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Visual attention patterns in social anxiety disorder across various socio-evaluative tasks: Findings from a virtual reality eye-tracking study

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ABSTRACT

Background: Social Anxiety Disorder (SAD) is a prevalent and impairing condition that is often underdiagnosed and undertreated, leading to chronic symptoms and comorbidities. Identifying objective behavioral markers is critical for improving early detection. Aberrant visual attention such as gaze avoidance and hyperscanning have been proposed as key mechanisms underlying SAD, yet findings from traditional eye-tracking studies using static or limited social stimuli remain inconsistent. Virtual Reality (VR) combined with integrated eye-tracking offers an ecologically valid approach to studying visual attention within realistic, socially evaluative contexts.

Objective: This study examined visual attention patterns in individuals with SAD using an immersive VR paradigm with integrated eye-tracking designed to simulate naturalistic socio-evaluative situations.

Methods: Thirty individuals with SAD and thirty matched healthy controls (HCG) completed three 360° VR tasks: a job interview, an unstructured social interaction, and a presentation. Eye-tracking data were analyzed across predefined areas of interest (AOI) using temporal and spatial metrics.

Results: Individuals with SAD showed reduced fixation duration on faces and increased fixation duration on the environment compared with HCG. In the job interview task, significant group differences were found for the face AOI ($p = .048$) and environment AOI ($p = .022$). In the unstructured social interaction task, individuals with SAD again spent less time fixating on faces ($p = .006$) and more on the environment ($p < .001$). No group differences were observed in the presentation task. Individuals with SAD also demonstrated greater mean distance between fixations, indicative of hyperscanning across all tasks.

Conclusions: VR-based eye-tracking can capture distinct visual attention patterns in SAD, supporting its ecological validity and diagnostic potential as an objective tool for early detection and digital mental-health assessment method.

1. Background

Social Anxiety Disorder (SAD) is characterized by a persistent and excessive fear of being scrutinized, rejected, or humiliated in social and performance situations (Association, 2013). It is a common condition with a lifetime prevalence estimated at 12.1 % (Kessler et al., 2005). Worldwide, anxiety disorders are both prevalent and costly, affecting approximately four percent of the global population and is associated with about twofold higher healthcare costs compared to controls (Javaid et al., 2023; Konnopka & König, 2020). SAD is also highly comorbid, with around 80 % of individuals experiencing additional psychiatric disorders, which typically develop after the onset of SAD (Fehm et al., 2005; Lépine & Pélissolo, 2000; Wittchen & Fehm, 2003). Compared to other psychiatric disorders, SAD has one of the earliest age of onset, approximately 14.5 years, surpassed only by neurodevelopmental disorders (Kessler et al., 2005; Solmi et al., 2022). Despite its prevalence and impact, SAD is associated with undertreatment, delay in treatment initiation, poor treatment response, and high tendency to discontinuation of treatment. An inverse relationship between severity of SAD and seeking treatment appears to exist (Ruscio et al., 2008) in which individuals with the most severe SAD symptoms are less likely to receive treatment, significantly affecting their overall functioning and quality of life. The high comorbidity rate also contributes to the under-recognition of SAD by clinicians, as treatment of SAD is often initiated only after the

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onset of comorbid disorders, leading to substantial delay between symptom onset and treatment initiation (Zimmerman & Chelminski, 2003). Given these factors, SAD may serve both as a predisposition and a risk factor for development of other psychiatric disorders, highlighting a critical need for improved early detection methods.

A growing body of research is focusing on identifying behavioral markers of SAD, particularly through investigation of visual attention as a means of improving early detection. Consistent with cognitive models of the disorder, SAD has been linked to aberrant visual attention patterns (Schulze et al., 2013). These models propose that individuals with SAD engage in subtle avoidant behavior in situations where complete avoidance of the situation is not possible. Such avoidance is often expressed through reduced attention to social cues, such as avoiding eye contact or looking away from faces (Clark et al., 1995; Leigh & Clark, 2018). At the same time, individuals with SAD may also exhibit attentional bias and hypervigilant behavior to perceived social threat, such as scanning others 'facial expressions for signs of disapproval (Rapee & Heimberg, 1997). Building on these models, the vigilance-avoidance hypothesis suggests that individuals with SAD initially display a rapid orientation to perceived threatening stimuli but subsequently avoid them (Bögels & Mansell, 2004). More recently, the concept of hyperscanning has emerged, describing a distinct attentional pattern in SAD, characterized by an excessive monitoring of the environment for signs of negative social evaluation (Chen & Clarke, 2017; Chen et al., 2015; Toh et al., 2011). Together, these attentional patterns are thought to function as short term anxiety regulation strategies but ultimately contribute to the persistence of SAD symptoms (Clark & Wells, 1995).

Building on these proposed mechanisms, eye-tracking technology provides an objective and continuous method to quantify such attentional biases (Holmqvist & Andersson, 2017). Within this framework, avoidance can be reflected in reduced visual engagement with socially relevant stimuli (e.g., shorter fixation duration and fewer fixations on faces), whereas hyperscanning may manifest as broader and more dispersed visual exploration patterns. Vigilance–avoidance processes may be captured through early orienting and disengagement indices. Mapping these theoretically derived processes onto specific gaze metrics allows for a more direct test of cognitive models of SAD in ecologically valid contexts. While some previous studies have reported reduced fixations on faces, reflecting avoidance of socially threatening cues, findings are mixed, particularly for hyperscanning and vigilance-avoidance patterns. Such mixed findings likely reflect methodological variations across paradigms (Chen & Clarke, 2017; Chen et al., 2020). Most eye-tracking studies use passive viewing of static emotional faces (e.g., face-viewing, dot-probe task) which may not activate the core fear of negative evaluation (Günther et al., 2021). More naturalistic paradigms, in contrast, often rely on one single type of scenario, most commonly a public-speaking task. However, cognitive models of SAD conceptualize the disorder as context sensitive, with attentional processes shaped by perceived social evaluation, ambiguity, and situational threat (Clark et al., 1995; Rapee & Heimberg, 1997). As a result, it remains unclear whether visual attention patterns vary systematically across social contexts differing in evaluative demands, or whether attentional biases in SAD represent a stable pattern across different social situations. This underscores the need for ecologically valid designs that examines visual attention across multiple social scenarios.

Virtual Reality (VR) offers a promising solution by presenting realistic, socially evaluative contexts while maintaining experimental control (Freeman et al., 2017; Geraets et al., 2022). Although, VR is widely used in intervention studies (Zeka et al., 2024) its potential in assessment and screening of psychiatric disorders, including SAD, remains relatively underexplored (Geraets et al., 2022) particularly the combination of VR and eye-tracking technology. Combining VR with integrated eye-tracking allows researchers to examine visual attention dynamically within immersive, lifelike social situations, addressing the gap between traditional lab-based paradigms and real-world social behavior.

To date, only a limited number of studies have integrated VR and eye tracking to investigate visual attention in SAD (Dechant et al., 2017; Kim et al., 2018; Reichenberger et al., 2020; Rubin et al., 2020), highlighting the need to further explore the potential of this approach for assessment of SAD. The present study contributes to this emerging literature by examining whether VR-based eye-tracking can identify avoidance and hyperscanning patterns in individuals with SAD across multiple socio-evaluative contexts. To move beyond the common single-scenario focus in the literature, the present study deliberately incorporated three VR-based social scenarios, a job interview, social interaction, and public speaking task, selected to represent distinct forms of socio-evaluative threat. These scenarios were chosen to reflect variation in evaluative intensity, ambiguity, and performance demands, thereby enabling a theoretically grounded examination of whether visual attention patterns in SAD remain stable across contexts or vary as a function of situational demands. Identifying objective patterns of visual attention may contribute to the development of scalable, digital assessment approaches for SAD by providing complementary, behavior-based information that complement self-report and clinician-administered measures.

2. Objectives and hypotheses

The primary objective of the present study was to characterize differences in visual attention patterns between individuals with SAD and healthy control participants (HCG) using VR-based eye-tracking across three, ecologically valid VR tasks that varying in evaluative demand:

Task A (a job interview),

Task B (an unstructured social interaction) and,

Task C (a presentation).

Secondary aims included testing predictions derived from hyperscanning and vigilance–avoidance models, examining task-specific attentional effects, and evaluating the ecological validity of a multi-scenario VR paradigm for the assessment of SAD.

We formulated the following a priori hypotheses:

Compared with healthy controls (HCG), participants with SAD will exhibit avoidant visual attention toward social cues, reflected in shorter fixation duration, fewer number of fixations, and shorter mean fixation duration on faces and bodies across tasks.

SAD participants will demonstrate a hyperscanning pattern, indicated by increased total scanpath length and greater mean distance between fixations across tasks.

Consistent with the vigilance-avoidance model, SAD participants will orient more quickly (shorter time to first fixation) but disengage sooner (shorter first fixation duration) from social cues than HCG participants.

Task effects are anticipated, with both groups showing stronger avoidance and hyperscanning in the high-evaluation condition (Task C) relative to Tasks A and B.

3. Methods

3.1. Design, setting, and participants

This study used a cross-sectional design, with participants with SAD matched to HCG on age, gender, and country income level. The required sample size was determined a priori based on the primary outcome (fixation duration), as described in the published study protocol (Zeka et al., 2023). Sixty-three participants were initially recruited. Three participants from the HCG were excluded; one was diagnosed with SAD during the study, one lacked a suitable country income level match, and one had high social anxiety levels based on Liebowitz Social Anxiety Scale (LSAS). This resulted in a final sample of sixty participants, with thirty in each group. All participants were screened using Mini International Neuropsychiatric Interview (MINI) (Lecrubier et al., 1997). Participants who met the criteria for a primary diagnosis of SAD were

Table 1
Demographic characteristics.

