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Original article

The paradox of social avoidance and the yearning for understanding: Elevated interbrain synchrony among socially avoidant individuals during expression of negative emotions

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ABSTRACT

Social avoidance refers to the tendency to be alone and non-participating to social interactions, which is considered to hamper health interpersonal relationship. However, the neural underpinnings of social and emotional interactions among social avoidant individuals have not been fully studied. In the present study, we used EEG hyperscanning technology to investigate the brain activity and its synchronization of 25 socially avoidant dyads and 28 comparison dyads during an emotional communication task. The emotional communication task consisted of the emotional processing stage and emotional interaction stage. Event-related potentials (ERPs) of the senders during the emotional processing stage and the interbrain synchrony (IBS) of the dyads during the emotional interaction stage were analyzed. Results showed that (1) socially avoidant group showed higher beta, theta and gamma IBS in the negative condition than in the positive and neutral condition; (2) in positive condition, the N1 and LPP amplitudes during the emotional processing stage of socially avoidant individuals were negatively correlated with the IBS within dyads during the emotional communication stage. The findings suggest that the dysfunctional emotional interaction of social avoidant individuals may be attributed to the negative impact of emotional stimuli processing during emotional communication.

Introduction

Social avoidance, a significant social dysfunction, involves reluctance to engage in social activities and fear of social evaluation (Coplan et al., 2013). This behavior correlates with social maladjustments and affective issues like poor interpersonal relationships, anxiety, and depression (Coplan et al., 2013). Previous research suggests socially avoidant individuals exhibit emotional processing biases and deficits in expression (Deng et al., 2023). However, neural mechanisms underlying emotional stimulus processing and its impact on emotional interaction among avoidants remain unclear. Hyperscanning technology now enables measuring neural foundations of emotional interaction in natural settings (Deng et al., 2022, 2024). Hence, this study uses hyperscanning to examine emotional interaction differences between socially avoidant and non-avoidant adults during human-to-human emotional communication, exploring the effects of emotional stimulus processing on avoidants' emotional interactions.

Social avoidance and emotional processing

The avoidant tendency impairs emotional information processing and comprehension (Zettle et al., 2007). Socially avoidant individuals exhibit a negativity bias, tending to interpret emotional stimuli more negatively (Sloan, 2004). For example, Sloan (2004) found that individuals with avoidance tendencies had higher negative emotional ratings of film clips of fear and disgust. Similarly, Cochrane et al. (2007) found that individuals with avoidant tendencies required longer response times and higher anxiety ratings when viewing negative images. This bias may stem from stronger cognitive associations with aversive experiences (Barnes-Holmes et al., 2001). Due to the negativity bias of emotional processing, the positive emotional experience of socially avoidant people derived from positive daily events is limited (Pickett & Kurby, 2010). Furthermore, avoidant individuals are shown to have difficulties in experiencing others' positive emotions. A recent study compared the frontal alpha asymmetry between socially avoidant

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people and non-withdrawn comparison people during processing emotional facial stimuli. Results showed that socially avoidant group had significantly lower frontal alpha asymmetry scores in response to positive stimuli than the comparison group (Deng et al., 2023).

Social avoidance and emotional interaction

The avoidant motivation and tendency of socially avoidant people may trigger stronger reactions in response to negative social stimuli during emotional interaction. For example, Zhu et al. (2022) found that socially avoidant individuals would have stronger reactivity and mood fluctuation when encountering negative social events. Such deficits in emotional regulation and increased instability may in turn reinforce socially avoidant individuals' inappropriate social interaction and lead to peer rejection (Zhu et al., 2021). The lack of social connectedness and social skills will also lead to a series of adaptive problems in socially avoidant individuals (Coplan et al., 2009).

