjective Units of Distress Scale (SUDS, 0–10). SUDS scores at each level and overall are used for analysis.

In the "Automatic Thought Identification" step, potential automatic thoughts are presented (5 at the beginner/intermediate level and 6 at the advanced level) based on the preceding scenario. Participants are required to select a correct thought among 3 examples at the beginner/intermediate level and 4 examples at the advanced level using a VR controller. Incorrect responses prompt repeated attempts until correct selections are made. The number of errors is recorded as the Error Frequency of Automatic Thought Identification (EF-ATI) and used in the analysis.

In the "Cognitive Distortion Identification" step, participants should match the previously selected automatic thoughts with appropriate cognitive errors. A table of 12 cognitive error types is displayed, and hovering over each reveals a descriptive explanation. Participants are required to select correct errors to advance. The number of errors, recorded as the Error Frequency of Cognitive Distortion Identification (EF-CDI), is analyzed similarly.

During the "Evaluating Thoughts" step, Socratic questions are presented for each automatic thought. Participants are encouraged to assess the validity and rationality of their thoughts. At the beginner level, appropriate responses are selected from multiple-choice options. At the intermediate and advanced levels, participants should verbally respond to Dr. Change's questions by expressing their rational thoughts. Afterward, the virtual person provides an ideal rational response, allowing participants to compare their answer. Similarity between their response and the virtual person's example is rated on a 0–100 Visual Analog Scale (VAS) by participants, and the average score across thoughts is referred to as the Automatic Thought Evaluation Score (ATES). Based on the ATES range, symbolic imagery (e.g., seed, sprout, flower, tree) provides visual feedback. However, due to inconsistencies in task format across levels, ATES values are excluded from statistical analysis.

In the final step, "Finding New Perspectives and Coping Strategies," participants should express new perspectives, and problem-solving strategies as self-affirming statements. As before, the virtual person provides a model response, and participants can compare it to their own. Similarity is rated on a 0–100 VAS for each thought. After completing this step, the average VAS score is displayed along with symbolic feedback. This score is termed the Automatic Thought Modification Score (ATMS), and both level-specific and total ATMS values are included in the analysis.

2.3.3 Applied training

The purpose of the applied training stage is to help participants practice applying cognitive therapy concepts to situations based on

their own experiences, within the VR environment. Although the content is grounded in participants' real-life situations, the entire process takes place in VR as a guided self-reflection exercise. This stage consists of five steps, mirroring the structure of the theoretical learning and basic training stages, but tailored to each participant's personal experiences and conducted entirely through their verbal responses in the VR context (see the third row of Figure 2). First, participants verbally describe a situation in which they experienced anxiety, including their thoughts and emotions. Second, they identify and articulate one automatic thought related to that situation. Third, they determine the cognitive distortion associated with the selected automatic thought. Fourth, they answer three Socratic questions designed to challenge the cognitive distortion. Finally, in the fifth step, they formulate a new perspective and coping strategy to replace the challenged automatic thought. To assess participants' engagement in this applied training stage, the total duration of their verbal responses is analyzed.

2.4 Psychological assessments

Participants completed self-report questionnaires to assess social anxiety symptoms and cognitive distortions before starting the program at the first visit and after completing the program at the second visit. To assess social anxiety symptoms, participants completed the Social Phobia Scale (SPS), Social Interaction Anxiety Scale (SIAS), and the Liebowitz Social Anxiety Scale–Self-Report (LSAS-SR). The SPS measures anxiety in performance or observational situations (Mattick and Clarke, 1998), whereas the SIAS focuses on interactional anxiety (Brown et al., 1997), and both consist of 20 items rated on a 5-point Likert scale (0–4). The LSAS-SR comprises 48 items assessing anxiety and avoidance (24 items each) across 24 common social situations, rated on a 4-point scale (0–3) (Fresco et al., 2001).

Cognitive distortions in social contexts were assessed using the Brief Fear of Negative Evaluation Scale (BFNE), Dysfunctional Belief Test (DBT), Consequences of Negative Social Events Questionnaire (CONSE-Q), and Social Interaction Self-Statement Test (SISST). The BFNE includes 12 items rated on a 5-point scale (1–5), with reflecting fear of negative evaluation (Leary, 1983). The DBT consists of 70 items rated on a 7-point scale (1–7), assessing dysfunctional beliefs related to social anxiety (Cho and Won, 1999). The CONSE-Q includes 48 items (16 per domain) rated on a 9-point Likert scale (0–8), measuring catastrophic interpretations of negative social events across three domains: negative evaluation by others, negative self-appraisal, and long-term consequences (Wilson and Rapee, 2005). The SISST includes 30 items (15 positive, 15 negative) rated on a 5-point scale (1–5), with higher scores on the negative subscale reflecting greater cognitive distortion, while higher positive subscale scores reflect less distortion (Glass et al., 1982).

In addition, after completing the program at the second visit, participants completed self-report questionnaires to assess factors related to program implementation. Treatment satisfaction was measured using a revised version of the Client Satisfaction Questionnaire-8 (CSQ-8; Larsen et al., 1979), with wording adjusted from "counseling" to "treatment." The scale includes 8 items rated on a 4-point Likert scale (1–4). To evaluate participants' understanding of the treatment, a newly developed 9-item self-report scale, the Developed Understanding Questionnaire (DUQ), was used. Each item is rated on a 5-point scale (1–5), with higher scores indicating greater understanding of treatment content (e.g., cognitive distortions, thought evaluation, adaptive coping).

