Physiological Responses to Video Conferencing Exposure in Individuals with Social Anxiety: An iPPG-Based HRV Analysis

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Running title: iPPG-Based Stress Response in Virtual Settings

This is an Author's Accepted Manuscript for Acta Neuropsychiatrica. This version may be subject to change during the production process.

https://doi.org/10.1017/neu.2025.10029 Published online by Cambridge University Press

ABSTRACT

Background: Although social anxiety remains prevalent, conventional exposure therapy faces limitations such as limited accessibility, high cost, and low ecological validity. These barriers highlight the need for alternative, scalable methods that can effectively simulate social evaluative contexts.

Objective: This study aims to evaluate the anxiety-inducing effects of video conferencing exposure, measured through heart rate variability (HRV), using a fully online based methodology.

Methods: A total of 31 participants who reported social anxiety were recruited online and engaged in a simulated video conference task, where they interacted with multiple audience members' emotional faces on a 3×3 split screen. Their video recordings were analyzed using imaging photoplethysmography (iPPG) to obtain HRV data. Baseline anxiety levels were assessed using validated self-report questionnaires, including the State Anxiety Scale (STAI-X1), Trait Anxiety Scale (STAI-X2), Social Interaction Anxiety Scale (SIAS), and Social Phobia Scale (SPS).

Results: Pearson correlation analysis revealed that STAI-X1 scores negatively correlated with high-frequency normalized units (HFnu) changes and positively correlated with low-frequency high-frequency (LF–HF) ratio and low-frequency normalized units (LFnu) changes. Similar patterns were observed for STAI-X2. These findings suggest that higher levels of trait and state anxiety are associated with greater reductions in parasympathetic activity and increased sympathetic activation during online video conferencing.

Conclusions: This study underscores the clinical potential of online video conferencing as a scalable and accessible exposure therapy for the digital era, eliminating spatial and logistical constraints associated with traditional in-person exposure therapy.

Keywords: exposure therapy; heart rate variability; iPPG; social anxiety; video conference

https://doi.org/10.1017/neu.2025.10029 Published online by Cambridge University Press

SIGNIFICANT OUTCOMES

- Individuals with higher trait and state anxiety showed increased LF and LF/HF, and decreased HFnu during video conferencing.
- These HRV changes reflect heightened autonomic arousal under social stress.
- The findings suggest that virtual social exposure triggers physiological anxiety responses in vulnerable individuals.

LIMITATIONS

- The study is limited by a small sample size and the absence of a control group.
- Reliance on self-report measures and pre-recorded stimuli may affect the generalizability of the findings.

INTRODUCTION

Anxiety disorders rank among the most prevalent mental health conditions, impacting millions of individuals across the globe. These disorders present as emotional and somatic symptoms in reaction to perceived challenging or threatening situations. Research consistently demonstrates a connection between anxiety disorders and autonomic nervous system (ANS) dysregulation, which carries significant consequences for the physiological and psychological well-being of those affected (Bajkó *et al.*, 2012; Makovac *et al.*, 2016).

The ANS plays a crucial role in preserving homeostasis and controlling a variety of bodily processes, including cardiovascular, respiratory, and digestive systems. ANS dysregulation has been associated with impaired vagal function and diminished heart rate variability (HRV) in individuals with anxiety disorders. Meta-analysis has shown that anxiety disorders are significantly associated with a decrease in heart rate variability (HRV). Notably, anxiety disorders, such as generalized anxiety disorder (GAD) and social anxiety disorder (SAD), are linked to a reduction in the high-frequency (HF) component of HRV. These results suggest that HRV may serve as a reliable indicator of anxiety disorders (Åhs *et al.*, 2009; Appelhans and Luecken, 2006; Chalmers *et al.*, 2014).

Additionally, HRV may be an effective tool for assessing autonomous nervous system (ANS) dysfunction. Stress changes HRV variables and reduces parasympathetic activity, as indicated by a decrease in HF and an increase in low frequency (LF) (H.-G. Kim *et al.*,

https://doi.org/10.1017/neu.2025.10029 Published online by Cambridge University Press

2018a). Understanding the relationship between anxiety disorders and ANS dysregulation is essential for developing effective treatment strategies and enhancing patient outcomes.

Exposure therapy has emerged as a key treatment approach for anxiety disorders, particularly in the case of social anxiety disorder (Kaczkurkin and Foa, 2022). This therapeutic technique involves incrementally exposing individuals to anxiety inducing situations, thoughts, or stimuli, assisting them learning to confront and alleviate their fear and anxiety over time. However, the accessibility and cost-effectiveness of exposure therapy remains limited for some individuals. In certain instances, this therapy demands considerable time, effort, and resources to develop and execute realistic exposure scenarios, which can prove burdensome for both therapists and clients. Moreover, the requirement for specialized training for therapists and the limited availability of treatment providers may hinder access to this form of therapy for numerous individuals.

To address these limitations, alternative methods such as virtual reality exposure therapy (VRET) and self-help resources have been developed (Krijn *et al.*, 2004). However, these approaches present their own set of challenges, including reduced realism in VRET and insufficient guidance and support from self-help resources (Tsai *et al.*, 2018). Virtual Reality Exposure Therapy (VRET) has emerged as a promising modality for treating anxiety disorders by providing immersive, controlled, and individualized exposure to anxiety-provoking stimuli. Its advantages include the ability to simulate a wide range of scenarios in a safe environment, making it particularly effective for conditions like social anxiety and specific phobias (Freitas *et al.*, 2021). However, limitations such as high development costs, the need for specialized equipment, and the challenge of creating personalized virtual environments can hinder its widespread adoption. Additionally, some individuals may find it difficult to fully immerse themselves in virtual settings, which could affect treatment efficacy. Self-help interventions, including bibliotherapy and internet-based programs, offer accessible and cost-effective alternatives for managing anxiety disorders (Cuijpers and Schuurmans, 2007). These interventions can reduce barriers to treatment by allowing individuals to engage with therapeutic content at their own pace and convenience. Guided self-help, in particular, has shown efficacy comparable to traditional therapy for certain anxiety conditions (Lewis *et al.*, 2012). Nevertheless, challenges such as lower adherence rates, the absence of personalized feedback, and the potential for misinterpretation of materials can limit their effectiveness. Furthermore, self-help approaches may not be suitable for individuals with severe symptoms or those requiring more intensive support.