In addition to being sensitive to negative information during interaction, neuroscience research has also found that socially avoidant individuals perceive and interpret emotional more negatively during interaction (Miskovic & Schmidt, 2012). For example, Schmidt et al. (1999) examined the neural mechanisms of socially avoidant individuals during stressful events by using a self-report social stress task. They found that socially avoidant individuals experienced increased anxiety and enhanced right frontal cortex activity during the social stress tasks (Schmidt et al., 1999). Right frontal lobe activation is associated with increased negative emotion (Coan et al., 2006). The result indicated that the socially avoidant individuals have more negative evaluations and experience more negative emotions during the negative social events. Bianchi et al. (2020) found that social avoidance reduced the quality of peer communication in boys because of their low perspective taking and high empathic concern. In a behavioral mimicry task, it was found that excessive self-focus in shy individuals led to lower levels of behavioral perception and behavioral mimicry during social interactions (Poole & Henderson, 2022). In addition, individuals with high motivation for social avoidance have an attentional bias toward negative emotional information, consistently directing their focus towards negative stimuli, which may lead to reinforced negative expectations in social interactions (Nikitin & Freund, 2015). Therefore, it is possible that the socially avoidant individuals have more self-focus and understand social information in a bias way and subsequently impede social interaction.

Hyperscanning research and interbrain synchrony

Social interaction, a core human activity, is avoided by socially avoidant individuals due to lack of social acclimation (Zhu et al., 2021). However, self-report and single-participant designs fail to elucidate emotional processing and expression during real social interactions. Electroencephalography (EEG-based hyperscanning approach takes the advantages of examining the brain activity and functional connections of two or more individuals simultaneously in naturalistic circumstances (Dikker et al., 2017). Hyperscanning therefore provides an approach to study the neural underpinnings and dysfunction of emotional communication in socially avoidant individuals in the human-to-human context (Balconi & Fronda, 2020).

Prior research establishes that perceiving another's emotion elicits neural representations and brain coupling in dyads (Balconi & Vanutelli, 2017). In emotional communication, observer's brain activity aligns with the sender's shared emotions (Hasson et al., 2012). Interbrain synchrony (IBS), a neural marker in hyperscanning, reflects neural coupling during interpersonal interaction (Richard et al., 2021). The mirror neuron system (MNS), the primary IBS network, activates during social interaction (Wang et al., 2018), linked to empathy and social information processing. IBS in dyads arises from emotional understanding, empathy, and shared experience (Deng et al., 2023). For example, an EEG-based hyperscanning study examined conditional differences in IBS when viewing different emotional film clips together. Results showed that IBS increased between interacting individuals under positive and negative conditions rather than neural condition (Lee & Hsieh, 2014). Similarly, prior research has found enhancement of IBS within mothers and children when mothers express emotions toward their children (Santamaria et al., 2020). In other words, the IBS was enhanced in emotional sharing (Deng et al., 2023; Lee & Hsieh, 2014) and emotional communication (Santamaria et al., 2020) demanding higher level of empathy and better social understanding between dyads. These findings highlighted the importance of IBS in indexing the social interaction and emotional communication. Therefore, examining IBS in socially avoidant individuals during emotional communication tasks could elucidate the neural mechanisms and dysfunction of social avoidance.

The present study

To our knowledge, empirical evidence on neural underpinnings of emotional communication in socially avoidant individuals is limited. This study employed EEG-based hyperscanning to investigate IBS between socially avoidant individuals and partners during emotional communication. Prior work indicates socially avoidant individuals exhibit a negativity bias, interpreting positive and neutral events negatively (Sloan, 2004). This bias may impair emotional expression and communication. According to the hyperscanning literature, low frequency-bands like theta may be an important marker of emotional engagement and social information processing (Balconi et al., 2018; Deng et al., 2023). Beta band IBS seems to be evoked by sharing a common goal in the interactive context (Ménoret et al., 2014). The gamma frequency band IBS has been highly related to emotional interaction (Mu et al., 2017). Therefore, we expect a negative correlation between ERP amplitudes during emotional processing and IBS (e.g., theta, beta, and gamma IBS) during communication for socially avoidant dyads. In other words, greater emotional stimulus impact during processing predicts lower IBS during communication.