User experience was assessed using the Presence Questionnaire (PQ), Simulator Sickness Questionnaire (SSQ), and System Usability Scale (SUS). The PQ used in this study included 22 items from the original 29-item version, excluding items related to sensory fidelity and focusing on involvement, immersion, and interface quality (Witmer et al., 2005). Each item was rated on a 7-point Likert scale (1–7), with higher scores indicating a greater sense of presence. The SSQ consists of 16 items rated on a 4-point scale (0–3), with total scores ranging from 0 to 48. Higher scores indicate greater cybersickness symptoms (Kennedy et al., 1993). The SUS consists of 10 items rated on a 5-point Likert scale (1–5), evaluating overall system usability, including ease of use and learnability (Brooke, 1996). Higher scores indicate better perceived usability.

2.5 Statistical analysis

Descriptive statistics were used to explore participants' demographic characteristics, social anxiety–related symptoms, treatment satisfaction, and user experience. In particular, descriptive analyses (means, medians, and frequencies) were conducted to examine perceived difficulty and engagement in the VRCT program. Key indicators included error rates in identifying automatic thoughts and cognitive distortions, error frequency by distortion type, automatic thought modification scores, and task completion times during the applied training stage. To examine the clinical effectiveness of the program, paired t-tests were conducted to compare pre- and post-treatment scores on social anxiety symptoms and cognitive distortions. To investigate the construct validity of the program, repeated measures analysis of variance (ANOVA) and *post hoc* analyses were performed on subjective anxiety ratings for each level, error rates in identifying automatic thoughts and cognitive distortions, and automatic thought modification scores. To assess the convergent validity of the program, Pearson correlations were conducted between behavioral indices derived from VR tasks (e.g., subjective anxiety, EF-ATI, EF-CDI, ATMS) and pre-treatment psychological measures. In addition, simple linear regression analyses were conducted to examine whether speech duration in applied training predicted treatment outcomes. The statistical significance level was set at $\alpha = 0.05$, and all analyses were performed using IBM SPSS Statistics Version 27.0 (IBM Corporation, Armonk, NY, United States).

3 Results

3.1 Treatment effects on social anxiety and cognitive distortions

The analysis revealed a significant reduction across all measures related to social anxiety symptom (Table 1). Specifically, scores related to social performance and interpersonal interaction anxiety

TABLE 1 Pre- and Post-treatment statistics of social anxiety and cognitive distortion measures (n = 24).

Scale (Range of the total score)	Pre		Post		t	p	d^a
	Mean	SD	Mean	SD			
Social anxiety symptom							
SPS (0–80)	50.0	10.6	43.9	10.4	3.44	0.002	0.703
SIAS (0–80)	64.3	7.8	60.1	8.4	3.99	0.001	0.815
LSAS total (0–144)	101.7	16.8	94.0	19.1	3.95	0.001	0.807
Fear (0–72)	53.1	8.7	50.0	9.6	3.43	0.002	0.700
Avoidance (0–72)	48.5	9.2	44.0	10.4	3.88	0.001	0.793
Cognitive distortion							
BFNE (12–60)	51.5	6.0	47.8	7.8	3.22	0.004	0.659
DBT (70–490)	344.5	47.1	302.4	62.3	5.03	<0.001	1.027
CONSE-Q total (0–384)	254.0	64.1	212.2	67.9	3.72	0.001	0.777
Others (0–128)	96.7	17.5	86.8	20.2	2.73	0.012	0.570
Self (0–128)	83.6	25.8	71.5	27.9	2.81	0.010	0.587
Future (0–128)	73.6	28.2	53.7	30.1	3.15	<0.001	0.867
SISST positive (15–75)	32.3	8.1	37.5	9.8	−4.33	<0.001	0.884
Negative (15–75)	55.9	6.6	52.5	7.4	2.52	0.019	0.515

SPS, social phobia scale; SIAS, social interaction anxiety scale; LSAS, liebowitz social anxiety scale; BFNE, brief fear of negative evaluation; DBT, dysfunctional belief test; CONSE-Q, consequences of negative social events questionnaire; SISST, Social Interaction Self-Statement Test.
[a]d represents Cohen's d.

(SPS: $p = 0.002$, SIAS: $p = 0.001$) showed a significant decrease, as did general anxiety and avoidance in social situations (LSAS fear: $p = 0.002$, LSAS avoidance: $p = 0.001$).

All measures related to cognitive distortions also showed a consistent pattern of reduction (Table 1). In particular, negative automatic thoughts, core beliefs, and sensitivity to evaluation significantly decreased (BFNE: $p = 0.004$, DBT: $p < 0.001$). Among negative thoughts, future-related negative thoughts showed the greatest reduction (CONSE-Q future: $p < 0.001$), followed by self-related (CONSE-Q self: $p = 0.010$) and other-related (CONSE-Q other: $p = 0.012$) negative thoughts. Perceptions of social self also showed significant changes in both positive and negative self-statements (SISST positive: $p < 0.001$, SISST negative: $p = 0.019$), with a greater increase in positive statements. Effect sizes for all social anxiety and cognitive distortion measures ranged from a minimum of 0.515 to a maximum of 1.027.

3.2 Treatment satisfaction, understanding, and VR user experience

Treatment satisfaction and understanding were evaluated using the CSQ-8 revised and DUQ, respectively. The mean CSQ-8 revised score was 21.9 (SD = 6.1), with 70.8% of participants providing responses categorized as neutral or positive (i.e., "somewhat," "moderately," "agree," or "strongly agree"). Similarly, the mean DUQ score was 31.2 (SD = 6.6), with 75.9% of participants reporting at least moderate understanding of the treatment content.