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In response to these challenges, we developed a fully online exposure therapy approach using video conferencing technology, combined with remote imaging photoplethysmography (iPPG) for non-contact physiological monitoring (Yu *et al.*, 2018). Cardiac ejection affects cutaneous blood volume and iPPG detects variations in peripheral cutaneous circulation by monitoring light reflected from the outer layers of the skin. Cutaneous perfusion is closely linked to the amount of cutaneous hemoglobin, and the primary mechanism of iPPG is based on the variation in light absorbed by hemoglobin (Rasche *et al.*, 2020). Remote iPPG offers a significant advantage compare to conventional PPG by being completely non-intrusive and non-contact, making it ideal for continuous monitoring without causing discomfort or inconvenience to the subject. Moreover, this technique, which extracts HRV data from facial video recordings, enables seamless, contact-free anxiety assessment using only a webcam or smartphone camera, making it highly scalable and accessible. Studies shown the feasibility of deriving various HRV parameters—such as the standard deviation of NN intervals (SDNN), the root mean square of successive differences between NN intervals (RMSSD), and frequency-domain components (LF, HF, LF/HF ratio)—from iPPG signals (Kaviya Dharshini and Jeeva, 2025; Pilz *et al.*, 2018). Since the HRV metrics derived from iPPG exhibit higher variability and reduced accuracy, particularly during active states. Given these findings, we acknowledge that the current application of the LGI method in our study does not fully address the precise indices of HRV. Considering the limitation, we rather focused on the change of HRV within individual participants.

This study aims to evaluate the anxiety-inducing potential of video conferencing in individuals with social anxiety by analyzing HRV changes and self-reported anxiety levels. Our hypothesis posits that exposure to real-time virtual social interactions will elicit significant autonomic responses, making online video conferencing a promising medium for remote anxiety assessment and treatment.

METHODS

Participants

The power analysis targeting a within-subject comparison of HRV between baseline and anxiety-inducing conditions, using a paired t-test with a moderate effect size (0.5), an α error probability of 0.05, and a power of 0.8, resulted in a required sample size of 34. The present study recruited 34 participants, but only 31 participants followed instruction properly and were included in the analysis. The participants were recruited entirely through online

https://doi.org/10.1017/neu.2025.10029 Published online by Cambridge University Press

platforms. The inclusion criteria were for individuals without a previous psychiatric history. Participation in the research was entirely voluntary, and written informed consent was obtained from all the participants. The study protocol was reviewed and approved by the Institutional Review Board at Korea University. All the methods were performed in accordance with the declaration of Helsinki.

Procedures

After providing online informed consent, participants completed a series of self-report questionnaires, including STAI-X1, STAI-X2, SIAS, SPS, and CES-D. Following this, they began the main experimental task. The task comprised two 5-minute phases: a simple reading phase (baseline) and a simulated interview phase designed to induce anxiety. Participants' facial videos were continuously recorded via webcam for iPPG-based HRV analysis. To manipulation check, single 5-point Likert item ("How anxious were you while doing the task?") was asked after the interview phase. The entire session took approximately 20–30 minutes to complete.

Virtual Job Interview Task

The Trier Social Stress Test (TSST) is a widely used paradigm for inducing social anxiety. In TSST, the participants are instructed to deliver a speech ahead of two or three panels (Allen *et al.*, 2017). Inspired by the Trier Social Stress Test (TSST), the fully digital virtual job interview task was designed to induce anxiety in a highly ecological and modern format. Given that modern communication relies heavily on virtual interactions, this paradigm closely mimics real-world scenarios such as online job interviews or virtual meetings. The participants were instructed to prepare for a remote virtual job interview lasting five minutes, which was preceded by a five-minute simple reading phase. During the pre-simple reading phase, participants were instructed to read the provided text aloud for 300 seconds (Fig. 1). The post-anxiety provoking stimuli phase was designed to expose participants to an anxiety-inducing situation. Participants were asked to discuss the predetermined topic "Provide specific examples of your three strengths and three weaknesses" for 300 seconds. In both phases, the faces of the participants themselves and the eight interviewers who were previously recorded are displayed on a 3 x 3 split screen. The interviewers were instructed to regularly convey indifference and boredom (Fig. 2). Heart rate was monitored remotely using iPPG technology, allowing for non-contact HRV assessment via webcam. To account for the heterogeneity of camera and environmental factors (e.g. lighting, distance), the Local Group

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Invariance (LGI) method was employed for blood volume pulse (BVP) extraction (Pilz *et al.*, 2018). Using patch-based decomposition, LGI allows feature extraction invariant to local transformations such as motion artifact or illumination changes, then leads to more consistent BVP signals. Heartbeat estimation from the BVP signal was conducted using the improved Welch FFT method (Fukunishi *et al.*, 2018). In this study, we used simple public reading session as baseline rather than simple resting-state. Speaking itself can influence heart rate, indicating that the act of speaking alone may have an impact on HRV (Mackersie and Calderon-Moultrie, 2016). Temporal and frequency domain heart rate variability indices were calculated and the difference between interview phase and public reading phase were used in statistical analysis.