Group (n = 60)	SAD (n = 30)	HCG (n = 30)
Mean age, (years)	29.6	29.1
Female n (%)	19 (63.3%)	19 (63.3%)
Country income level		
High Income Country	29 (97%)	29 (97%)
Low Income Country	1 (3%)	1 (3%)
Civil status		
Single	15 (50%)	15 (50%)
In a relationship/married	14 (47%)	14 (47%)
Divorced/other	1 (3%)	1 (3%)
Current occupation		
Student	11 (37%)	17 (57%)
Full/part Time Employment	9 (30%)	12 (40%)
Sick leave/unemployed	10 (33%)	1/3%)
Education level		
Primary school	6 (20%)	2 (7%)
Secondary school	8 (27%)	13 (43%)
Vocational Education	3 (10%)	0
Short Higher Education (up to 2 years)	0	3 (10%)
Intermediate Higher education (two-four years	9 (30%)	5 (17%)
Long Higher education (five years or more	4 (13%)	7 (23%)
Parent Education Level		
Primary school	1 (3%)	1 (3%)
Secondary school	3 (10%)	1 (3%)
Vocational Education	10 (33%)	5 (17%)
Short Higher Education (up to 2 years)	1 (3%)	2 (7%)
Intermediate Higher education (two-four years	9 (30%)	10 (33%)
Long Higher education (five years or more	6 (20%)	11 (37%)
Psychopharmaceutical treatment	Yes: 56.67% No: 43.33%	N/A
Comorbid disorders	Depression: 6 GAD: 7 Agoraphobia/Panic attacks: 4 PTSD: 1 OCD:2	N/A

Note. SAD = Social Anxiety Disorder; HCG = Healthy Control Group; GAD = Generalized Anxiety Disorder.
PTSD = Post-Traumatic Stress Disorder; OCD = Obsessive-Compulsive Disorder.
Percentages are rounded to the nearest whole number. Education levels are based on national classification standards.
VR experience and IT skills were rated on a 0–10 Likert scale.

included in the study. Individuals with severe psychopathology, including neurodevelopmental disorders (e.g., autism spectrum disorder), psychotic disorders, bipolar disorder, or substance dependence, were excluded from participation. See Table 1 for sample characteristics. Data quality was evaluated using the predefined validity criteria implemented in iMotions prior to data export. Participants were excluded if more than 80% of their gaze data was missing or invalid, as flagged by the iMotions software. Although specific causes for the data loss were not recorded, it likely resulted from a combination of common issues in VR-based eye tracking, including calibration problems, excessive head movement, blinking, or headset misalignment. Due to missing eye-tracking data, two HCG participants and one SAD participant were excluded from Task A, and one participant from each group was excluded from Task B and Task C. Exclusion rates were low and comparable between groups across tasks. Analyses were conducted on an available-case basis, with each task analyzed using all participants with valid eye-tracking data for that task.

3.2. Clinical and self-report measures

All clinical measures were administered by a trained psychologist. LSAS was used to measure symptom severity of social anxiety across 24 situations. LSAS is divided into two subscales; performance anxiety and social situations; rating both anxiety and avoidance behavior. Each situation was rated twice, once for anxiety (0 = none, 1 = mild, 2 = moderate, 3 = severe) and once for avoidance (0 = never, 1 = occasionally, 2 = often, 3 = usually). Example items include “Speaking in front of an audience,” “Meeting new people,” and “Eating in front of other people.” (Heimberg et al., 1999). Internal consistency in the present sample was excellent (Cronbach's α = .97 for the anxiety subscale; α = .96 for the avoidance subscale; α = .98 for the total score; 95% CIs: [.96, .98], [.94, .97], and [.98, .99], respectively).The Brief Fear of Negative Evaluation Scale (BFNE), a 12-item scale, was used to measure fear of being subject to negative evaluation (e.g., “I worry about what other people think of me”). Participants rated each item on a 5-point Likert scale ranging from 1 (not at all characteristics of me) to 5 (extremely characteristic of me). Items 2, 4, 7, and 10 were reverse scored (Leary, 1983). Internal consistency in the present sample was excellent (Cronbach's α = .96, 95% CI [.95, .98]). The Personal and Social Performance Scale (PSP), a clinician rating scale, measures functioning across four domains; socially useful activities, personal and social relationships, self-care, and disturbing and aggressive behaviors (Nasrallah et al., 2008). The PSP was used to assess overall social and occupational functioning. The scale has a total score ranging from 1 to 100, with higher scores indicating better functioning. As the PSP represents a global clinician-rated composite rather than a multi-item self-report scale, internal consistency (Cronbach's α) was not applicable. The sense of presence during the virtual-reality tasks was assessed with 10 items from the Multimodal Presence Scale (MPS) developed and validated by Makransky et al. (Makransky et al., 2017), measuring physical, social, and self-presence (e.g., “The virtual environment seemed real to me,” “I felt as if I was interacting with other people in the virtual environment rather than a computer simulation.“).

The original scale contains 15 items, but the five items assessing virtual embodiment were excluded because participants were not represented by a virtual body in the current VR setup. Items were rated on a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree). Internal consistency for the adapted 10-item version in the present sample was

Fig. 1. Demonstration of the VR job interview scenario.

good (Cronbach's α = .88, 95% CI [.83, .92]). Lastly, subjective units of distress (SUDS) a single-item measure ranging from 0 = no distress to 100 = extreme distress were used to rate the state anxiety pre and post the experimental tasks (Tanner, 2012).

3.3. Experimental procedure

After completion of the diagnostic assessment, the participants were directed to the laboratory room, where the experiment was conducted. The purpose of the study was explained, followed by an introduction to the different tasks. Participants were informed that they would engage in three socio evaluative tasks and were instructed to react as they would in a real-life situation. Participants were informed that their behavior in the virtual environments would be recorded for research purposes; however, the specific focus on visual attention patterns and the between-group comparison were not disclosed to avoid potential interference with the experimental purpose. To increase realism in the VR experience, participants were explicitly asked to verbally engage in the tasks (e.g., answering the interviewer's questions). Before beginning, participants rated their SUDS by answering to the question “on a scale from 0 to 100 how anxious do you currently feel?“. Eye tracker calibration was completed in collaboration with the researcher. Calibration quality was visually inspected prior to task onset, and recalibration was performed when necessary to ensure acceptable tracking accuracy. Calibration procedures were identical for all participants, and no systematic differences in calibration quality were observed between groups. The participants were informed that the researcher would leave the laboratory room before the experiment began. Once the experiment began, the researcher left the laboratory room to prevent any influence this presence might have on participants ́reactions. The entire experiment lasted approximately 15 min. After the experiment the participants rated their SUDS levels once again and filled in the MPS questionnaire. Finally, they were debriefed about the study rationale.

3.4. VR tasks (job interview, social interaction, presentation)

The experimental tasks consisted of high-resolution 360°stereoscopic videos presented in a VR head mounted display (HMD). The stimuli material was developed in an iterative process in close collaboration with a panel of patients, clinicians and VR developers. Actors were used to deliver the content in the different tasks. Listening loops were added throughout the scenarios to stimulate interaction. A detailed overview of the experimental tasks can be found in the study protocol (Zeka et al., 2023).

The tree experimental tasks were:

- Task A: A job interview situation, conceptualized as a performance task. In the scenario, two interviewers (a male and a female) ask job-related questions such as: ‘can you tell us something about yourself’, what is your motivation for applying for this job’, ‘how can you contribute to this job?‘. A ‘listening loop’ of 30 s follows after each question, allowing the participant to answer while the two interviewers appear to listen. Both interviewers maintain a welcoming and warm attitude. The total duration of Task A was 2.43 min (See Fig. 1).
- Task B: A small talk/discussion in a canteen while eating lunch in a work setting with four colleagues, conceptualized as an unstructured social interaction situation. The participant is not asked direct questions but can engage freely in the conversation. The colleagues look sporadically at the participant and smile at times. The atmosphere is welcoming and warm. The total duration of Task B was 2.35 min (See Fig. 2).
- Task C: A presentation task, involving a direct threat of negative evaluation. The participant is asked to deliver a presentation alongside a colleague in front of an audience. The task starts with the colleague first introducing himself to the audience and then asks the participant to present him/herself to the audience. However, after receiving a phone call, the colleague must leave, leaving the participant to present alone. During the presentation, a technical issue occurs: the computer designated for running the PowerPoint presentation material stops functioning. As a result, the participant must deliver the presentation without PowerPoint. The atmosphere becomes increasingly tense, with the audience displaying signs of impatience. However, the task ends before the participant must do a presentation. The total duration of Task C was 2.18 min (See Fig. 3).

3.5. VR hardware, eye-tracking, and software

The HTC Vive Pro Eye HMD (HTC Corporation, Taiwan) with an integrated Tobii eye-tracking system (Tobii AB, Sweden) was used to record gaze data. Eye movements were tracked binocularly at 120 Hz with a 110° field of view and an accuracy of .5°–1.1°, using a five-point calibration procedure. The headset operated via the SteamVR tracking system to ensure precise spatial tracking and alignment. Eye-tracking data were collected, preprocessed, and analyzed using the iMotions software platform version 10.0.10 (iMotions A/S, Copenhagen, Denmark) (iMotions, 2025). A powerful gaming computer (CPU Intel COREi9-10850K3.60Ghz; GPU NVIDIA GeForce RTX 2070 super, 8 GB) served as an interface between the HMD and the software.