Regarding the VR-based user experience, the PQ yielded a mean score of 102.5 (SD = 17.0), with 80.8% of participants reporting a moderate to high sense of presence. The SSQ showed a mean score of 13.6 (SD = 9.6), and 73.4% of participants indicated experiencing little to no simulator sickness (i.e., "none" or "slightly"). In contrast, the SUS had a mean score of 59.8 (SD = 10.5), which corresponds to a D rating according to the Sauro-Lewis Curved Grading Scale (Lewis, 2018).

In the correlation analysis between treatment understanding measured by the DUQ and VR experience measured by the SUS, SSQ, and PQ, treatment understanding showed no significant relationship with usability (SUS) or simulator sickness (SSQ), but showed a significant positive correlation with presence (PQ) ($r = 0.71$, $p < 0.01$).

3.3 Task validity

3.3.1 Construct validity based on error frequency and automatic thought modification score

Descriptive statistics for performance on the VR-based behavioral tasks are summarized as follows. For EF-ATI ($n = 220$), both the mode and median were 0, with a mean of 0.8 (SD = 2.1; range = 0–12), as shown in Figure 3. The first quartile (Q1) was 0, and the third quartile (Q3) was 1.0. An analysis of the average error frequency per item (12 items total) revealed that the item with the fewest errors had a mean of 0.1 errors (SD = 0.5), while the item with the most errors had a mean of 3.3 errors (SD = 4.1). For EF-CDI ($n = 794$), the mode was 0, the median was 1, and the mean was 2.9 (SD = 4.9; range = 0–66), with the first quartile (Q1) at 0 and the third quartile (Q3) at 4.0 (Figure 3). An analysis of the average error frequency per item (40 items total) showed that the item with the fewest errors had a mean of 0.2 errors (SD = 0.7), while the item with the most errors had a mean of 6.7 errors (SD = 4.7). For ATMS, the mean score was 45.5 (SD = 24.7; range = 0–100), with a median of 47.0 and a mode of 67.0. The first quartile (Q1) was 25.0, and the third quartile (Q3) was 65.0.

To examine differences in EF-ATI, EF-CDI across the beginner, intermediate, and advanced levels, a repeated measures ANOVA was conducted. As shown in Table 2, the results indicated no

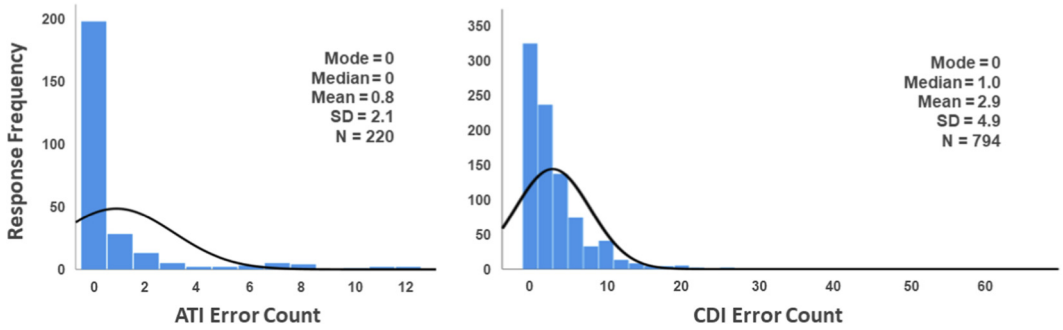

FIGURE 3
Histograms of Error Frequency in Automatic Thought Identification (ATI) and Cognitive Distortion Identification (CDI) (n = 22), showing descriptive statistics for performance on virtual reality-based behavioral tasks to demonstrate construct validity.

TABLE 2 **Repeated measures analysis of variance results for Error Frequency of Automatic Thought Identification (EF-ATI), Error Frequency of Cognitive Distortion Identification (EF-CDI), and Automatic Thought Modification Score (ATMS), and Subjective Units of Distress Scale (SUDS) across skill levels.**

Variable	Mean (SD)	*SS*	*Df*	*MS*	*F*	*P*	ηp^{2a}
EF-ATI[b]							
EF-ATI beginner	0.7 (1.3)	4.108	2	2.054	2.72	0.078	
EF-ATI intermediate	1.2 (1.4)						0.115
EF-ATI advanced	0.6 (1.3)						
EF-CDI[b]							
EF-CDI beginner	3.7 (3.0)	21.652	2	10.826	4.32	0.020	
EF-CDI intermediate	3.0 (1.9)						0.170
EF-CDI advanced	2.3 (1.1)						
ATMS[b]							
ATMS beginner	43.5 (20.6)	290.430	1.384	209.916	1.57	0.225	0.070
ATMS intermediate	44.6 (24.5)						
ATMS advanced	48.4 (22.2)						
SUDS[b]							
SUDS beginner	5.4 (2.1)						
SUDS intermediate	7.4 (1.4)	87.969	1.168	75.307	24.18	<0.001	0.523
SUDS advanced	8.1 (1.0)						

[a]*ηp2* represents partial eta squared.
[b]SUDS, measurements were calculated with n = 23, while EF-ATI, EF-CDI, and ATMS, measurements were calculated with n = 22.

significant differences (p = 0.078). In contrast, EF-CDI showed significant differences across conditions (p = 0.02). Post hoc tests for EF-CDI revealed a significant decrease in errors from the beginner to the advanced level (Figure 4). To examine whether ATMS differed across levels, a repeated measures ANOVA was conducted. The results indicated no significant differences (p = 0.225). These findings suggest that participants demonstrated reduced cognitive distortions as the training progressed, reflecting the structured learning progression of the program and supporting its construct validity.