HRV Data

HRV encompasses both time and frequency domain measure. Within the time domain, key parameters include the RMSSD (square root of the mean squared differences successive NN intervals), pNN50(proportion of NN50 divided by the total number of NN intervals), and SDNN(standard deviation of all NN intervals). The frequency domain features LF (power in the low- frequency range) and HF(power in the high- frequency range) (Malik, 1996). Frequency domain analysis is valuable for quantifying the activity of the sympathetic and parasympathetic nervous systems. HF (0.15-0.4 Hz) reflects the parasympathetic activity, specifically vagal tone, while LF (0.04-0.15 Hz) can reflect both sympathetic and parasympathetic activity. LF is often associated with sympathetic activity, but the underlying mechanisms are far more complex. Notably, the LF–HF ratio is regarded as an indicator of the balance between sympathetic and parasympathetic activity (Goldstein *et al.*, 2011; Malik, 1996; Reyes del Paso *et al.*, 2013; Xhyheri *et al.*, 2012).

Psychological Scales

Anxiety severity was assessed through self-reported questionnaires, which included the State Anxiety Scale (STAI-X1), Trait Anxiety Scale (STAI-X2), Social Interaction Anxiety Scale(SIAS), Social Phobia Scale(SPS), and Center for Epidemiologic Studies Depression Scale (CES-D). The State Trait Anxiety Inventory (STAI) is a 40-item self-report questionnaire using a 4-point Likert scale to measure the severity of current anxiety symptoms and anxiety proneness. The STAI comprises two subscales –: STAI-X1 and STAI-X2. STAI-X1 evaluates the present state of anxiety, including tension and activation of the autonomic nervous system, as a response to a provoked situation. STAI-X2 assesses the

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varying degrees of anxiety provoked, depending on an individual's tendency to perceive situations as threatening, thus indicating a generalized propensity for anxiety (Julian, 2011). The SIAS, a 20- items self-report assessment tool scored on a 5-point Likert scale, was developed to measure anxiety about social interaction and being observed by others (Herbert *et al.*, 2014; Mortberg *et al.*, 2017). The SPS is a 20-item self-report questionnaire, scored on a 5-point Likert scale, measuring anticipatory anxiety and fear of being observed. It reflects reactions to diverse social performance situations and is associated with social anxiety severity (Herbert *et al.*, 2014; Mortberg *et al.*, 2017). Anxiety and depression are interrelated, and patients may exhibit a combination of anxiety and depressive symptoms. A systematic meta-analysis revealed that depression is linked to reduced HF HRV, and the degree of depression negatively correlates with HRV (Kemp *et al.*, 2010). To exclude the effects of depression on anxiety, the CES-D, a widely-used self-report scale measuring depressive symptoms was considered. The CES-D consists of 20 items with scores ranging from 0 to 60 (Radloff, 1977). These instruments are widely recognized for their psychometric properties, ensuring the reliability and validity of the anxiety and depression assessments conducted in this study.(Clark *et al.*, 2002; de Beurs *et al.*, 2014; Jiang *et al.*, 2019; Metzger, 1976)

Statistical Analyses

For the 31 participants who completed the video conferencing task, cardiac autonomic responses were analyzed by comparing values from the pre-simple reading phase (baseline) to those from the post-anxiety provoking stimuli phase. Given the high inter-individual variability of HRV, we focused on within-subject changes rather than absolute values. The degree of HRV change was calculated using a simplified formula:

$$\Delta\mathrm{HRV} = \frac{\mathrm{HRV}_{\text{post-anxiety provoking stimuli phase}} - \mathrm{HRV}_{\text{pre-simple reading phase}}}{\mathrm{HRV}_{\text{post-anxiety provoking stimuli phase}}}$$

This relative change score allowed us to better account for individual differences at baseline and capture meaningful physiological shifts induced by the task. Pearson correlation analysis was used to assess associations between HRV changes and self-reported questionnaires. Additionally, a partial correlation was performed to evaluate the differences between anxiety scales and HRV variance while controlling for CES-D. All analyses were conducted using SPSS for Windows (IBM Corp., Armonk, NY, USA). A significance level of $p < 0.05$ was applied in all tests.

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RESULTS

Demographics

A total of 31 participants were enrolled in the study, comprising 15 males and 16 females. The participants had a mean age of 23.9 years (range: 21-29) and the average years of education was 15.39 (range: 11-19).

Psychological Scales

The mean scores for the psychological scales were as follows: STAI-X1, 40.06; STAI-X2, 41.74; SPS,14.87; and SIAS, 24.06. The CES-D had a mean value of 22.77 (Fig. 3). No statistically significant differences were observed based on gender (The correlation between scales are presented in Fig. 4). The manipulation check question showed that the Virtual Job Interview Task induced significant anxiety (mean=3.39 (SD=0.96), T=19.7, p<.001, Cohen's d=3.55).

Correlation Analysis between HRV Parameters and Anxiety Scales

Test of normal distribution: To conduct Pearson correlation analysis, the Shapiro-Wilk test was conducted for all ΔHRV values and anxiety scale scores to ensure the assumption of normality (Table 1).

Impact of anxiety on HRV: The Pearson correlation analysis was employed to assess the relationship between STAI-X1 scores and HRV changes. In the frequency domain, ΔLF–HF ratio (r = 0.486, p = 0.006**), ΔLFnu (r = 0.454, p = 0.010*) and ΔHFnu (r = -0.381, p = 0.035*) were statistically significant (Table 2). Scatter plots displayed a negative relationship between STAI-X1 and HFnu change, while a positive linear relationship was observed for LFnu and LF–HF ratio changes (Fig. 5). All parameters in the time domain were found to be insignificant.