Method

Participants

This study selected 55 undergraduate dyads from a large sample ($N = 384$) based on self-reported social avoidance scores (see details in Measures). The required sample size for the present study was estimated using G *Power 3.1 software (Faul et al., 2007). According to the criteria proposed by Cohen (1992) and previous hyperscanning research (Deng et al., 2022, 2023), the parameters were set as follows: *F* test, repeated measure analysis of variance, effect size $f = 0.25$, $\alpha = 0.05$, $1\text{-}\beta = 0.90$, group number = 2, number of measurements = 3. The required sample size was 36 dyads. Two dyads with poor EEG quality were removed following the follow-up EEG data processing. In the final sample, there were 28 comparison dyads (9 male dyads, 19 female dyads, between 17 and 24 years, $M_{age} = 19.77$ years, $SD = 1.82$ years) and 25 socially avoidant dyads (7 male dyads, 18 female dyads, between 17 and 25 years, $M_{age} = 19.67$ years, $SD = 1.75$ years). Each socially avoidant dyad consisted of one avoidant and one non-avoidant participant, unknown to each other prior to the study. Similarly, comparison dyads comprised two non-avoidant participants, also unknown to each other. Results of the paired samples *t*-test showed that there was no significant difference in age or sex ($ps > .05$) between the two participants in either the socially avoidant dyads or the comparison dyads. Additionally, independent samples *t*-tests indicated there was no significant difference in age or sex ($ps > .05$) between the socially avoidant dyads and the comparison dyads.

Participants had normal or corrected vision, were physically healthy, and had adequate sleep prior to the experiment, excluding other illnesses. Before the study, they signed an informed consent form. This study adhered to the 1964 Helsinki Declaration ethical standards and was approved by Shenzhen University's Institutional Review Board (PN-202200010).

Study design and procedure

The study was conducted using a between-participant design. Scalp recordings of IBS during an emotional communication task were compared between the socially avoidant group and non-avoidant group. University students were recruited via flyers posted on campus and individuals ($N = 384$) who were interested in this study were invited to complete the Chinese version of the Social Preference Scale - Revised (Deng et al., 2023). Recruited participants were allocated to the socially avoidant group and non-avoidant group according to their ratings of the Social Preference Scale. All the dyads included randomly paired same sex participants. Participants completed an informed consent form and demographic questionnaire in 10 min, then participated in the emotional communication task. Research assistants were blinded about the aim and hypotheses of the study.

Measures

Social avoidance

The Chinese version of the *Social Preference Scale - Revised* was used to select socially avoidant participants (Deng et al., 2023). The Chinese version of the *Social Preference Scale - Revised* (Cronbach's $\alpha = 0.85$) has four subscales for social withdrawal, including shyness (e.g., "I want to invite others to play, but I am often too nervous or scared to do so''), unsociability (e.g., "I really don't mind spending time alone''), social avoidance (e.g., "I prefer to be by myself rather than with others."), and isolate (e.g., "I wanted to play with others, but I was often excluded."). The scale consists of 21 items and is scored on a 5-point scale (1 = *completely disagreeing*, 5 = *completely agreeing*). The observed internal consistency for this scale was alpha = 0.85, indicating adequate reliability.

Prior studies suggest social avoidance correlates to shyness and unsociability (Nelson et al., 2021). Socially avoidant individuals exhibit high social avoidance yet low shyness and unsociability (Coplan et al., 2013; Eggum et al., 2020). This study categorized participants based on social avoidance, shyness, and unsociability scores. Socially avoidant participants ($N = 25$) scored in the top 25 % for avoidance and bottom 75 % for shyness and unsociability. Non-avoidant participants ($N = 85$) scored in the bottom 75 % for all measures.