3.3.2 Construct validity based on SUDS

The overall mean SUDS score was 7.0 (SD = 1.1). To assess construct validity, a repeated measures ANOVA was performed on SUDS scores across levels, revealing significant differences (p < 0.001, Table 2). Post hoc comparisons indicated that SUDS scores significantly increased from the beginner to the advanced level (Figure 4), reflecting the program's structured design and supporting its construct validity.

3.3.3 Convergent validity with psychological measures

Table 3 shows Pearson correlations between behavioral indices of VR tasks and pre-treatment psychological measures, and a heatmap for these correlations is provided in Supplementary Material S3. Correlations between SUDS scores and pre-treatment social anxiety measures (SPS, SIAS, LSAS fear, LSAS avoidance, and LSAS total) were analyzed to examine whether the program's scenarios validly reflect social anxiety symptoms. Most SUDS scores showed significant correlations with social anxiety measures. In particular, LSAS fear was significantly correlated across all levels (p < 0.05, Figure 5). Additionally, SPS

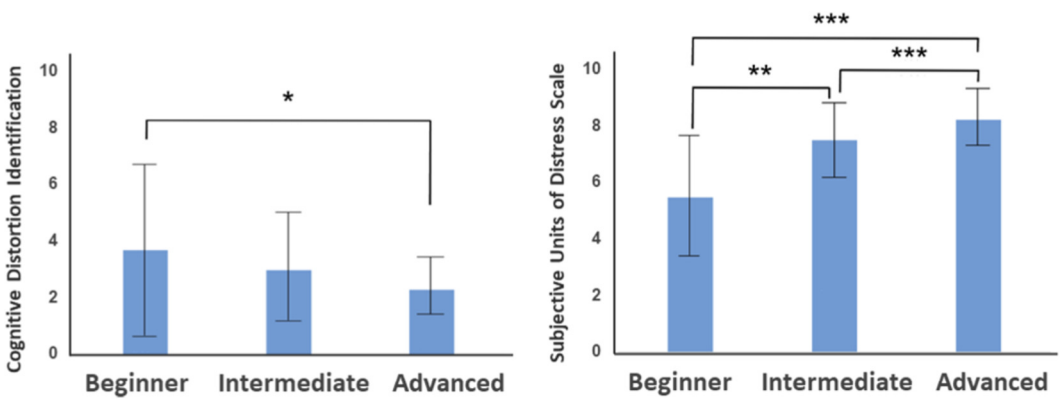

FIGURE 4
Post hoc analysis of Cognitive Distortion Identification (CDI) (n = 22) results, which showed a significant decrease in errors from the beginner to the advanced level, and Subjective Units of Distress Scale (SUDS) (n = 23) results, which showed a significant increase from the beginner to the advanced level.

TABLE 3 Correlations between Subjective Units of Distress Scale (SUDS) Scores and pre-treatment psychological measures (n = 23), and between Automatic Thought Modification Scores (ATMS) and pre-treatment cognitive distortion measures (n = 22).

			R	
Pre-test	SUDS beginner	SUDS intermediate	SUDS advanced	SUDS total
SPS	0.55**	0.31	0.25	0.54**
SIAS	−0.05	0.46*	0.45*	0.28
LSAS total	0.32	0.54**	0.44*	0.55**
Fear	0.44*	0.49*	0.46*	0.61*
Avoidance	0.17	0.53**	0.37	0.43*
	ATMS beginner	ATMS intermediate	ATMS advanced	ATMS total
BFNE	−0.22	−0.24	−0.23	−0.25
DBT	−0.39	−0.38	−0.42*	−0.43*
CONSE-Q total	−0.33	−0.44*	−0.49*	−0.45*
SISST positive	0.56**	0.77**	0.72**	0.73**
Negative	−0.26	−0.24	−0.31	−0.29

SPS, social phobia scale; SIAS, social interaction anxiety scale; LSAS, Liebowitz Social Anxiety Scale; BFNE, brief fear of negative evaluation; DBT, dysfunctional belief test; CONSE-Q, consequences of negative social events questionnaire; SISST, Social Interaction Self-Statement Test.
*$p < 0.05$, **$p < 0.01$.

scores, a measure of performance-related anxiety, were positively correlated with SUDS scores at the beginner level (SPS-basic: r = 0.55, $p < 0.01$). SIAS scores, a measure of interpersonal anxiety, were positively correlated with SUDS scores at the intermediate level (SIAS-intermediate: r = 0.46, $p < 0.05$). Together, these results supported the convergent validity of the SUDS scores as an index of social anxiety within the context of the VRCT program.

To examine whether the VR-based behavioral measures validly reflect the level of cognitive distortions, correlations were analyzed between error frequency (EF-ATI, EF-CDI, and ATMS) and pre-treatment cognitive distortion measures (BFNE, DBT, CONSE-Q total, SISST positive, and SISST negative). EF-ATI and EF-CDI did not exhibit significant correlations with any of the pre-treatment cognitive distortion measures. In contrast, ATMS showed significant correlations with some pre-treatment cognitive distortion measures. Specifically, DBT and CONSE-Q total were negatively correlated with ATMS total (both: $p < 0.05$), whereas SISST positive had a strong positive correlation (SISST positive-all levels of ATMS: $p < 0.01$). Together, these findings supported the convergent validity of the behavioral indices derived from the VRCT program.