For STAI-X2, the statistically significant parameters were ΔLF–HF ratio (r = 0.541, p = 0.002**), ΔLFnu (r = 0.507, p = 0.004**), and ΔHFnu (r = -0.436, p = 0.014*) (Table 3). A negative linear association was observed for HFnu change, whereas positive linear associations were identified for LFnu and LF–HF ratio changes (Fig. 6). The relationship between HRV changes during the task and social anxiety scales, including SPS and SIAS, was examined. No significant results were observed in both the time and frequency domains.

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Partial correlation between STAI and HRV controlling CES-D: To account for potential confounding factors such as depression, a partial correlation analysis between STAI-X1 and HRV changes, controlling for CES-D was performed. Statistical significance HRV indices were identified as ΔLF–HF ratio (r = 0.472 p = 0.009**) and ΔLFnu (r = 0.439, p = 0.015*) (Table 4). For STAI-X2, the statistically significant HRV indices were ΔLF–HF ratio (r = 0.491, p = 0.006**), ΔLFnu (r = 0.444, p = 0.014*), and ΔHFnu (r = -0.370, p = 0.044*) (Table 5).

DISCUSSION

This study provides compelling evidence that online video conferencing can serve as an effective method for assessing physiological anxiety responses, particularly in individuals with heightened trait and state anxiety. These findings suggest that while HRV responses may be associated with anxiety levels, further research is needed to determine whether video conferencing reliably induces anxiety in a controlled experimental setting. Unlike traditional in-person paradigms, this fully digital approach reflects real-world virtual interactions, aligning with the evolving communication habits of younger generations.

Notably, higher STAI-X1 and STAI-X2 scores were associated with greater reductions in HF, which may suggest a potential link between higher anxiety levels and decreased parasympathetic activity. Additionally, positive correlations with LF and the LF–HF ratio suggest that sympathetic nervous system activity may also be influenced by anxiety levels. Significant correlations between anxiety severity and HRV frequency-domain indices indicate a meaningful physiological response to online social exposure, characterized by increased sympathetic activity and reduced parasympathetic regulation. However, it remains unclear whether these changes reflect the experimental task's effectiveness in inducing anxiety or simply individual differences in baseline anxiety responses.

On the other hand, no significant associations were found between HRV changes and social anxiety scales (SPS, SIAS). This may be attributed to the limited statistical power due to the small sample size or the possibility that performance anxiety, rather than social anxiety, played a dominant role in this non-contact interview context. Some studies have suggested that technology-mediated communication is less anxiety-inducing than face-to-face communication (Pierce, 2009). However, other studies have reported that video-based communication can be as stressful as in-person interactions for individuals with social

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anxiety, although the autonomic responses in such settings remain underexplored (Maeda, 2023).

It is also noteworthy that only frequency-domain HRV indices exhibited significant correlations with anxiety, whereas time-domain indices did not. This may be due to the characteristics of HR data collected via iPPG technology. While iPPG generally correlates well with sensor-based measurements, time-domain HRV indices (e.g., RMSSD) may be more vulnerable to beat-by-beat variability (Bourdillon *et al.*, 2022).

Recent advancements in digital interventions—such as internet-based cognitive behavioral therapy (ICBT), virtual reality exposure therapy (VRET), and AI-assisted treatments—have expanded therapeutic possibilities for anxiety disorders (Anderson *et al.*, 2013; Reeves *et al.*, 2021). Despite the initial promise of innovative solutions such as internet-based interventions (ICBT) and VRET, several disappointing outcomes have emerged. A meta-analytic review of three major technology-assisted interventions for social anxiety disorder (SAD)—internet-based cognitive behavioral therapy (ICBT), virtual reality exposure therapy (VRET), and cognitive bias modification (CBM)—reported that ICBT showed a small advantage ($g = 0.38$), VRET demonstrated effects that were not statistically significant ($P > .05$), and CBM failed to show superiority over passive control conditions. (Kampmann *et al.*, 2016).

Limitations of ICBT may encompass a lack of personalized guidance and real-time interaction with a therapist, potentially impacting the therapeutic alliance and reducing treatment effectiveness. Moreover, ICBT may not be appropriate for all patients, as some might necessitate more intensive support or be uncomfortable with an exclusively online format. Regarding VRET, a primary limitation is that virtual environments may not achieve the same level of realism as real-life exposure, potentially influencing the therapy's effectiveness (Emmelkamp *et al.*, 2020; Pallavicini *et al.*, 2013). Additionally, the technology required for VRET can be costly and inaccessible to some individuals. A subset of users may also encounter side effects such as motion sickness or discomfort when utilizing virtual reality equipment, potentially impeding their therapeutic progress (Dziuda *et al.*, 2014; H. K. Kim *et al.*, 2018b). The fully online nature of this study offers several advantages over conventional in-person methods. Remote HRV monitoring via rPPG eliminates the need for wearable sensors, while digital recruitment and video conferencing tasks ensure accessibility for individuals who may be reluctant or unable to attend in-person therapy. This technology-driven approach enhances scalability, flexibility, and ecological validity, making it a

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promising avenue for future research and clinical applications.

Recently, video conferencing platforms like Zoom, Webex, and Microsoft Teams have gained prevalence, resulting in increased participation in virtual meetings. Individuals with social anxiety may also experience anxiety in these video conference settings, akin to their experiences in face-to-face social situations (Yuen *et al.*, 2019). Our developed method acknowledges these social changes and, more importantly, offers the advantage of being easily accessible remotely. Furthermore, measuring HRV does not necessitate any specialized equipment. Instead, we employ remote iPPG technology, which leverages the cameras found on desktops and laptops. This approach presents a significant departure from existing techniques, rendering our method more convenient and user-friendly.