Fig. 2. Demonstration of the VR social interaction scenario.

Fig. 3. Demonstration of the VR presentation scenario.

3.6. Gaze mapping and preprocessing

Data were prepared and analyzed using Imotions software. For all three tasks, gaze estimates obtained from the dynamic VR scenes were mapped onto a static image that covers the entire area of interest. This gaze mapping process utilizes an object recognition algorithm to detect visual features in the reference images and align them with the original recordings (Imotions Software). For Tasks A and B, a single reference image was sufficient as the stimuli remained static. In contrast, Task C involved frequent changes in stimuli, requiring five reference images to account for these variations. The same reference images were used for all participants. The quality of the automated gaze mapping was visually inspected for each participant. Manual corrections were made when gaze points were visibly misaligned with the corresponding reference image content, based on consistent deviation patterns to ensure reliable data interpretation. Minor errors in gaze mapping were observed and corrected across all participants and tasks. AOIs were manually categorized into social areas (faces and bodies) and a nonsocial area (the environment). AOIs were defined as shape-based regions following the outlines of faces, bodies, and the environment in the reference images, enabling precise correspondence with the visual extent of each AOI in the VR scenes. To accommodate the inherent imprecision of the eye-tracker, the AOIs were slightly enlarged beyond the actual dimensions of faces and bodies. Additionally, a small buffer space was left between AOIs to ensure that gaze points fell within the designated areas, as recommended by Clay et al., 2019 (Clay et al., 2019). Visual examples of the manually defined AOIs (faces, bodies, and environment) used for gaze mapping for TASK A, B and C are provided in the Supplementary Figures (See Supplementary Figs. S1–S3). An I-VT (Velocity-Threshold Identification) filter was applied to analyze the raw eye tracking data by classifying fixations and saccades based on eye movement speed relative to a velocity threshold. The velocity threshold was set at 100°/s, with a minimum fixation duration of 100 ms. Eye movements below this threshold were classified as fixations, while exceeding it were classified as saccades. The filter parameters were predefined and applied consistently across all participants and tasks, following standard velocity and duration-based criteria commonly used in eye-tracking research (Holmqvist & Andersson, 2017). The analysis was based on predefined AOIs.

3.7. Eye-tracking outcomes (temporal and spatial metrics)

Outcome measures comprised of eye movements, consisting of temporal and spatial eye tracking metrics. Temporal metrics were fixation-based measured in milliseconds. These included fixation duration, number of fixations, mean fixation duration, time to first fixation (TTFF), and first fixation duration. Fixation duration was defined as the total time spent fixating within a given AOI, number of fixations as the count of discrete fixation events within an AOI, and mean fixation duration as the average duration per fixation. Time to first fixation (TTFF) reflected the latency from scene onset to the first fixation within an AOI, and first fixation duration represented the duration of the initial fixation on that AOI. All fixation-based metrics were computed within the predefined AOIs outlined in the previous section, categorized as social (faces and bodies) and nonsocial (environment). Spatial metrics comprised the mean distance between fixations (in pixels), calculated by summing the Euclidean distances between each pair of consecutive fixation points and dividing by the total number of fixation pairs. This metric indexed the spatial dispersion of gaze. Additionally, scan path length (in pixels) was calculated by the sum of Euclidean distances between pairs of consecutive fixation points along the gaze path, representing the overall extent of visual exploration during each task.

Table 2
Psychometric characteristics.

Group	SAD mean (SD)	HCG mean (SD)	F (1.58)	P value
LSAS total	81.9 (18.8)	9.73 (5.97)	400.9	<.001
Anxiety total	44.7 (9.6)	5.5 (3.4)	442	<.001
Avoidance total	37.2 (10.3)	4.2 (3.0)	283.2	<.001
BFNE	50.94 (7.29)	23.97 (4.94)	281.3	<.001
PSP	60.5 (7.2)	84.5 (6.8)	173.2	<.001
MPS	39.1 (5.0)	38.7 (7.41)	.06	.808
SUDS pre-experiment	52.3 (21.4)	15.6 (13.3)	63.32	<.001
SUDS post-experiment	32 (26.8)	4 (8.9)	29.4	<.001

Note. Values represent means. Standard deviations are in parentheses. SAD = Social Anxiety Disorder; HCG = Healthy Control Group.
LSAS = Liebowitz Social Anxiety Scale; BFNE = Brief Fear of Negative Evaluation; PSP = Personal and Social Performance Scale.
MPS = Multimodal Presence Scale; SUDS = Subjective Units of Distress Scale. Higher scores on LSAS, BFNE, and SUDS indicate.
Greater symptom severity, whereas higher scores on the PSP reflect better functioning.MPS assesses perceived presence in the VR environment.
All comparisons were conducted using one-way ANOVAs.

3.8. Statistical analysis

Data were analyzed using the statistical program R version 4.4.1 (2024-06-14 ucrt). A one-way Analysis of Variance (ANOVA) was conducted to assess group differences on psychometric measures. A repeated measure ANOVA was used to analyze SUDS score, with group (SAD vs HCG) as a between-subject factor and time (pre vs post experimental task) as a within-subject factor. A mixed design ANOVA was conducted with group (SAD vs HCG) as the between-subject factor and AOI (face vs body vs environment) as the within-subjects factor separately for each task (tasks A, B and C). This test was used to analyze the first and third hypothesis. T-tests were conducted for spatial metrics and used to analyze the second hypothesis. Eye-tracking metrics (temporal and spatial metrics) were the dependent variables. Post-hoc Bonferroni corrections were applied for pairwise comparisons when a statistically significant interaction effect between participant group and AOI was found. To test the fourth hypothesis a multivariate analysis of variance (MANOVA) was conducted to assess differences in gaze behavior across tasks (A, B and C). Spearman correlational analyses were conducted within the SAD group to assess relationships between temporal and spatial eye movements and psychometric measures (LSAS, BFNE, PSP). All statistical tests of significance were two-tailed, with significance level set at $p < .05$.

Normality assumptions were assessed using Shapiro-Wilks and Leven's test for each task, variable, participant group and AOI. Due to minor normality deviations ($p < .05$), square root transformations were applied on all temporal metrics except mean average fixation, which met normality assumptions. Minor normality deviations persisted in certain groups; however, given ANOVA's robustness to such deviations (Blanca et al., 2018), the analyses proceeded using mixed ANOVAs. Mauchly's test was used to assess sphericity violations and a Greenhouse-Geisser and Huynh-Feldt corrections were applied, in case of sphericity violations.

4. Results

4.1. Sample characteristics

Table 1 depicts the demographic data of the two groups. As the groups were matched on age, gender, and country income level, no differences in these parameters were expected. The participants had a mean age of 29 years of whom 63 % were females. No significant differences were found in civil status, educational level, and parental educational level. However, a group difference emerged in current occupation, with 33 % of the SAD group being on sick-leave or unemployed, compared to only 3% in the HCG group. Regarding the onset of SAD symptoms, 35 % of participants reported experiencing symptoms before the age of 10, 30 % between ages 10-15 years of age, 35 %

Table 3
Means and standard deviation on fixation variables for task A, B & C and for SAD & HCG.

TASK	AOI category	Fixation duration (s)		Number of fixations		Mean fixation duration (ms)		TTFF (s)		First fixation duration (ms)	
TASK A		**SAD (29)**	**HCG (28)**	**SAD** (29)	**HCG (28)**	**SAD** (29)	**HCG (28)**	**SAD (29)**	**HCG (28)**	**SAD (29)**	**HCG (28)**
	Face	81.2 (29.9)	95.9 (27.2)	171.3 (60.4)	199.6 (63.7)	974.27 (298.59)	1006.15.7 (400.19)	4.2 (3.62)	3.3 (4.0)	780.8 (528.7)	1022.8 (822.9)
	Body	12.0 (9.5)	9.4 (8.2)	51.3 (43.9)	41.8 (45.6)	483.55 (138.29)	463.05 (132.86)	37.1 (36.12)	49.4 (36.5)	360.7 (130.8)	374.2 (142.7)
	Environment	25.2 (17.8)	15.5 (8.6)	91.0 (60.4)	63.8 (31.9)	276.1 (67.5)	241.2 (53.9)	10.3 (13.9)	13.6 (14.4)	287.1 (239.2)	219.7 (188.9)
TASK B		**SAD (29)**	**HCG (29)**	**SAD (29)**	**HCG (29)**	**SAD (29)**	**HCG (29)**	**SAD (29)**	**HCG (29)**	**SAD (29)**	**HCG (29)**
	Face	82.8 (22.8)	100.0 (15.5)	132.9 (36.0	143.4 (20.8)	2541.6 (642.4)	2769.4 (626.9)	32.36 (24.97)	22.66 (14.97)	2087.95 (2149.16)	1549.53 (1250.77)
	Body	16.3 (8.9)	13.2 (8.6)	44.3 (25.2)	44.4 (41.4)	1368.1 (512.7)	1262.2 (371.3)	87.16 (67.61)	93.79 (63.27)	986.86 (383.49)	1067.99 (517.65)
	Environment	29.0 (14.4)	17.6 (8.3)	87.5 (39.2)	60.9 (34.9)	650.4 (171.3)	593.7 (154.6)	7.99 (9.30	10.98 (22.73)	427.70 (234.80)	398.64 (190.86)
TASK C		SAD(29)	**HCG (29)**	**SAD (29)**	**HCG (29)**	**SAD (29)**	**HCG (29)**	**SAD (29)**	**HCG (29)**	**SAD (29)**	**HCG (29)**
	Face	44.11 (15.90)	50.60 (12.14)	164.76 (53.11)	175.45 (47.78)	3217.36 (828.29)	3366.27 (695.13)	159.85 (69.88)	180.85 (63.36)	2843.53 (893.59)	2912.50 (669.09)
	Body	17.66 (10.88)	15.91 (11.33)	77.45 (45.05)	69.17 (37.12)	2059.34 (391.10)	2203.14 (694.60)	217.06 (100.83)	248.77 (100.99)	2135.59 (650.43)	2130.71 (741.60)
	Environment	37.7 (10.9)	35.5 (8.1)	167.4 (41.2)	149.5 (33.1)	2095.26 (377.64)	2193.40 (333.66)	84.57 (38.30)	102.10 (50.00)	1855.02 (492.98)	1932.91 (543.17)