3.3.4 Content validity: error distribution across cognitive distortion types

To explore the content validity of the distortion identification task, the number of errors for each of the 12 types of cognitive

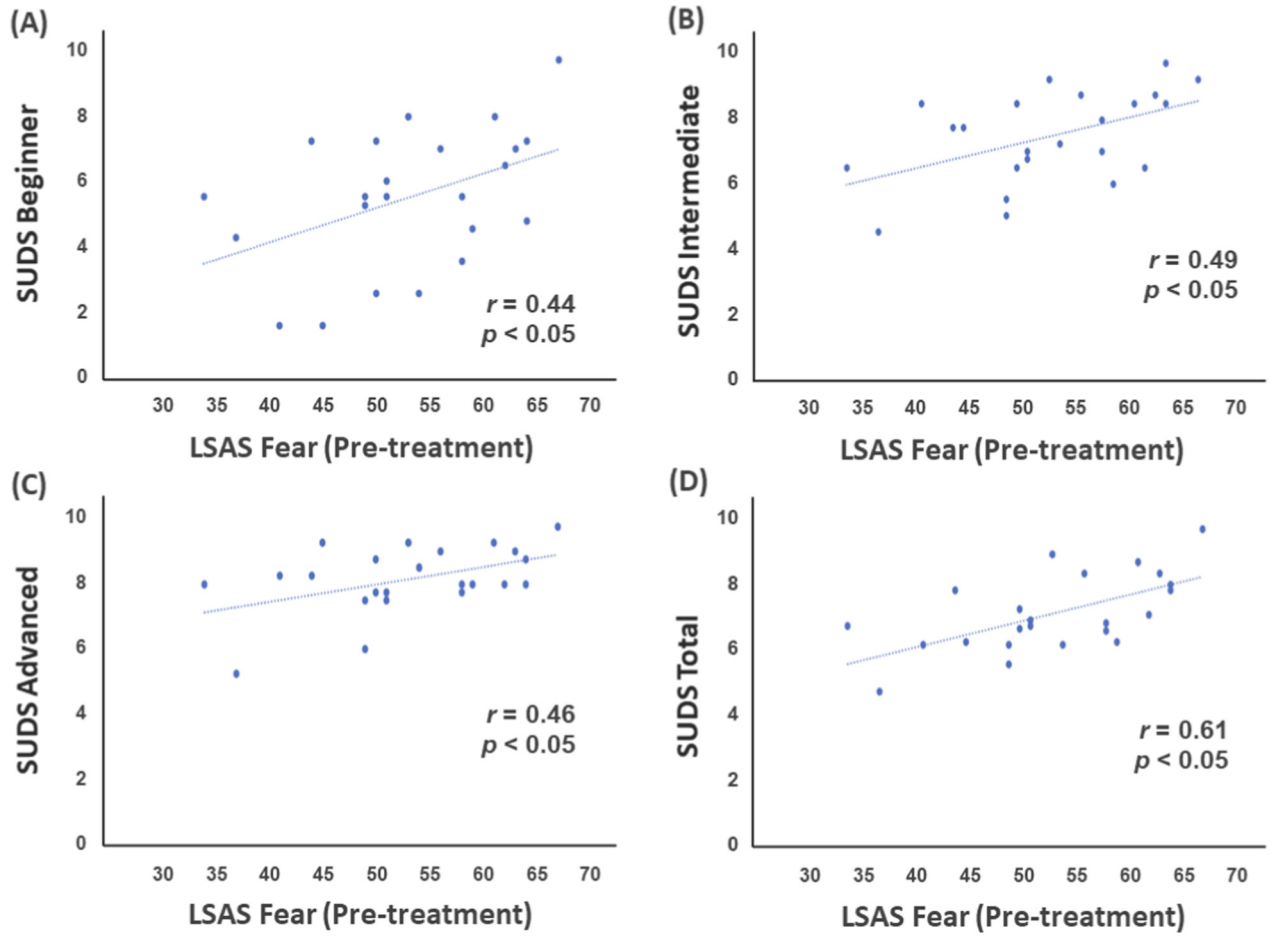

FIGURE 5
Correlations between pre-treatment scores of the Liebowitz Social Anxiety Scale (LSAS) - Fear and the Subjective Units of Distress Scale (SUDS) scores at the beginner **(A)**, intermediate **(B)**, advanced levels **(C)**, and across all levels **(D)**, showing that the program's scenarios validly reflect social anxiety symptoms.

distortions was counted and presented as percentages (Table 4). Since the total number of errors varied for each distortion, the proportions of 0–3 errors were calculated in relation to the total error count. Among the cognitive distortions, Compulsive Responsibility (type 3) and Mislabeling (type 12) had the highest percentage of 0 errors, at 78.7% and 63.6%, respectively. Conversely, Selective Abstraction (type 6) and Personalization (type 8) had the lowest percentage of 0 errors, at just 3.0% and 7.5%, respectively. For Selective Abstraction (type 6), the most frequently chosen incorrect response was Overgeneralization (type 5), while for Personalization (type 8), the most common error was Mind Reading (type 2).

3.4 Engagement in applied training

Participants' engagement in the treatment was assessed by measuring total speech duration during applied training. The mean speech duration was 169.7 s (SD = 92.3, range = 53–390 s). In the applied training, Mind Reading (Type 2) was the most frequently selected cognitive distortion (n = 8), whereas Selective Abstraction (Type 6), Minimization (Type 10), and Dichotomous Thinking (Type 11) were never chosen.