This study has several limitations that should be acknowledged. First, a considerable number of participants exhibited negative change values, suggesting a decrease in anxiety rather than an increase during the experimental phase. This indicates that anxiety was not consistently heightened across participants, and for some, anxiety appeared to diminish. One plausible explanation is that certain individuals may have experienced partial habituation or desensitization during the baseline simple reading phase, which in turn reduced their anxiety during the subsequent interview phase. This suggests that the baseline phase itself may have had a calming effect, influencing subsequent responses to the experimental stimulus. Schommer et al. (Schommer *et al.*, 2003) found that the stress response measured by cortisol adapts with repetition, and another study adopted TSST observed that when a TSST was repeated, the overall group exhibited a smaller cortisol reaction the second time (Gianferante *et al.*, 2014). To address this, future studies should consider measuring baseline signals in a more neutral environment to minimize potential pre-exposure effects and ensure a clearer assessment of anxiety induction during the experimental phase.

Although the current study utilized iPPG rather than ECG or contact-based PPG for HRV measurement, this approach has some methodological constraints. Compared to ECG, which offers sub-millisecond-level precision for beat-to-beat interval detection, iPPG has inherent limitations in temporal resolution. Finger-based PPG sensors also provide more stable signals under controlled conditions. Specifically, iPPG may exhibit reduced reliability for time-domain HRV metrics due to its susceptibility to noise, lighting variability, and camera quality, nevertheless, . iPPG offers a unique advantage with respect to accessibility, as it enables remote physiological monitoring through a non-contact, camera-based approach without

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necessitating dedicated hardware.

Another limitation lies in the lack of a control group. Although participants were selected based on elevated anxiety levels, the absence of a comparison group without anxiety symptoms limits the ability to determine whether observed HRV changes were due to the experimental task itself or underlying individual traits. Including a control group in future studies would help clarify the specificity of task-induced physiological responses.

It is also important to note that the study did not find significant associations between HRV changes and social anxiety measures such as the SPS and SIAS. This may partly stem from the exclusive use of self-reported questionnaires, without incorporating structured clinical interviews, which could have offered a more accurate classification of social anxiety severity. Additionally, since both trait and state anxiety were measured only once prior to the task, it remains unclear whether observed physiological changes were driven by baseline anxiety tendencies or the task manipulation itself. Employing repeated measurements before and after exposure could help distinguish these effects in future research.

Another important consideration is the sample size, which was relatively small and may have contributed to the lack of significant findings in certain analyses. A larger sample could provide greater statistical power to detect more subtle physiological responses. Lastly, while the use of pre-recorded video interviewers improved ecological validity and standardization, it inherently lacks the real-time interaction and dynamic feedback present in live conversations. This may have reduced the immediacy and intensity of the social stressor.

Given these factors, future research should aim to refine the experimental design by incorporating real-time interactive video sessions, using larger and more diverse samples, and employing more comprehensive anxiety assessments. These improvements will be essential in determining whether video conferencing can serve as a reliable tool for assessing and potentially addressing social anxiety through exposure-based methods.

AUTHOR CONTRIBUTIONS

H.M.K., J.C.K., and H.K.Y. designed and directed the project; H.M.K., and J.C.K. performed the experiments; H.M.K., J.C.K. and H.K.Y. analyzed the data. H.M.K., J.C.K. C.S., Y.H.K., and H.K.Y. wrote the manuscript.

https://doi.org/10.1017/neu.2025.10029 Published online by Cambridge University Press

ACKNOWLEDGEMENTS

J.K and H.Y. holds pending patents in video conference exposure therapy system [PCT/KR2021/018962]. No other author has competing interests.

FINANCIAL SUPPORT

This study was supported by the National Research Fund (NRF-2020R1A2C1008072) and by a grant of the Korea Health Technology R&D Project through the Korea Health Industry Development Institute (KHIDI), funded by the Ministry of Health & Welfare, Republic of Korea (HI23C0035). The funder had no role in the design and conduct of the study, or in the decision to submit the article for publication.

DATA AVAILABILITY STATEMENT

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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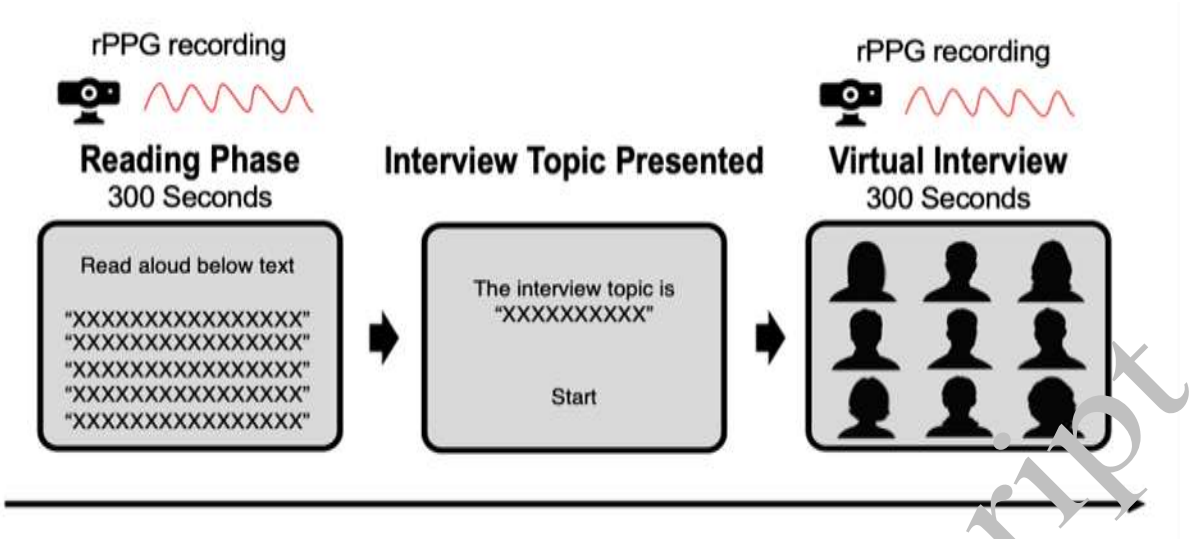