Note. Values represent means. Standard deviations are in parentheses. SAD = Social Anxiety Disorder group; HCG = Healthy Control Group; TTFF = Time to First Fixation; AOI = Area of Interest. All values are based on untransformed raw data for interpretability. Fixation durations are in seconds (s) unless otherwise specified; mean fixation duration and first fixation duration are in milliseconds (ms).

between ages 15-20, and 10 % after the age of 20. Additionally, 57% of the SAD group were receiving psychopharmacological treatment, and 86% had a comorbid diagnosis, most frequently depression and generalized anxiety disorder (See Table 1). Group differences between SAD and HCG on the psychometric measures (LSAS, BFNE, PSP), MPS and SUDS are depicted in Table 2. As expected, the SAD group, reported significantly higher social anxiety symptoms on LSAS and BFNE, as well as lower functioning on the PSP. Additionally, SUDS scores revealed that the SAD group reported significantly higher state anxiety before the experiment compared to the HCG. However, post-experiment ratings showed a marked reduction in anxiety for the SAD group, suggesting a decrease in distress after task completion. No differences were found on the MPS (See Table 2).

4.2. Visual avoidance across tasks

Table 3 shows the means and standard deviations for the fixation variables across Task A, Task B, and Task C for both SAD and HCG groups, based on untransformed data. Untransformed data were used to present the raw, unaltered results for clarity and transparency (See Table 3). For a visual representation, Fig. 4 displays boxplots of fixation duration across the three tasks.

For fixation duration mixed ANOVAS revealed a significant interaction between group and AOI in both Task A $F(2,110) = 4.034$, $p = .020$, $np^2 = .0683$ and Task B $F(2,112) = 11.269$, $p < .001$, $np^2 = .1675$, indicating that SAD and HCG participants allocated their visual attention differently across AOIs. Post hoc tests using pairwise comparisons with Bonferroni corrections revealed, that in Task A, SAD participants spent significantly less time fixating on faces compared to HCG ($t(112) = 2.0002$, $p = .048$) and spent significantly more time on the environment AOI ($t(55) = -2.351$, $p = .022$). No statistically significant difference was found for fixation duration on the body AOI ($t(110) = -1.675$, $p = .097$). A similar pattern was also observed in Task B, SAD participants spent significantly less time fixating on faces ($t(230) = 2.746$, $p = .006$) and significantly more time on the environment ($t(114) = -3.946$, $p < .001$). No significant difference was found for the body ($t(223) = -1.239$, $p = .216$).

For number of fixations, mixed ANOVAS revealed a significant group by AOI interaction in Task A $F(2,110) = 3.072$, $p = .050$, $np^2 = .0529$ and Task B $F(2,112) = 8.063$, $p < .001$, $np^2 = .1259$. Post hoc tests revealed that in Task A, SAD participants had fewer number of fixations on faces compared to HCG ($t(112) = 2.0002$, $p = .039$). No significant difference was found for the environment ($t(55) = -1.775$, $p = .081$) nor for the body ($t(110) = -1.473$, $p = .144$). In Task B, SAD participants had significantly more number of fixations on the environment ($t(114) = -3.612$, $p = <.001$), but not for the faces ($t(230) = 1.776$, $p = .77$) or body ($t(223) = -.3250$, $p = .745$).

Unlike the findings in Task A and B, Task C did not follow the same trend. No significant interaction effects were found between participant group and AOI for fixation duration $F(2,112) = 1.641$, $p = .198$, $np^2 = .0285$, number of fixations $F(2,112) = 1.362$, $p = .260$, $np^2 = .0237$.

For mean fixation duration no statistically, significant differences were found for either tasks (See Tables 5 and 6 for detailed statistics).

4.3. Hyperscanning and Vigilance–Avoidance analyses across tasks

Table 4 presents the means and standard deviations for the spatial variables; mean distance between fixations and scanpath length, across Task A, Task B, and Task C for both SAD and HCG groups (See Table 4) For a visual representation, Fig. 5 displays boxplots of mean distance between fixations across the three tasks.

For mean distance between fixations, t-tests revealed a marginally statistically significant difference in Task A, with the SAD group exhibiting greater distances t (Al-Ezzi, Kamel, et al., 2021) $= -1.96$, $p = .055$, $d = .52$. Also in Task B, the SAD group showed significantly greater mean distances between fixations compared to the HCG group t (Al-Ezzi, Yahya, et al., 2021) $= -2.30$, $p = .025$, $d = .60$. Similarly, in Task C, the SAD group demonstrated significantly greater mean distance between fixations t (Al-Ezzi, Yahya, et al., 2021) $= -2.75$, $p = .008$, $d = .72$. For scanpath length, t-tests revealed significantly longer scanpath lengths for the SAD group in Task B t (Al-Ezzi, Yahya, et al., 2021) $= -2.38$, $p = .021$, $d = .63$. However, no significant differences in scan path length were observed in Task A t (Al-Ezzi, Kamel, et al., 2021) $= -1.24$, $p = .219$, $d = .33$, nor in Task C t (Al-Ezzi, Yahya, et al., 2021) $= -1.74$, $p = .087$, $d = .46$. (See Table 7 for detailed statistics).

No significant Interaction effects were found for TTFF or first fixation duration in any of the tasks (See Table 5 with detailed statistics).

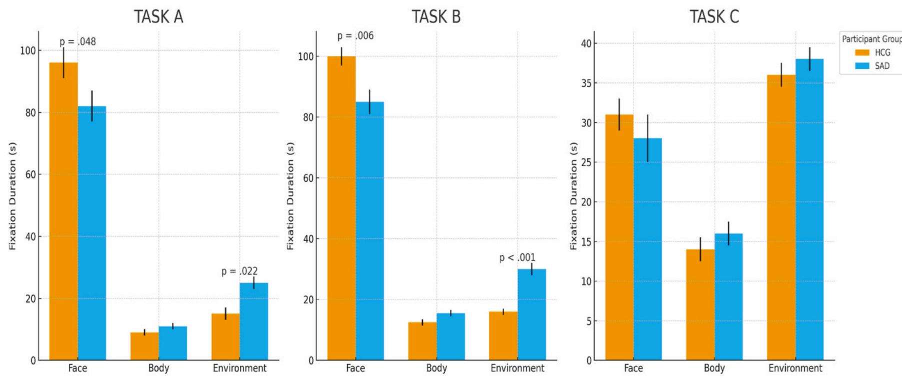

Fig. 4. Box plot for Fixation duration for Task A, B and C.

4.4. *Task effects on visual attention*

A two-way repeated measures MANOVA was conducted to examine the effects of Task, AOI), and Participant Group based on fixation metrics. A significant interaction between Task and AOI was found $F(20,1964) = 16.766$, $p < .001$, Pillai's Trace = .583, indicating that the effect of Task on visual attention varied by AOI. Post-hoc comparisons revealed significant differences in attention to faces across tasks. Task C showed lower fixation duration, and fewer number of fixations compared to Tasks A and B (both $p < .0001$), with no difference between Tasks A and B for fixation duration ($p = .8752$). Task C also exhibited longer mean fixation duration than Task A and B ($p < .0001$), with Task B showing longer fixations than Task A ($p < .0001$).

5. Discussion

The present study highlights the value of using 360-degree videos presented through VR HMD to create immersive experimental paradigms. Compared to traditional static or screen-based eye-tracking paradigms, the immersive multi-scenario VR setup enhanced ecological validity while maintaining experimental control. The integration of eye-tracking was not only technically feasible but also enabled precise real-time measurement of visual attention. The lack of real-time interaction inherent to 360-degree videos was addressed by simulating interaction through embedded response loops. The participants in both groups reported high levels of presence, realism and interactivity, as measured with the Multimodal Presence Scale. Overall, our VR-based eye tracking paradigm effectively differentiated individuals with SAD from healthy controls, particularly through fixation duration and mean distance between fixations. Importantly, the inclusion of three distinct socio-evaluative VR scenarios represents a methodological strength, as it enabled comparison of visual attention across different socio-evaluative contexts. The multi-scenario approach further allowed us to distinguish between context-dependent avoidance patterns, which emerged in specific socio-evaluative situations, and more task-general hyper-scanning tendencies that were evident across all three scenarios. This distinction would not have been possible within a single-task or static paradigm. Furthermore, the rigorous eye-tracking procedures, predefined AOIs and identical quality criteria across groups strengthen the reliability and robustness of the findings.