Total speech duration was not significantly associated with pre–post changes in social anxiety measures (SPS, SIAS, and LSAS) and most cognitive distortion measures (BFNE, CONSEQ, and DBT) (all: $p > 0.05$). However, speech duration significantly predicted changes in SISST-positive ($\beta = 0.574$, $p < 0.01$, $R^2 = 0.33$) and SISST-negative scores ($\beta = -0.465$, $p < 0.05$, $R^2 = 0.22$).

4 Discussion

This study assessed the potential feasibility and validity of VR CHANGE, a virtual reality-based cognitive therapy program developed for individuals with SAD. As hypothesized, VR CHANGE reduced both cognitive distortions and symptoms of social anxiety among participants, demonstrating its potential as a viable intervention. The program improved overall social anxiety symptoms, including performance anxiety, difficulties in interpersonal interactions, and avoidance behaviors. Moreover, the intervention reduced several cognitive distortions commonly associated with SAD, such as fear of negative evaluation, negative automatic thoughts, and maladaptive core beliefs. Notably, in terms

TABLE 4 Error frequency (%) by type of cognitive distortions (n = 22, N = 794).

No.	Cognitive distortion	Error count			
		0	1	2	3
1	Fortune telling	27.2	28.4	11.3	9.0
2	Mind reading	44.3	14.7	4.5	9.0
3	Compulsive responsibility	78.7	7.5	4.5	1.5
4	Arbitrary inference	34.0	26.1	13.6	9.0
5	Overgeneralization	20.0	16.9	21.5	16.9
6	Selective abstraction	3.0	13.8	15.3	20.0
7	Catastrophizing	50.0	21.2	13.6	3.0
8	Personalization	7.5	10.6	12.1	12.1
9	Magnification	28.7	15.1	12.1	10.6
10	Minimization	52.3	6.1	6.1	4.6
11	Dichotomous thinking	19.7	7.5	9.0	6.0
12	Mislabeling	63.6	13.6	7.9	4.5

of cognitive distortions, participants showed a substantial reduction in negative expectations about future social situations, along with a significant increase in positive self-perceptions in social contexts. These findings suggest that the program may enhance self-efficacy in anticipating social encounters—an effect consistent with previous research indicating that cognitive reappraisal self-efficacy mediates the impact of CBT on social anxiety symptoms (Goldin et al., 2012).

Participants also reported high satisfaction and comprehension, and their user experience was generally favorable. One aspect of feasibility was supported by participants' high ratings of treatment satisfaction (CSQ-8 revised) and content understanding (DUQ), with over 70% reporting favorable responses. These findings indicate that participants viewed the program as both comprehensible and effective. Also, the user experience appeared favorable, with a mean PQ score of 102.5—well within the range reported in previous studies (89.61 in Parrish et al., 2016; 106.97 in Kim et al., 2020). The mean SSQ score was 13.6, indicating an acceptable level of side effects relative to prior findings (34.68 in Kim et al., 2023; 10.76 in Kim et al., 2020). These results suggest that the program offers a generally positive VR experience, with sufficient presence and minimal adverse effects. Notably, there was a significant positive correlation between participants' understanding of the treatment content (DUQ) and their sense of presence (PQ), suggesting that greater immersion was associated with better comprehension. Given the established importance of presence in VR-based training (Ling et al., 2014), the high presence observed in this study may have directly contributed to the program's effectiveness.

SUS scores were relatively low, falling within the D grade range. Some participants reported difficulty navigating the system, indicating potential areas for improving user-friendliness. These moderate usability scores may primarily be due to the participants' lack of experience with VR devices. Many participants struggled to adapt to VR-specific controls, such as gaze-based selection and head-direction navigation, which were less intuitive than conventional mobile interfaces and required a certain degree of learning. Another reason may be the inherent structural complexity of the VRCT program. Unlike exposure-focused VR programs, where users simply remain in a virtual scenario, our VRCT required them to perform multiple cognitive tasks within a single, multi-step training framework. This complexity likely increased cognitive load, leading to moderate usability ratings for those with little experience using VR devices. Nonetheless, no significant correlation was found between SUS and DUQ scores, suggesting that lower usability did not directly affect participants' understanding or the overall effectiveness of the training. Future versions of the program may include a brief interactive onboarding tutorial to facilitate early familiarization with VR controls, simplify navigation steps where possible, and provide stronger visual and auditory feedback for option selections. Additionally, offering a treatment flowchart at the beginning of the program—allowing users to understand the overall structure and sequence at a glance—may further support navigation without altering the therapeutic components. These improvements could enhance user experience while preserving the core structure of the intervention.

However, no significant correlation was found between SUS and DUQ scores, suggesting that lower usability did not directly affect participants' understanding or the overall effectiveness of the training.

Taken together, these findings support the feasibility of VR CHANGE in terms of both clinical effectiveness and user experience. Building on this, we further examined the validity of the behavioral measures and task structure. To assess the validity of the program, descriptive statistics were examined for the VR-based behavioral measures (EF-ATI, EF-CDI, and ATMS). The error frequency of identifying automatic thoughts (EF-ATI) was very low, with minimal variation across items. Likewise, the average number of errors for identifying cognitive distortions (EF-CDI) was 2.9, indicating that the tasks were generally not difficult. Given that a higher error count typically reflects greater item difficulty (Wu et al., 2016), the overall difficulty level of the error-identification tasks appears to have been relatively low. According to Cognitive Evaluation Theory (Deci and Ryan, 2008), an optimal level of task difficulty can enhance intrinsic motivation and perceived competence. In this context, the manageable difficulty of the program may have reduced therapy-related stress or frustration while simultaneously promoting motivation and a sense of competence, thereby facilitating the application of therapeutic content to real-world situations. In contrast, the average score for modifying automatic thoughts (ATMS) was 45.5, slightly below the midpoint of 50. This suggests that participants' subjective evaluations of how closely their responses matched the virtual person's model responses were somewhat conservative. Unlike EF-ATI and EF-CDI, the ATMS task involved open-ended responses, which may have been perceived as more challenging. Additionally, individuals with SAD often hold negative self-perceptions regarding their coping abilities and tend to maintain unrealistically high internal standards (Hofmann, 2007), which may have led participants to underestimate their performance.