Figure 1

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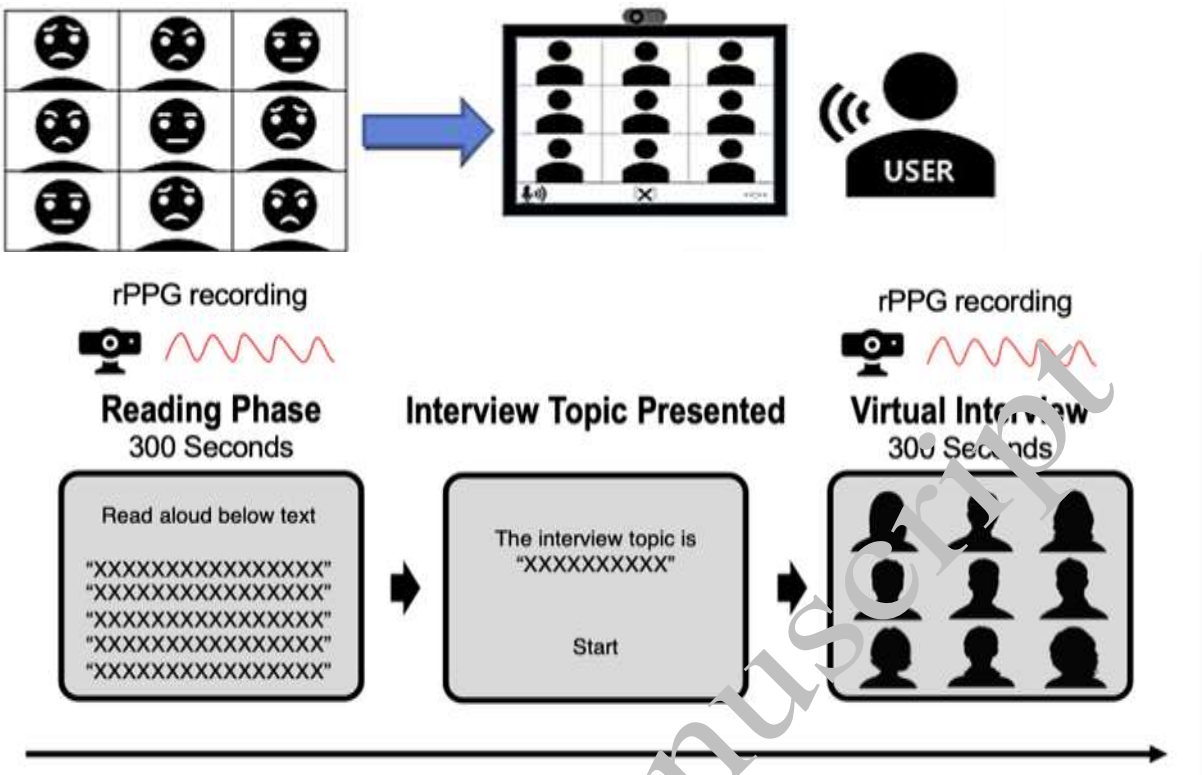

Figure 2

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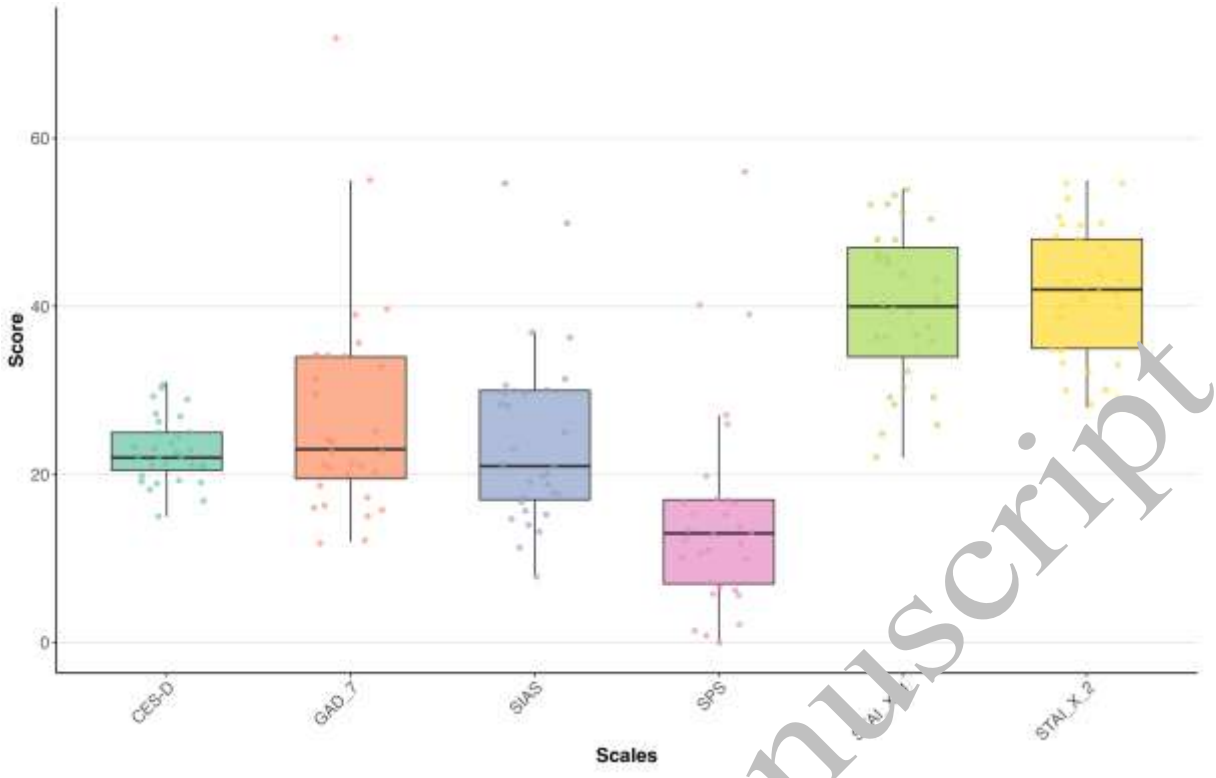