Our study revealed task-specific patterns and two co-occurring visual attention patterns in SAD in two of the three tasks. Consistent with cognitive models of SAD (Clark & Wells, 1995; Rapee & Heimberg, 1997), the observed pattern of reduced attention to faces and increased attention to the environment can be understood as a safety behavior that helps individuals manage anxiety when full avoidance is impossible (Leigh & Clark, 2018; Rapee & Heimberg, 1997). At the same time, the hyperscanning pattern evident across all three tasks reflects increased vigilance toward potential social threats. Together, these findings suggest impaired attentional flexibility, a reduced ability to shift attention between threat-related and socially relevant cues, which may contribute to the maintenance of SAD symptoms. This interpretation also aligns with Eysenck's Attentional Control Theory (2007), proposing that anxiety weakens top-down, goal-directed attention and increases reliance on bottom-up, stimulus-driven processing (Eysenck & Derakshan, 2011). Such disrupted control could explain why individuals with SAD focus less on socially meaningful cues such as faces and more on neutral, nonthreatening aspects of their environment.

In line with our first hypothesis and previous eye-tracking studies (Chen et al., 2012, 2015, 2020; Weeks et al., 2013), individuals with SAD exhibited reduced engagement with faces and increased attention to non-social cues in both the job interview task and the unstructured social interaction task. Interestingly, the presentation task involving an explicit negative evaluation did not show significant group differences in visual attention patterns. One speculative explanation for the absence of group differences is that the explicit nature of the negative evaluation may have led to a convergence in gaze behavior either by reducing avoidance in the SAD group or by eliciting similar avoidance responses in healthy controls due to the high emotional salience of the task, potentially producing ceiling effects that reduced observable between-group differences.

Our findings indicate that avoidance in SAD is highly selective to

Table 4
Means and standard deviation on spatial variables for task A, B & C and for SAD & HCG.

TASK	Mean distance between fixations (p)		Scanpath length (p)	
TASK A	**SAD (29)**	**HCG (28)**	**SAD (29)**	**HCG (29)**
	173.2 (43.4)	152.2 (37.1)	59770.39 (17423,35)	53930.34 (18070.80)
TASK B	**SAD (29)**	**HCG** (29)	**SAD** (29)	**HCG** (29)
	197.6 (43.7)	176.1 (25.1)	63632.99 (16609.46)	55129.70 (9651.31)
TASK C	**SAD (29)**	**HCG (29)**	**SAD (29)**	**HCG (29)**
	185.3 (35.1)	163.5 (24.3)	51014.88 (12428.56)	45949.47 (9488.39)

Note: Values represent means. Standard deviations are in parentheses. SAD: social anxiety disorder.
HCG: healthy control group; p = in pixels.

Table 5
ANOVA summary TASK A, B & C.

TASK	Variable	Effect	DF1	DF2	F.Value	p.value	np^2
TASK A	Fixation Duration (sqrt)	Participant group	1	55	4.108	**.047**	.0695
		AOI	2	110	136.181	**<.001**	.7123
		Interaction: Participant group/AOI	2	110	4.034	**.020**	.0683
	Number of Fixations (sqrt)	Participant group	1	55	1.611	.2096	.0285
		AOI	2	110	81.265	**<.001**	.5964
		Interaction: Participant group/AOI	2	110	3.072	**.050**	.0529
	Mean Fixation Duration (sqrt)	Participant group	1	55	.193	.662	.0035
		AOI	2	110	123.323	**<.001**	.6916
		Interaction: Participant group/AOI	2	110	.995	.373	.0178
	TTFF (sqrt)	Participant group	1	55	2.582	.114	.0448
		AOI	2	110	50.720	**<.001**	.4798
		Interaction: Participant group/AOI	2	110	.386	.681	.0070
	First Fixation Duration (sqrt)	Participant group	1	55	.0006	.981	.0000
		AOI	2	110	21.282	**<.001**	.2790
		Interaction: Participant group/AOI	2	110	2.249	.110	.0393
TASK B	Fixation Duration (sqrt)	Participant group	1	56	8.769	**.004**	.1354
		AOI	2	112	224.069	**<.001**	.8001
		Interaction: Participant group/AOI	2	112	11.269	**<.001**	.1675
	Number of Fixations (sqrt)	Participant group	1	56	3.327	.073	.0561
		AOI	2	112	134.054	**<.001**	.7053
		Interaction: Participant group/AOI	2	112	8.063	**<.001**	.1259
	Mean Fixation Duration (sqrt)	Participant group	1	56	.009	.924	.0002
		AOI	2	112	233.522	**<.001**	.8066
		Interaction: Participant group/AOI	2	112	3.438	**.036**	.0578
	TTFF (sqrt)	Participant group	1	56	.203	.65	.0036
		AOI	2	112	89.194	**<.001**	.6143
		Interaction: Participant group/AOI	2	112	1.139	.324	.0199
	First Fixation Duration (sqrt)	Participant group	1	56	1.405	.241	.0245
		AOI	2	112	24.866	**<.001**	.3075
		Interaction: Participant group/AOI	2	112	1.499	.228	.0261
TASK C	Fixation Duration (sqrt)	Participant group	1	56	.0349	.853	.0006
		AOI	2	112	130.481	**<.001**	.6997
		Interaction: Participant group/AOI	2	112	1.6411	.198	.0285
	Number of Fixations (sqrt)	Participant group	1	56	.8262	.367	.0145
		AOI	2	112	128.703	**<.001**	.6968
		Interaction: Participant group/AOI	2	112	1.3620	.260	.0237
	Mean Fixation Duration (sqrt)	Participant group	1	56	.4970	.484	.0088
		AOI	2	112	36.6782	**<.001**	.3958
		Interaction: Participant group/AOI	2	112	.2915	.747	.0052
	TTFF (sqrt)	Participant group	1	56	1.2032	.277	.0210
		AOI	2	112	55.2962	**<.001**	.4968
		Interaction: Participant group/AOI	2	112	.0438	.957	.0008
	First Fixation Duration (sqrt)	Participant group	1	56	.0039	.950	.0001
		AOI	2	112	6.2998	**.003**	.1011
		Interaction: Participant group/AOI	2	112	.2165	.080	.0038

Note: SAD = Social Anxiety Disorder group; HCG = Healthy Control Group; AOI = Area of Interest; TTFF = Time to First Fixation; DF = Degrees of Freedom; F = F-statistic.
p = p-value; np^2 = partial eta-squared.

Table 6
Between-subject pairwise comparisons TASK A & B.

TASK A	Variable	AOI	Contrast	Estimate	SE	DoF	t.value	p.value
	Fixation Duration (sqrt)	Body	HCG - SAD	−9.8959	.4005.9087	110.0	−1.6748	.097
		Environment	HCG - SAD	−29.5731	12.5818	55.0	−2.3505	**.022***
		Face	HCG - SAD	17.7541	8.8761	112.0	2.0002	**.048***
	Number of Fixations (sqrt)	Body	HCG - SAD	−.5863	.3981	110.0	−1.4728	.144
		Environment	HCG - SAD	−1.2874	.7252	55.0	−1.7753	.081
		Face	HCG - SAD	.7499	.3602	112.0	2.0822	**.039***
TASK B	Fixation Duration (sqrt)	Body	HCG - SAD	−4.4157	3.5640	223.0	−1.2390	.216
		Environment	HCG - SAD	−26.1287	6.6217	114.0	−3.9459	**<.001***
		Face	HCG - SAD	14.2264	5.1818	230.0	2.7455	**.006***
	Number of Fixations (sqrt)	Body	HCG - SAD	−.0581	.1787	223.0	−.3250	.745
		Environment	HCG - SAD	−1.1731	.3248	114.0	−3.6116	**<.001****
		Face	HCG - SAD	.2780	.1565	230.0	1.7764	.077
	Mean Fixation Duration (sqrt)	Body	HCG - SAD	−24.2967	25.3761	223.0	−.9575	.339
		Environment	HCG - SAD	−28.3422	21.5354	114.0	−1.3161	.190
		Face	HCG - SAD	57.0522	32.2778	230.0	1.7675	.078

Note: SE= Standard error; DoF; degrees of freedom; Significant p-values are marked with an asterisk (*).

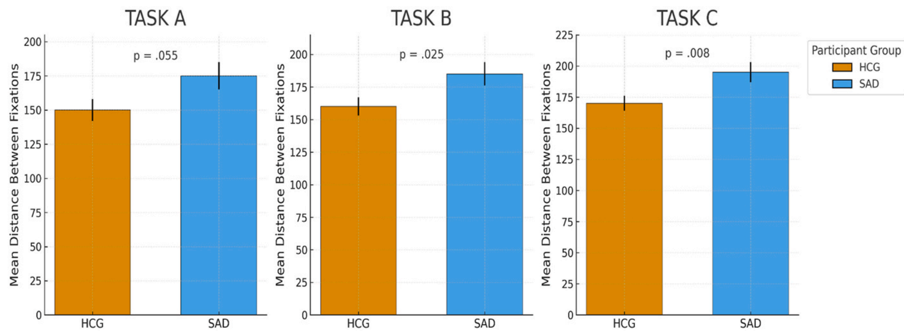

Fig. 5. Boxplot for mean distance between fixations in pixels for task A, B & C.

Table 7
Summary of Independent t-tests on scanpath and mean distance between fixaitons on TASK A, B and C.