As predicted, the structured learning design of the program was supported by improvements across training levels in EF-CDI and ATMS, as well as systematically increasing SUDS scores across

scenario stages. To determine whether the program facilitated effective learning across its structured levels—basic, intermediate, and advanced—and whether its difficulty progression was validly organized, we analyzed level-based differences in the VR-based behavioral measures (EF-ATI, EF-CDI, and ATMS). No significant differences were found across levels for EF-ATI, which may suggest that error frequencies remained consistently low or that the item difficulty did not vary meaningfully across levels. In contrast, EF-CDI showed significant differences across levels, with error frequency decreasing from the basic to the advanced stage. This pattern indicates that participants effectively learned to identify cognitive distortions and made increasing efforts to understand and apply the program content. For ATMS, no statistically significant differences were observed across levels; however, mean scores showed a slight upward trend from basic to advanced. While not significant, this trend may reflect a gradual improvement in participants' alignment with the ideal responses, indicating increased comprehension. It may also suggest a growing tendency among participants to internalize the program content over time.

To examine whether the program's scenario structure validly reflected social anxiety, we analyzed SUDS scores. The average SUDS score across all scenarios was 7 out of 10, and participants' reported distress significantly increased from the basic to the advanced level. These findings suggest that the scenarios were appropriately designed to elicit social anxiety and that the level of induced anxiety increased systematically across stages, supporting the construct validity of the scenario progression. To further assess convergent validity, correlations were examined between pre-treatment social anxiety measures (SPS, SIAS, LSAS fear, LSAS avoidance, and LSAS total) and SUDS scores. Most measures showed significant correlations with SUDS scores, particularly LSAS fear, which exhibited stronger associations than LSAS avoidance. These findings indicate that the scenarios effectively reflected anxiety specific to social contexts. Notably, each stage of the program was designed to target distinct dimensions of social anxiety—performance anxiety at the basic level and interpersonal anxiety at the intermediate level. Consistent with this structure, SUDS scores at the basic and intermediate stages showed significant correlations exclusively with the corresponding social anxiety scales (SPS and SIAS, respectively), further supporting the concurrent validity of the scenario design at each level.

Finally, as expected, evidence supporting both the content and convergent validity of the program was found through two key patterns: (1) the alignment between participants' behavioral responses (e.g., ATMS, SUDS) and their baseline measures of social anxiety and cognitive distortions, and (2) meaningful variation in difficulty across cognitive distortion items, reflecting content-specific performance differences. To assess the convergent validity of the VR-based behavioral measures in capturing cognitive distortions, correlations were examined between pre-treatment distortion scales (BFNE, DBT, CONSE-Q total, SISST positive, and SISST negative) and behavioral indices (EF-ATI, EF-CDI, and ATMS). No significant associations were found between EF-ATI or EF-CDI and the baseline measures, suggesting that participants were able to identify automatic thoughts and cognitive distortions during the tasks regardless of their initial levels of cognitive distortion. In contrast, ATMS showed significant correlations with several pre-treatment cognitive distortion measures, including CONSE-Q total, DBT, and SISST positive. This finding suggests that participants with lower levels of cognitive distortion at baseline were better able to generate appropriate modified thoughts, indicating that the ATMS task was validly designed to reflect these differences. Notably, the standard deviation of ATMS was relatively high (SD = 24.7), indicating considerable variability in participants' ability to modify automatic thoughts. According to cognitive load theory (Van Merrienboer and Sweller, 2005), learners' preexisting schemas and familiarity with a concept influence how efficiently they process and integrate new information. The relatively higher complexity of the ATMS task—compared to EF-ATI and EF-CDI—may have amplified individual differences depending on participants' cognitive schemas related to distortion. In this context, those with fewer baseline distortions may have found it easier to integrate the training content and modify their automatic thoughts. Moreover, the strong positive correlation between SISST positive and ATMS, combined with the fact that ATMS was subjectively rated, suggests that participants' confidence or self-efficacy in evaluation may have influenced how highly they rated their own responses.

To assess content validity—specifically, whether task difficulty varied across different types of cognitive distortions and whether certain types were disproportionately easy or difficult—we analyzed accuracy rates for all 12 distortion types. Error frequencies per item (ranging from 0 to 3) showed considerable variation depending on distortion type. For example, the percentage of participants who answered correctly on the first attempt ranged from as low as 3% to as high as 78.7%, indicating substantial differences in item difficulty across distortion categories. Further analysis of error frequencies in the cognitive distortion identification task showed that the average number of errors per item ranged from 0.2 to 6.7. The overall standard deviation was also relatively high (SD = 4.9), indicating substantial variability in item difficulty across both participants and items. More specifically, participants tended to perceive Compulsive Responsibility and Mislabeling as easier, while Selective Abstraction and Personalization were perceived as more difficult. Selective Abstraction was frequently confused with Overgeneralization, and participants often had difficulty distinguishing between Personalization and Mind Reading. These challenges may stem from conceptual overlap—for example, both Selective Abstraction and Overgeneralization involve drawing broad conclusions from limited evidence, while both Personalization and Mind Reading reflect distorted self-referential interpretations of events. Although these difficulties did not appear to significantly affect overall learning outcomes, offering clearer definitions or additional examples to better distinguish between similar distortion types could improve the clarity and instructional value of the training, without reducing its challenge or diminishing participants' sense of achievement.