Figure 3

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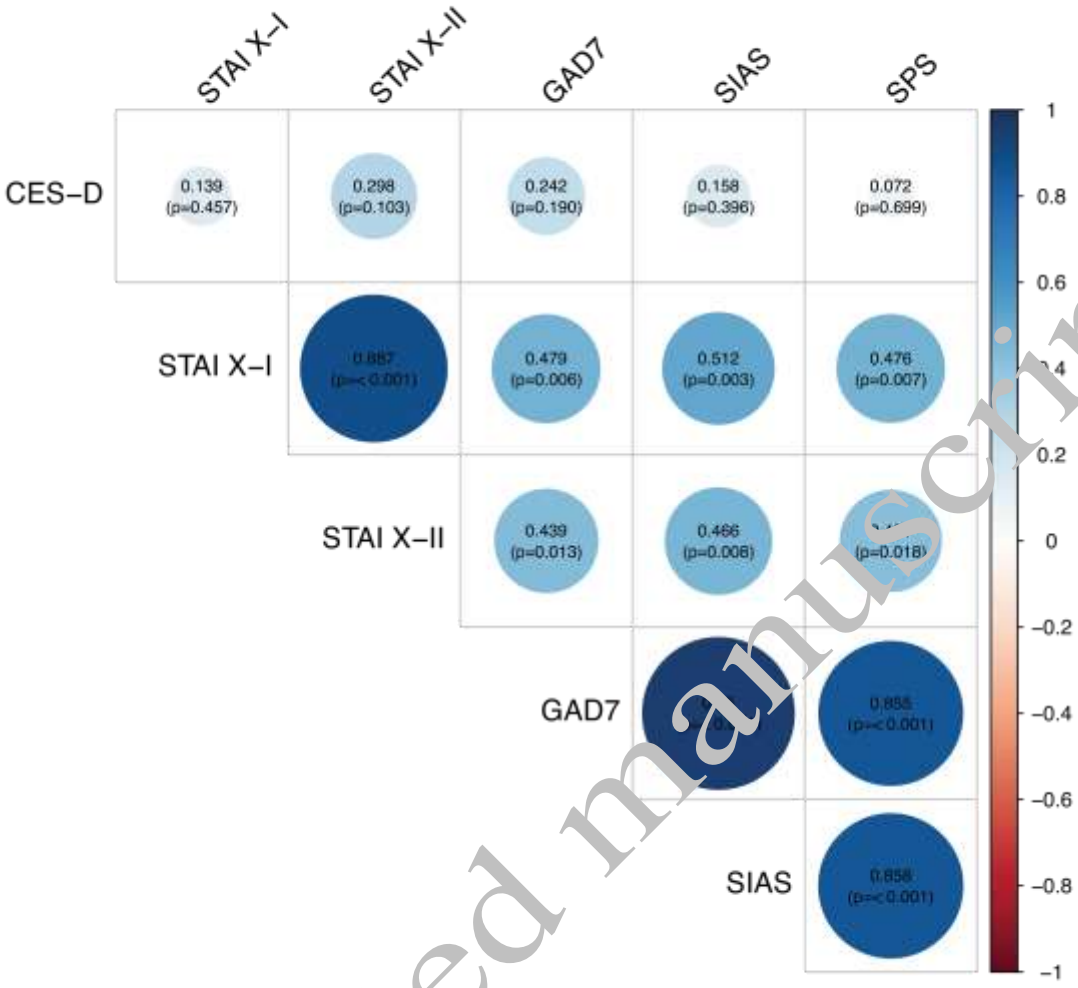

Figure 4

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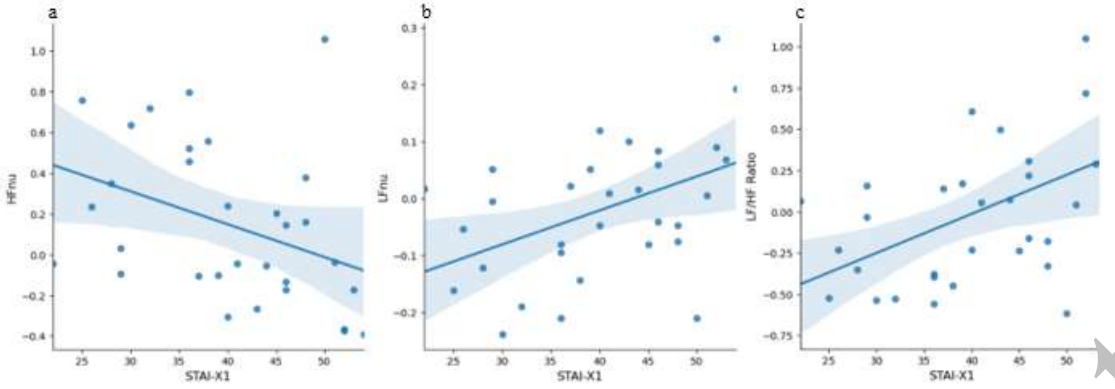