Emotional communication task

An emotional communication task assessed sender-receiver emotional interaction (Kunecke et al., 2017). It comprised an emotional processing stage (passive viewing of emotional pictures) and a communication stage (sender expressing emotions, receiver rating emotional intensity). In socially avoidant dyads, the avoidant participant was the sender. In non-avoidant dyads, a random non-avoidant participant served as the sender.

Seventy-five pictures were selected from the Chinese Affective Picture System (Gong et al., 2011) and used in the emotional processing stage of the emotional communication task. There were 25 positive, 25 negative and 25 neutral pictures. Each picture has 330 * 340 pixels and a dimension of 7.20 cm by 6.99 cm. The valence score of positive pictures was significantly higher than that of neutral and negative pictures ($ps < 0.001$), and the valence score of neutral pictures was significantly higher than that of negative pictures ($p < 0.001$). Both positive and negative pictures had higher arousal scores than neutral pictures ($ps < 0.001$), but there was no significant difference between positive and negative pictures ($p = .833$).

The emotional communication task comprised emotional processing and communication stages. After confirming the instructions, the experiment began. In the beginning of each trial, a fixation point was displayed on both participants' computer screens for 500 ms. Followed by the emotional processing stage, an emotional picture was displayed on the sender's screen for 4000 ms. The sender was asked to fully feel the emotions expressed by the pictures. Meanwhile, the receiver's screen displayed a "Wait" cue for 4000 ms. The receiver was instructed to just sit and wait. Subsequently, the communication stage began with a "Start Expressing" cue and beep signal on the sender's screen for 3000 ms. The sender was asked to express their experienced emotions towards the receiver by facial expressions until a second beep. Meanwhile, the receiver's screen displayed an "Observe" cue and beep for 3000 ms, instructing them to observe the sender's facial expressions until the second beep. Finally, both participants rated their emotional intensity on a 1–5 scale.

This experiment encompassed 75 trials, presenting emotional pictures randomly using E-Prime 3.0 on a 21-inch monitor at a viewing distance of 80 cm. Each participant's experiment lasted 30–35 min Fig. 1. The dyads were fully debriefed post-study.

EEG recording and analyses

EEG data during the emotional communication task was recorded simultaneously and continuously using two 32-channel portable EEG systems (BrainAmp, Brainproducts GmbH, Germany) with two reference electrodes placed on the left and right mastoids. The EEG data were sampled at 500 Hz and impedances below 5 kΩ. EEG signals were referenced offline to the averaged mastoid (TP9 and TP10), and band-pass filtering was performed at 1–40 Hz. Artifact correction was conducted using ICA in Brain Vision Analyzer 2.0, with manual inspection to remove eye movements or other artifacts. Trials with artifacts exceeding ±100 μV were excluded (Schubring & Schupp, 2021). The average valid trials obtained were 20.30 (81.20 %) for positive, 20.06 (80.24 %) for negative, and 21.49 (85.96 %) for neutral conditions.

To evaluate the brain activity of the senders in both socially avoidant group and non-avoidant group during the emotional processing stage, event-related potential (ERP) components related to emotional processing were examined. EEG epochs consisted of 500 ms before and 1500 ms after the onset of the emotional picture in each trial. In each condition, 25 EEG epochs were averaged. According to the prior literature, late positive potential (LPP) at Pz (Murata et al., 2013) and the N1 and N2 at Fz and Cz (Guney et al., 2009) of the sender were analyzed.

To assess interbrain synchrony in emotional communication between socially avoidant and non-avoidant groups, phase locking value (PLV) was applied (Lachaux et al., 1999). After preprocessing in Matlab, EEG data underwent Short Time Fourier Transform (STFT). 500 ms before the emotional communication stage was taken as the baseline, and 3000 ms during the emotional communication stage was taken as the analysis time. Averaged PLVs were categorized into theta (4–7 Hz), beta (14–30 Hz), and gamma (31–40 Hz) bands.[1] Frontal (Fz), central (Cz), and parietal (Pz) areas were analyzed for inter-brain synchrony.