The final applied training stage was designed to elicit voluntary responses from participants. To evaluate their level of engagement in the therapeutic process, we analyzed the total duration of spontaneous verbal responses during this stage. The average speaking time was 169.7 s (approximately 3 minutes), with substantial variability across participants. This suggests that individual motivation to actively engage with the content and

participate in the learning process varied considerably. The presence of a research assistant may have influenced participants' verbal behavior—particularly among those sensitive to social evaluation—potentially leading to reduced engagement for some individuals. Individuals who demonstrated greater verbal engagement may have processed their automatic thoughts and self-directed statements more deeply, leading to more adaptive self-perceptions. In particular, speech duration was not associated with changes in most symptom or cognitive-distortion measures, but was significantly associated with improvements in both positive and negative self-statements on the SISST. This finding suggests that participants who engaged more actively during applied training tended to show reductions in negative self-statements and increases in positive self-statements in social contexts. Meanwhile, the types of cognitive distortions identified by participants during applied training were not strongly associated with item-level error frequency. For example, while Compulsive Responsibility and Mislabeling had the highest accuracy rates and Selective Abstraction and Personalization the lowest, participants did not exclusively select the distortions they previously found easier. This suggests that most participants were able to appropriately identify the cognitive distortions underlying their own automatic thoughts, indirectly supporting the applicability of the cognitive therapy content to real-world social anxiety situations.

Despite the encouraging findings, several limitations of this study warrant consideration. First, the sample was too small to confirm external validity, and primarily consisted of individuals in their 20s and 30s without a control group, making it difficult to address the therapeutic effectiveness of the program. Future research employing randomized controlled trial designs with large, well-defined samples that can ensure sufficient statistical power is needed to establish robust evidence for the program's efficacy. Second, the study did not investigate how individual cognitive resources, motivational levels, or personal characteristics may have influenced treatment outcomes. Third, the scoring procedures used in the ATES and ATMS tasks relied on the subjective judgment of participants, assessing how closely their responses matched the model responses of the virtual character. This prevented the application of fully standardized or predefined scoring criteria, limiting direct comparisons between individual scores. Fourth, the study did not incorporate qualitative interviews to gather participants' subjective perspectives on usability. Although usability was assessed through various feasibility measures and behavioral indices, integrating direct user feedback may help identify areas for refinement and enhance the overall completeness of the program. Fifth, the study was based on a single implementation of the VRCT program. Previous research has shown a dose–response trend, wherein increased exposure to VRET leads to greater treatment effects, nearing statistical significance (Powers and Emmelkamp, 2008). Potential effectiveness was observed after just one session in this study. However, it is not known how long the effect will last. Therefore, further investigation is needed to determine whether repeated training can produce stronger and more sustained outcomes. Future studies should also investigate optimal training schedules and the potential benefits of supplementary learning materials to maximize treatment efficacy. Finally, although the program incorporated feedback mechanisms within the VR environment, it did not support direct interaction with virtual persons or real individuals. Future iterations of the program should consider integrating interactive elements—such as AI-driven virtual characters—to facilitate more dynamic experiences. Real-time interaction may enhance therapeutic immersion, responsiveness, and user engagement.

5 Conclusion

This exploratory study demonstrated that our VRCT program has both feasibility and validity in treating SAD, supported by improvements in symptoms, usability, and multiple forms of validity. Cognitive therapy for social anxiety involves restructuring individuals' maladaptive thought patterns, a process that closely resembles learning. According to cognitive load theory, effective learning requires the gradual introduction of complex concepts in structured stages, along with progressive increases in task difficulty. The use of multimedia materials can help reduce cognitive overload, while clear and specific feedback supports error correction and reinforces understanding (Sweller, 2011). The VRCT program applied in this study successfully implemented these principles by presenting complex cognitive therapy concepts in a sequenced manner, gradually increasing difficulty, and utilizing audiovisual materials alongside example responses. These features served to minimize cognitive load and enhance learning efficiency for individuals with social anxiety. Notably, the error-identification tasks employed a repeated-response format, requiring participants to continue attempting until they met predefined accuracy criteria—an approach likely to have strengthened the learning impact of the training tool. The results of this study suggest that this VRCT program is worthy of consideration as a subject for a large-scale randomized controlled trial to determine whether it can be effectively used to treat SAD. Future studies could also explore the effectiveness of combining this program with other therapeutic components, such as VRET sessions or self-guided workbooks. This integration may further expand the scope of its applications, enabling it to serve as a flexible and effective therapeutic tool in remote or self-directed settings, contributing to the enhancement of mental health in the public.

6 Key takeaways

- VR CHANGE is the first mobile-based VR cognitive therapy (VRCT) program targeting maladaptive thought patterns in social anxiety disorder (SAD), extending beyond exposure-only approaches.
- The program showed strong feasibility, usability, and behavioral validity as a potential digital therapeutic tool.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by Institutional Review Board of Yonsei University Gangnam Severance Hospital. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

EK: Formal Analysis, Investigation, Project administration, Visualization, Writing – original draft. YJ: Data curation, Investigation, Writing – review and editing. BP: Conceptualization, Writing – review and editing. HK: Data curation, Resources, Writing – review and editing. B-HK: Methodology, Resources, Writing – review and editing. J-JK: Conceptualization, Funding acquisition, Software, Supervision, 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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