Figure 5

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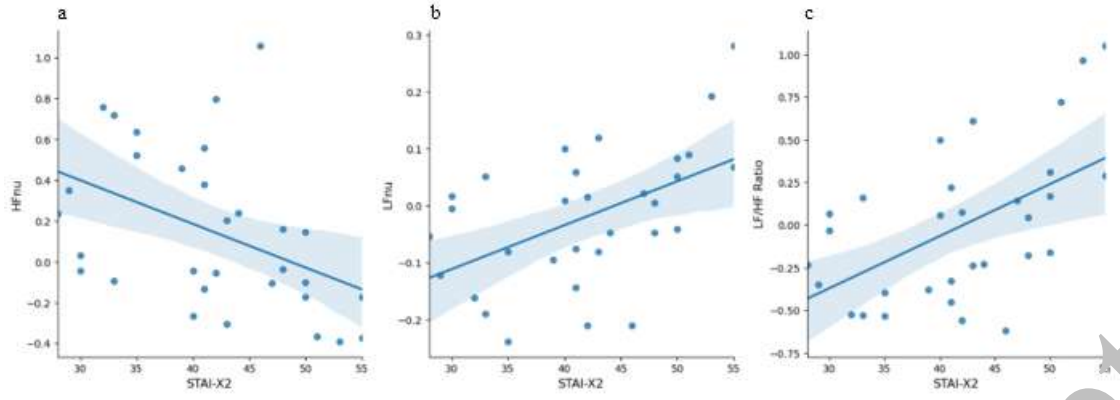

Figure 6

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Table 1. Normality Test Results (Shapiro-Wilk Test) for ΔHRV and Psychological Scales

Variable	Parameter (unit)	W	P
HRV			
Time domain	SDNN (ms)	0.974	0.643
	RMSSD (ms)	0.942	0.096
	pNN50(%)	0.539	<.001**
Frequency domain	LF–HF ratio	0.936	0.0685
	LFnu	0.980	0.826
	HFnu	0.944	0.109
Self-Report Scale			
	STAI-X1	0.957	0.243
	STAI-X2	0.958	0.259
	SPS	0.837	<.001**
	SIAS	0.906	0.010*
	CES-D	0.944	0.109

*p<0.05 **p<0.01

HRV, heart rate variability; SDNN, standard deviation of all NN intervals; RMSSD, square root of the mean squared differences successive NN intervals; pNN50, proportion of NN50 divided by the total number of NN intervals; LF–HF ratio, low frequency – high frequency ratio; LFnu, low frequency normalized units; HFnu, high frequency normalized units; STAI-X1, state anxiety scale; STAI-X2, trait anxiety scale; SPS, social phobia scale; SIAS, social interaction anxiety scale; CES-D, Center for epidemiologic studies depression scale.

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Table 2. Impact of STAI-X1 on HRV changes

Domain	Parameter (unit)	STAI-X1	P
Time	SDNN (ms)	0.318	0.081
	RMSSD (ms)	0.084	0.654
	pNN50(%)	-0.148	0.426†
Frequency	LF–HF ratio	0.486	0.006**
	LFnu	0.454	0.010*
	HFnu	-0.381	0.035*

*p<0.05 **p<0.01
SDNN, standard deviation of all NN interval; RMSSD, square root of the mean squared differences successive NN intervals; pNN50, proportion of NN50 divided by the total number of NN intervals; LF–HF ratio, low frequency – high frequency ratio; LFnu, low frequency normalized units; HFnu, high frequency normalized units. †Spearman correlation

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Table 3. Impact of STAI-X2 on HRV changes

Domain	Parameter (unit)	STAI-X2	P
Time	SDNN (ms)	0.299	0.102
	RMSSD (ms)	0.033	0.859
	pNN50(%)	-0.109	0.559†
Frequency	LF–HF ratio	0.541	0.002**
	LFnu	0.507	0.004**
	HFnu	-0.436	0.014*

*p<0.05 **p<0.01
SDNN, standard deviation of all NN interval; RMSSD, square root of the mean squared differences successive NN intervals; pNN50, proportion of NN50 divided by the total number of NN intervals; LF–HF ratio, low frequency – high frequency ratio; LFnu, low frequency normalized units; HFnu, high frequency normalized units. †Spearman correlation

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Table 4. Partial correlation between STAI-X1 and HRV changes controlling for CES-D

Domain	Parameter (unit)	STAI-X1	P
Time	SDNN (ms)	0.306	0.100.
	RMSSD (ms)	0.071	0.708
	pNN50(%)	-0.216	0.251†
Frequency	LF–HF ratio	0.472	0.009**
	LFnu	0.439	0.015*
	HFnu	-0.358	0.052

*p<0.05 **p<0.01

SDNN, standard deviation of all NN interval; RMSSD, square root of the mean squared differences successive NN intervals; pNN50, proportion of NN50 divided by the total number of NN intervals; LF–HF ratio, low frequency – high frequency ratio; LFnu, low frequency normalized units; HFnu, high frequency normalized units. †Spearman correlation

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Table 5. Partial correlation between STAI-X2 and HRV changes controlling for CES-D

Domain	Parameter (unit)	STAI-X2	P
Time	SDNN (ms)	0.275	0.141.
	RMSSD (ms)	0.004	0.982
	pNN50(%)	-0.234	0.214†
Frequency	LF–HF ratio	0.491	0.006**
	LFnu	0.444	0.014*
	HFnu	-0.370	0.044*

*p<0.05 **p<0.01

SDNN, standard deviation of all NN interval; RMSSD, square root of the mean squared differences of successive NN intervals; pNN50, proportion of NN50 divided by the total number of NN intervals; LF–HF ratio, low frequency – high frequency ratio; LFnu, low frequency normalized units; HFnu, high frequency normalized units.

†Spearman correlation

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