Task	Measure	Group Comparison	t-value	DoF	p_value	Cohen's d
A	Mean Distance between Fixations	HCG vs SAD	−1.96	55	**.055**	.52
	Scanpath Length	HCG vs SAD	−1.24	55	.219	.33
B	Mean Distance between Fixations	HCG vs SAD	−2.30	56	**.025***	.60
	Scanpath Length	HCG vs SAD	−2.38	56	**.021***	.63
C	Mean Distance between Fixations	HCG vs SAD	−2.75	56	**.008***	.72
	Scanpath Length	HCG vs SAD	−1.74	56	.087	.46

Note; DoF; degrees of freedom; Significant p-values are marked with an asterisk (*).

faces, as no significant group differences were found for the body AOI. Previous studies have either analyzed only the face as an AOI (Chen et al., 2015, 2021; Horley et al., 2004; Lazarov et al., 2016) or combined the face and body into a single AOI (Kim et al., 2018; Mühlberger et al., 2008; Rubin et al., 2022), limiting the ability to distinguish whether individuals with SAD shift attention away from the face to body regions or to the surrounding environment. Our findings suggest that while individuals with SAD are reluctant to engage with direct gaze and facial expressions, they do not necessarily redirect attention to other socially relevant cues such as body posture or gestures. Instead, they direct the attention to the environment, likely as a safety-seeking strategy. Interestingly, our findings contrast with Dechant et al. (2017) who found that subclinical individuals spent a greater proportion of their fixation time on the body AOI while avoiding faces, without showing increased attention to the environment (Dechant et al., 2017). These discrepancies highlight the need for further research to examine whether differences in sample characteristics (clinical vs. subclinical) or task related factors, such as setup and level of immersion, may influence the distribution of attention across non-face AOIs.

Our study suggests that fixation duration may be a more sensitive and robust marker of avoidance in SAD than either the number of fixations or mean fixation duration. We found significant differences in fixation duration in both the job interview and unstructured social interaction tasks, whereas mean fixation duration did not differ between groups. Although the number of fixations did not consistently reach significance across tasks, meaningful trends emerged: in the job interview task, individuals with SAD had significantly fewer number of fixations on faces and in the unstructured social interaction task, they had significantly more number fixations on the environment. Although these mixed findings may reflect limited statistical power, similar mixed results were seen in other studies. Weeks et al. (2013, 2019), using a covert eye-tracking paradigm with dynamic video stimuli, found that individuals with SAD exhibited reduced total time holding eye contact, fewer fixations on the eye region, and shorter fixation durations, regardless of feedback valence (Weeks et al., 2013, 2019). Similarly, Chen et al. (2021), examining a subclinical population during a naturalistic social interaction task, reported shorter fixation durations, fewer number of fixations on faces, and greater mean fixation distance from faces (Chen et al., 2021). In contrast, consistent with our results, Chen et al. (2015) found no significant differences in the number of fixation nor mean duration of fixations during a pre-recorded public-speaking task in a clinical SAD sample (Chen et al., 2015). Taken together, these findings suggest that fixation duration is the most reliable indicator of gaze avoidance in SAD. Future research should clarify whether variability across fixation-based metrics reflects differences in participant characteristics or task-related demands, such as the level of social engagement or evaluative threat.

In terms of hyperscanning, our findings identify mean distance between fixations as a more sensitive and stable indicator of hyperscanning as it was significantly greater in individuals with SAD across all three tasks. We also observed longer scanpath lengths in the unstructured social interaction task and a nonsignificant trend in the presentation task. Previous studies have reported increased scanpath lengths in SAD populations (Chen et al., 2015; Horley et al., 2004; (Horley et al., 2003) but only trends in mean distance between fixations (Chen et al., 2015). In contrast, Chen et al. (2021), using a subclinical sample of SAD during a naturalistic social interaction task, found no significant differences in either measure (Chen et al., 2021). These discrepancies raise important questions about whether they reflect differences in sample characteristics (clinical vs. subclinical) or the salience of social-evaluative threat within the task. Such variations point to the need for further research, particularly in child and adolescent populations, to determine whether hyperscanning represents an early-emerging trait-like bias or a symptom-specific attentional pattern that contributes to the onset and maintenance of SAD.

Related considerations apply to the vigilance-avoidance hypothesis. We found no evidence of faster initial orienting toward social cues or earlier disengagement, suggesting that hypervigilance may not manifest during early attentional stages but rather in later, sustained processes such as hyperscanning and avoidance. Previous studies have reported a vigilance–avoidance pattern, such as Reichenberger et al. (2020), who observed this pattern in a VR task involving explicit social rejection (Reichenberger et al., 2020). In contrast, our presentation task featured a delayed evaluative threat, emerging only when a virtual colleague left the room, and the audience displayed frustration after a technical failure. This delayed onset may have failed to trigger early threat-processing mechanisms typically associated with vigilance. However, our findings are consistent with Moukheiber et al. (2010), who similarly to our results reported no evidence of a vigilance–avoidance pattern in a face-viewing paradigm (Moukheiber et al., 2010). This interpretation is further supported by Günther et al. (2021), who emphasized that early attentional indicators, such as time to first fixation, often demonstrate poor reliability across studies, particularly in paradigms involving competing stimuli (Günther et al., 2021). Although our VR eye-tracking paradigm did not include competing stimuli, their critique underscores concern regarding the robustness and interpretability of early gaze metrics as indicators of vigilance.

Given the early onset of SAD and its association with later comorbidity, developing objective screening tools based on behavioral markers is crucial. Because current diagnostic procedures rely largely on self-report, which can be biased by social desirability, limited insight, and symptom overlap (particularly with autism spectrum disorder), many cases go undetected (Janssen et al., 2012; Letamendi et al., 2009; Maddox & White, 2015; Montaser et al., 2023; Zimmerman & Chelminski, 2003). VR-based eye-tracking may offer a valuable complement to traditional assessments by capturing gaze avoidance and hyperscanning patterns that may be difficult to observe or self-report. In particular, fixation duration and mean distance between fixations may represent quantifiable behavioral markers that could supplement clinician-administered interviews within structured assessment settings. By identifying objective behavior-based markers of SAD within immersive VR contexts, the present study contributes to the growing field of digital mental-health assessment and technology-enhanced diagnostics. This direction is consistent with emerging computational and neurophysiological research applying EEG-based effective connectivity analyses and deep learning models to characterize objective biomarkers of SAD severity (Al-Ezzi et al., 2021a, 2021b). While these approaches rely on neural connectivity measures rather than gaze behavior, they similarly illustrate the potential of technology-driven, quantitative markers to complement traditional clinical assessment. However, the findings of the present study remain preliminary and require replication in larger and more diverse samples before such metrics can be considered clinically reliable. Future research should examine whether gaze-based measures can help differentiate SAD from related conditions. For example, Kleberg et al. (2017) found that autistic traits were linked to delayed gaze orientation, whereas social anxiety involved rapid gaze aversion (Kleberg et al., 2017). Clarifying such differences may improve differential assessment, particularly in cases involving overlapping or co-occurring symptoms.

The findings of the current study should be interpreted in light of several limitations. The relatively modest sample size ($N = 60$) may have limited statistical power, potentially explaining why some trends, such as differences in the number of fixations or scanpath length did not reach significance in some of the tasks. In addition, the findings may not generalize to adolescents or culturally diverse populations, whose attentional patterns and social interpretations may differ. Moreover, some participants, may not have had direct experience with job interview or workplace contexts. Although they were instructed to imagine themselves in the scenario, differences in prior experience may have influenced immersion and gaze behavior. Participants' prior experience with virtual reality was not formally assessed, which may represent a limitation. Detailed data retention rates beyond the predefined exclusion threshold (>80% missing data) were not available, as validity metrics were computed internally by the software used in the study. While identical quality criteria were applied across groups and exclusion rates were comparable, subtle differences in data quality cannot be entirely excluded. Future studies should include detailed retention metrics to further strengthen transparency. Using the entire face as a single AOI also prevented differentiation between specific facial regions (e.g., eyes vs. mouth), which might have offered more detailed insights into the mechanisms of gaze avoidance. Moreover, while 360-degree video presented in a VR HMD increased ecological validity, it restricted real-time interaction, which could influence the naturalness of social engagement. In addition, the high rate of psychiatric comorbidity and ongoing psychopharmacological treatment in the SAD group may complicate interpretation of the observed visual attention patterns as SAD-specific. Comorbidities such as depression may influence visual attention, potentially affecting both orienting/disengagement and sustained allocation of attention to social cues. Supporting this, recent eye-tracking work indicates that depression and social anxiety can have distinct and interactive effects on orienting to, and disengaging from, socially salient cues such as the eye region (Su et al., 2026). Although the present study was not powered to test comorbidity- or medication-specific effects, future studies should stratify samples by common comorbidities and medication status, or model these factors analytically, to better determine the specificity of VR-based gaze markers to SAD.

6. Conclusion

This study demonstrates that VR-based eye-tracking can effectively capture distinct visual attention patterns in SAD offering an ecologically valid framework for examining visual attention patterns in realistic socio-evaluative contexts. Individuals with SAD showed reduced fixation duration on faces, indicating avoidance, and greater mean distance between fixations, reflecting hyperscanning across tasks. These results support cognitive models suggesting that social anxiety involves both safety-seeking avoidance and increased vigilance toward potential social threats.