Statistical analyses

(1) For each frequency band (i.e., theta, beta, and gamma), separate 2 (Group: Socially Avoidant Group vs. Non-avoidant Group) × 3 (Valence: Positive vs. Negative vs. Neutral) × 3 (Electrode: Fz vs. Cz vs. Pz) repeated measures ANOVAs were used to assess the IBS between the sender and receiver. (2) To explore how emotional processing influence emotional communication, Pearson correlations were conducted between the analyzed ERPs during the emotional processing stage of the

[1] As shown in Appendix 1 Table A1, results of the 2 × 3 × 3 repeated measures ANOVA on the interbrain synchrony in the delta and alpha bands showed that no significant main effect and interaction were observed (all $ps > .05$). Therefore, results of interbrain synchrony in the delta and alpha bands were not presented in the main text.

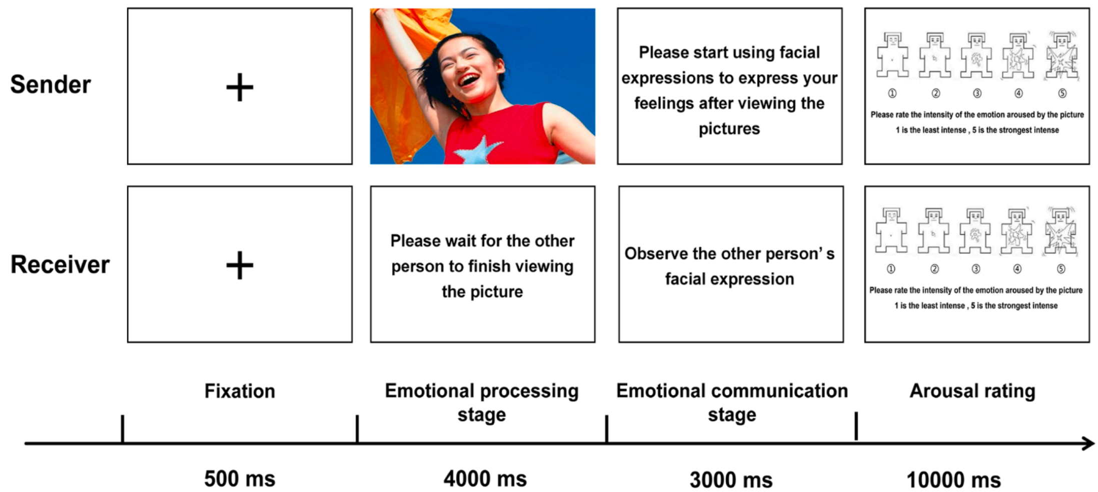

Fig. 1. Procedure of the emotional communication task.

sender and the interbrain synchrony (PLV) within the sender and the receiver during the emotional communication stage. In all repeated measure ANOVAs, the Greenhouse-Geisser's method was used to correct for violations of sphericity. Bonferroni method was used to correct *p* values for multiple comparisons, $p < .05$ was selected as the significant level.

Results

Existence of the interbrain synchrony (IBS) in the emotional communication stage

To demonstrate the existence of interbrain synchronization between the senders and receivers during the emotional communication task, a validation approach of the permutation test was applied. Permutation test was conducted 5000 times to yield a distribution (*t* value), which was then compared with the original data. As shown in Fig. 2, compared