Compared with traditional screen-based eye-tracking, the immersive VR paradigm used here allows participants to experience dynamic, lifelike social situations, capturing gaze behavior in a way that closely mirrors real-world interactions. This approach enables the detection of subtle, context-dependent attentional patterns that may be overlooked in more constrained laboratory settings. VR-integrated eye-tracking therefore holds promise as a tool for advancing the assessment of behavioral markers of SAD and improving the development of digital mental health applications. Future studies should replicate these findings in larger and more diverse samples to further establish their clinical reliability and diagnostic utility.

7. Protocol deviations

In the protocol, it was stated that the data would be analyzed using SPSS. This was later changed to R, as it was considered more appropriate for handling large datasets. While the protocol specified analyses on the Face and Body AOIs, the Environment AOI was additionally included post hoc, as it was deemed a relevant area that could provide valuable information about gaze behavior. The protocol also stated that task order would be included as a factor. However, this was omitted, as the task order was randomized for each participant by the iMotions software, eliminating the need to control for it as a confounding variable. Finally, although we had planned to explore associations between psychometric measures and eye-tracking metrics, these analyses are not included in the current manuscript. They will be reported separately to allow for a more focused and comprehensive presentation of findings.

CRediT authorship contribution statement

Fatime Zeka: Writing – review & editing, Writing – original draft, Visualization, Validation, Resources, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **Merete**

Nordentoft: Supervision, Funding acquisition, Conceptualization. **Teresa Hirzle:** Writing – review & editing, Methodology, Data curation. **Ingrid Jakobi Wolff Madsen:** Validation, Methodology, Formal analysis. **Benjamin Arnfred:** Writing – review & editing, Conceptualization. **Mette Øllgaard Pedersen:** Resources, Methodology. **Dan Witzner Hansen:** Writing – review & editing, Validation, Supervision, Methodology, Formal analysis, Data curation. **Louise Birkedal Glenthøj:** Writing – review & editing, Supervision, Methodology, Conceptualization.

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Declaration of competing interest

The authors declare no conflicts of interest related to this study.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.chbr.2026.101032.

Data availability

Data will be made available on request.

References

Al-Ezzi, A., Kamel, N., Faye, I., & Gunaseli, E. (2021). Analysis of default mode network in social anxiety disorder: Eeg resting-state effective connectivity study. *Sensors, 21*(12). https://doi.org/10.3390/s21124098. PubMed PMID: 34203578.

Al-Ezzi, A., Yahya, N., Kamel, N., Faye, I., Alsaih, K., & Gunaseli, E. (2021). Severity assessment of social anxiety disorder using deep learning models on brain effective connectivity. *IEEE Access, 9*, 86899–86913. https://doi.org/10.1109/ACCESS.2021.3089358

Association, A. P. (2013). *Diagnostic and statistical manual of mental disorders. DSM library* (Vol. 1). American Psychiatric Association. https://doi.org/10.1176/appi.books.9780890425596

Blanca, M. J., Alarcón, R., Arnau, J., Bono, R., & Bendayan, R. (2018). Effect of variance ratio on ANOVA robustness: Might 1.5 be the limit? *Behavior Research Methods, 50*(3), 937–962. https://doi.org/10.3758/s13428-017-0918-2. PubMed PMID: 28643157.

Bögels, S. M., & Mansell, W. (2004). Attention processes in the maintenance and treatment of social phobia: Hypervigilance, avoidance and self-focused attention. *Clinical Psychology Review, 24*(7), 827–856. https://doi.org/10.1016/j.cpr.2004.06.005

Chen, N. T. M., & Clarke, P. J. F. (2017). Gaze-based assessments of vigilance and avoidance in social anxiety: A review. *Current Psychiatry Reports. Current Medicine Group LLC, 1*. https://doi.org/10.1007/s11920-017-0808-4. PubMed PMID: 28726063.

Chen, N. T. M., Clarke, P. J. F., MacLeod, C., & Guastella, A. J. (2012). Biased attentional processing of positive stimuli in social anxiety disorder: An eye movement study. *Cognitive Behaviour Therapy, 41*(2), 96–107. https://doi.org/10.1080/16506073.2012.666562. PubMed PMID: 22489625.

Chen, N. T. M., Thomas, L. M., Clarke, P. J. F., Hickie, I. B., & Guastella, A. J. (2015). Hyperscanning and avoidance in social anxiety disorder: The visual scanpath during public speaking. *Psychiatry Research, 225*(3), 667–672. https://doi.org/10.1016/j.psychres.2014.11.025. PubMed PMID: 25530414.

Chen, J., van den Bos, E., L, M., Velthuizen, S., & Westenberg, P. M. (2021). Visual avoidance of faces in socially anxious individuals: The moderating effect of type of social situation. *Journal of Experimental Psychopathology, 12*(1). https://doi.org/10.1177/2043808721989628

Chen, J., van den Bos, E., & Westenberg, P. M. (2020). A systematic review of visual avoidance of faces in socially anxious individuals: Influence of severity, type of social situation, and development. In *Journal of anxiety disorders*. Elsevier Ltd. https://doi.org/10.1016/j.janxdis.2020.102193. PubMed PMID: 32058889.

Clark, D. M., & Wells, A. (1995). A cognitive model of social phobia. In R. G. Heimberg, M. R. Liebowitz, D. A. Hope, & F. R. Schneier (Eds.), *Social phobia: Diagnosis, assessment, and treatment* (pp. 69–93). The Guilford Press.

Clark, D. M., & Wells, A. (1995). The cognitive model of social phobia. In *Social phobia: Diagnosis, assessment, and treatment* (1st ed. 1. edition, pp. 69–93). New York: New York: Guilford Press.

Clay, V, König, P, & König, S (2019). Eye tracking in virtual reality. *Journal of Eye Movement Research, 12*(1).

Dechant, M., Trimpl, S., Wolff, C., Mühlberger, A., & Shiban, Y. (2017). Potential of virtual reality as a diagnostic tool for social anxiety: A pilot study. *Computers in Human Behavior, 76*, 128–134. https://doi.org/10.1016/j.chb.2017.07.005

Eysenck, M. W., & Derakshan, N. (2011). New perspectives in attentional control theory. *Personality and Individual Differences, 50*(7), 955–960. https://doi.org/10.1016/j.paid.2010.08.019

Fehm, L., Pelissolo, A., Furmark, T., & Wittchen, H. U. (2005). Size and burden of social phobia in Europe. *European Neuropsychopharmacology, 15*(4), 453–462. https://doi.org/10.1016/j.euroneuro.2005.04.002. PubMed PMID: 15921898.

Freeman, D., Reeve, S., Robinson, A., Ehlers, A., Clark, D., Spanlang, B., et al. (2017). Virtual reality in the assessment, understanding, and treatment of mental health disorders. In *Psychological medicine* (pp. 2393–2400). Cambridge University Press. https://doi.org/10.1017/S003329171700040X. PubMed PMID: 28325167.

Geraets, C. N. W., Wallinius, M., & Sygel, K. (2022). Use of virtual reality in psychiatric diagnostic assessments: A systematic review. *Frontiers in Psychiatry*, 13. https://doi.org/10.3389/fpsyt.2022.828410

Günther, V., Kropidlowski, A., Schmidt, F. M., Koelkebeck, K., Kersting, A., & Suslow, T. (2021). Attentional processes during emotional face perception in social anxiety disorder: A systematic review and meta-analysis of eye-tracking findings. In *Progress in neuro-psychopharmacology and biological psychiatry*Elsevier Inc.. https://doi.org/10.1016/j.pnpbp.2021.110353. PubMed PMID: 34000291.

Heimberg, R. G., Horner, K. J., Juster, H. R., Safren, S. A., Brown, E. J., Schneier, F. R., et al. (1999). Psychometric properties of the Liebowitz social anxiety scale. *Psychological Medicine, 29*(1), 199–212. https://doi.org/10.1017/S0033291798007879. PubMed PMID: 10077308.

Holmqvist, K., & Andersson, R. (2017). Eye tracking : A comprehensive guide to methods. *Paradigms and measures* (2. edition). Lund Eye-Tracking Research Institute. Lund.

Horley, K, Williams, DM, Gonsalvez, A, & Gordon, J (2003). Social phobics do not see eye to eye: A visual scanpath study of emotional expression processing. *Journal of Anxiety Disorders, 17*, 33–44.

Horley, K., Williams, L. M., Gonsalvez, C., & Gordon, E. (2004). Face to face: Visual scanpath evidence for abnormal processing of facial expressions in social phobia. *Psychiatry Research, 127*(1–2), 43–53. https://doi.org/10.1016/j.psychres.2004.02.016. PubMed PMID: 15261704.

Janssen, E. H. C., van de Ven, P. M., Terluin, B., Verhaak, P. F. M., van Marwijk, H. W. J., Smolders, M., et al. (2012). Recognition of anxiety disorders by family physicians after rigorous medical record case extraction. Results of the Netherlands study of depression and anxiety. *General Hospital Psychiatry, 34*(5), 460–467. https://doi.org/10.1016/j.genhosppsych.2012.04.010. PubMed PMID: 22717089.

Javaid, S. F., Hashim, I. J., Hashim, M. J., Stip, E., Samad, M. A., & Ahbabi, A Al (2023). Epidemiology of anxiety disorders: Global burden and sociodemographic associations. *Middle East Current Psychiatry, 30*(1). https://doi.org/10.1186/s43045-023-00315-3

Kessler, R. C., Berglund, P., Demler, O., Jin, R., Merikangas, K. R., & Walters, E. E. (2005). Lifetime prevalence and age-of-onset distributions of of DSM-IV Disorders in the National Comorbidity Survey Replication. *Archives of General Psychiatry, 62* (June), 593–602. PubMed PMID: 18188442.

iMotions (2025). iMotions software. Available at: https://www.imotions.com (Accessed: 25 March 2026).

Kim, H., Shin, J. E., Hong, Y. J., Shin, Y. B., Shin, Y. S., Han, K., et al. (2018). Aversive eye gaze during a speech in virtual environment in patients with social anxiety disorder. *Australian and New Zealand Journal of Psychiatry, 52*(3), 279–285. https://doi.org/10.1177/0004867417714335. PubMed PMID: 28610445.

Kleberg, J. L., Högström, J., Nord, M., Bölte, S., Serlachius, E., & Falck-Ytter, T. (2017). Autistic traits and symptoms of social anxiety are differentially related to attention to others' eyes in social anxiety disorder. *Journal of Autism and Developmental Disorders, 47*(12), 3814–3821. https://doi.org/10.1007/s10803-016-2978-z. PubMed PMID: 28000078.

Konnopka, A., & König, H. (2020). Economic burden of anxiety disorders: A systematic review and meta-analysis. *PharmacoEconomics. Adis*, 25–37. https://doi.org/10.1007/s40273-019-00849-7. PubMed PMID: 31646432.

Lazarov, A., Abend, R., & Bar-Haim, Y. (2016). Social anxiety is related to increased dwell time on socially threatening faces. *Journal of Affective Disorders, 193*, 282–288. https://doi.org/10.1016/j.jad.2016.01.007. PubMed PMID: 26774515.

Leary, M. R. (1983). A brief version of the fear of negative evaluation scale. *Personality and Psychology Bulletin, 9*(3), 5.

Lecrubier, Y., Sheehan, D. V., Weiller, E., Amorim, P., Bonora, I., Sheehan, K. H., et al. (1997). The mini international neuropsychiatric interview (MINI). A short diagnostic structured interview: Reliability and validity according to the CIDI. *European Psychiatry, 12*(5), 224–231. https://doi.org/10.1016/S0924-9338(97)83296-8

Leigh, E., & Clark, D. M. (2018). Understanding social anxiety disorder in adolescents and improving treatment outcomes: Applying the cognitive model of clark and Wells (1995). In *Clinical child and family psychology review* (pp. 388–414). Springer New York LLC. https://doi.org/10.1007/s10567-018-0258-5. PubMed PMID: 29654442.

Lépine, J pierre, & Pélissolo, A. (2000). *Theoretical papers* (Vol. 92, pp. 87–92), 92 (November 1999).

Maddox, B. B., & White, S. W. (2015). Comorbid social anxiety disorder in adults with autism spectrum disorder. *Journal of Autism and Developmental Disorders, 45*(12), 3949–3960. https://doi.org/10.1007/s10803-015-2531-5. PubMed PMID: 26243138.

Makransky, G., Lilleholt, L., & Aaby, A. (2017). Development and validation of the multimodal presence scale for virtual reality environments: A confirmatory factor analysis and item response theory approach. *Computers in Human Behavior, 72*, 276–285. https://doi.org/10.1016/j.chb.2017.02.066

Montaser, J., Umeano, L., Pujari, H. P., Nasiri, S. M. Z., Parisapogu, A., Shah, A., et al. (2023). Correlations between the development of social anxiety and individuals with autism spectrum disorder: A systematic review. *Cureus*. https://doi.org/10.7759/cureus.44841

Moukheiber, A., Rautureau, G., Perez-Diaz, F., Soussignan, R., Dubal, S., Jouvent, R., et al. (2010). Gaze avoidance in social phobia: Objective measure and correlates. *Behaviour Research and Therapy, 48*(2), 147–151. https://doi.org/10.1016/j.brat.2009.09.012. PubMed PMID: 19863948.

Mühlberger, A., Wieser, M. J., & Pauli, P. (2008). Visual attention during virtual social situations depends on social anxiety. *CyberPsychology and Behavior, 11*(4), 425–430. https://doi.org/10.1089/cpb.2007.0084. PubMed PMID: 18721090.

Nasrallah, H., Morosini, P. L., & Gagnon, D. D. (2008). Reliability, validity and ability to detect change of the personal and social performance scale in patients with stable schizophrenia. *Psychiatry Research, 161*(2), 213–224. https://doi.org/10.1016/j.psychres.2007.11.012. PubMed PMID: 18848731.

Rapee, R. M., & Heimberg, R. G. (1997). A cognitive-behavioral model of anxiety in social phobia. *Behaviour Research and Therapy*. Report.

Reichenberger, J., Pfaller, M., & Mühlberger, A. (2020). Gaze behavior in social fear conditioning: An eye-tracking study in virtual reality. *Frontiers in Psychology*, 11. https://doi.org/10.3389/fpsyg.2020.00035

Rubin, M., Guo, S., Muller, K., Zhang, R., Telch, M. J., & Hayhoe, M. M. (2022). Selective visual attention during public speaking in an immersive context. *Attention, Perception, & Psychophysics, 84*(2), 396–407. https://doi.org/10.3758/s13414-021-02430-x. PubMed PMID: 35064557.

Rubin, M., Minns, S., Muller, K., Tong, M. H., Hayhoe, M. M., & Telch, M. J. (2020). Avoidance of social threat: Evidence from eye movements during a public speaking challenge using 360°- video. *Behaviour Research and Therapy, 1*, 134. https://doi.org/10.1016/j.brat.2020.103706. PubMed PMID: 32920165.

Ruscio, A. M., Brown, T. A., Chiu, W. T., Sareen, J., Stein, M. B., & Kessler, R. C. (2008). Social fears and social phobia in the USA: Results from the national comorbidity survey replication. *Psychological Medicine, 38*(1), 15–28. https://doi.org/10.1017/S0033291707001699. PubMed PMID: 17976249.

Schulze, L., Renneberg, B., & Lobmaier, J. S. (2013). Gaze perception in social anxiety and social anxiety disorder. *Frontiers in Human Neuroscience. Frontiers Media S. A.* https://doi.org/10.3389/fnhum.2013.00872

Solmi, M., Radua, J., Olivola, M., Croce, E., Soardo, L., Salazar de Pablo, G., et al. (2022). Age at onset of mental disorders worldwide: Large-scale meta-analysis of 192 epidemiological studies. *Molecular Psychiatry, 27*(1), 281–295. https://doi.org/10.1038/s41380-021-01161-7. PubMed PMID: 34079068.

Su, W., Lin, X., Liu, W., Lam, T. K., Li, P., & Wang, Q. (2026). The impact of depression and social anxiety on eye orientation and disengagement in individuals with and without depression. *Journal of Psychiatric Research, 192*, 325–331. https://doi.org/10.1016/j.jpsychires.2025.10.077. PubMed PMID: 41192392.

Tanner, B. A. (2012). Validity of global physical and emotional SUDS. *Applied Psychophysiology and Biofeedback, 37*(1), 31–34. https://doi.org/10.1007/s10484-011-9174-x. PubMed PMID: 22038278.

Toh, W. L., Rossell, S. L., & Castle, D. J. (2011). Current visual scanpath research: A review of investigations into the psychotic, anxiety, and mood disorders. *Comprehensive Psychiatry, 52*(6), 567–579. https://doi.org/10.1016/j.comppsych.2010.12.005. PubMed PMID: 21333977.

Weeks, J. W., Howell, A. N., & Goldin, P. R. (2013). Gaze avoidance in social anxiety disorder. *Depression and Anxiety, 30*(8), 749–756. https://doi.org/10.1002/da.22146. PubMed PMID: 23798359.

Weeks, J. W., Howell, A. N., Srivastav, A., & Goldin, P. R. (2019). "Fear guides the eyes of the beholder": Assessing gaze avoidance in social anxiety disorder via covert eye tracking of dynamic social stimuli. *Journal of Anxiety Disorders, 65*, 56–63. https://doi.org/10.1016/j.janxdis.2019.05.005. PubMed PMID: 31170596.

Wittchen, H. U., & Fehm, L. (2003). Epidemiology and natural course of social fears and social phobia. *Acta Psychiatrica Scandinavica - Supplement, 108*(417), 4–18. https://doi.org/10.1034/j.1600-0447.108.s417.1.x. PubMed PMID: 12950432.

Zeka, F., Clemmensen, L., Arnfred, B. T., Nordentoft, M., & Glenthøj, L. B. (2023). Examination of gaze behaviour in social anxiety disorder using a virtual reality eye-tracking paradigm: Protocol for a case - Control study. *BMJ Open, 13*(8). https://doi.org/10.1136/bmjopen-2023-071927. PubMed PMID: 37620268.

Zeka, F., Clemmensen, L., Valmaggia, L., Veling, W., Hjorthøj, C., & Glenthøj, L. B. (2024). The effectiveness of immersive virtual reality-based treatment for mental disorders: A systematic review with meta-analysis. *Acta Psychiatrica Scandinavica*. https://doi.org/10.1111/acps.13777

Zimmerman, M., & Chelminski, I. (2003). Clinician recognition of anxiety disorders in depressed outpatients. *Journal of Psychiatric Research, 37*(4), 325–333. https://doi.org/10.1016/S0022-3956(03)00020-7. PubMed PMID: 12765855.

Letamendi AM, Chavira DA, Stein MB. (2009) Issues in the assessment of social phobia: a review. Isr J Psychiatry Relat Sci.;46(1):13-24. PMID: 19728569; PMCID: PMC2925842.