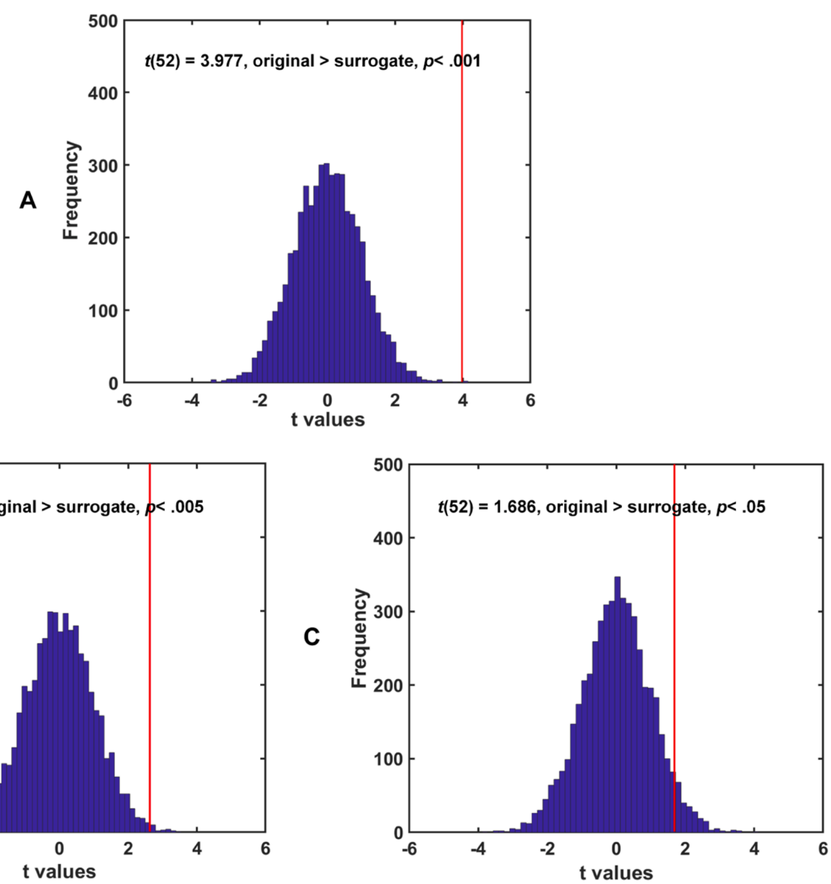

Fig. 2. The results of the permutation test. The effect (red line) in real dyads was significant within the 5 % area. The x-axis represents the t value, and the y-axis represents the number of the samples. (A. theta IBS permutation test results; B. beta IBS permutation test results; C. gamma IBS permutation test results).

with the distribution generated by the permutation procedure, there were significant differences in the PLV values of the original data sets and the surrogate data sets of the bands of interest ($ps < 0.05$).

Interbrain synchrony (IBS) in the emotional communication stage

For the theta IBS, the main effect of Electrode was significant, F (2102) = 6.87, p = .003, η_{p^2}= 0.12. The IBS in parietal region was significantly lower than that in central region (p = .002). The interaction of Electrode, Valence and Group was significant, F (4204) = 3.02, p = .026, η_{p^2}= 0.06. As shown in Fig. 3, the IBS of the socially avoidant group was significantly higher than that of the non-avoidant group in central region (p = .020) in the negative condition. There was no significant difference in the IBS between socially avoidant and non-avoidant group in central region in the positive (p = .561) and neutral condition (p = .282). No other significant effect was found (p = .072~998; F = 0.001~2.7; η_{p^2}= 0.001~.05).

For beta IBS, the main effect of Valence was significant, F (2102) = 4.30, p = .016, η_{p^2}= 0.08. The IBS of the dyads in the negative condition was significantly greater than that in the neutral condition. The interaction of Valence and Group was significant, F (2102) = 5.24, p = .007, η_{p^2}= 0.09. As shown in Fig. 3, the IBS of the non-avoidant group in the positive condition was significantly greater than that in the neutral condition (p = .020). The IBS of socially avoidant group in negative condition was significantly greater than that in neutral condition (p = .004) and positive condition (p = .004). The interaction of Electrode, Valence and Group was significant, F (4204) = 2.57, p = .048, η_{p^2}= 0.05. The IBS of the non-avoidant group was significantly higher than that of the socially avoidant group in the central (p = .015) and frontal regions (p = .039) in the positive condition. However, there was no significant

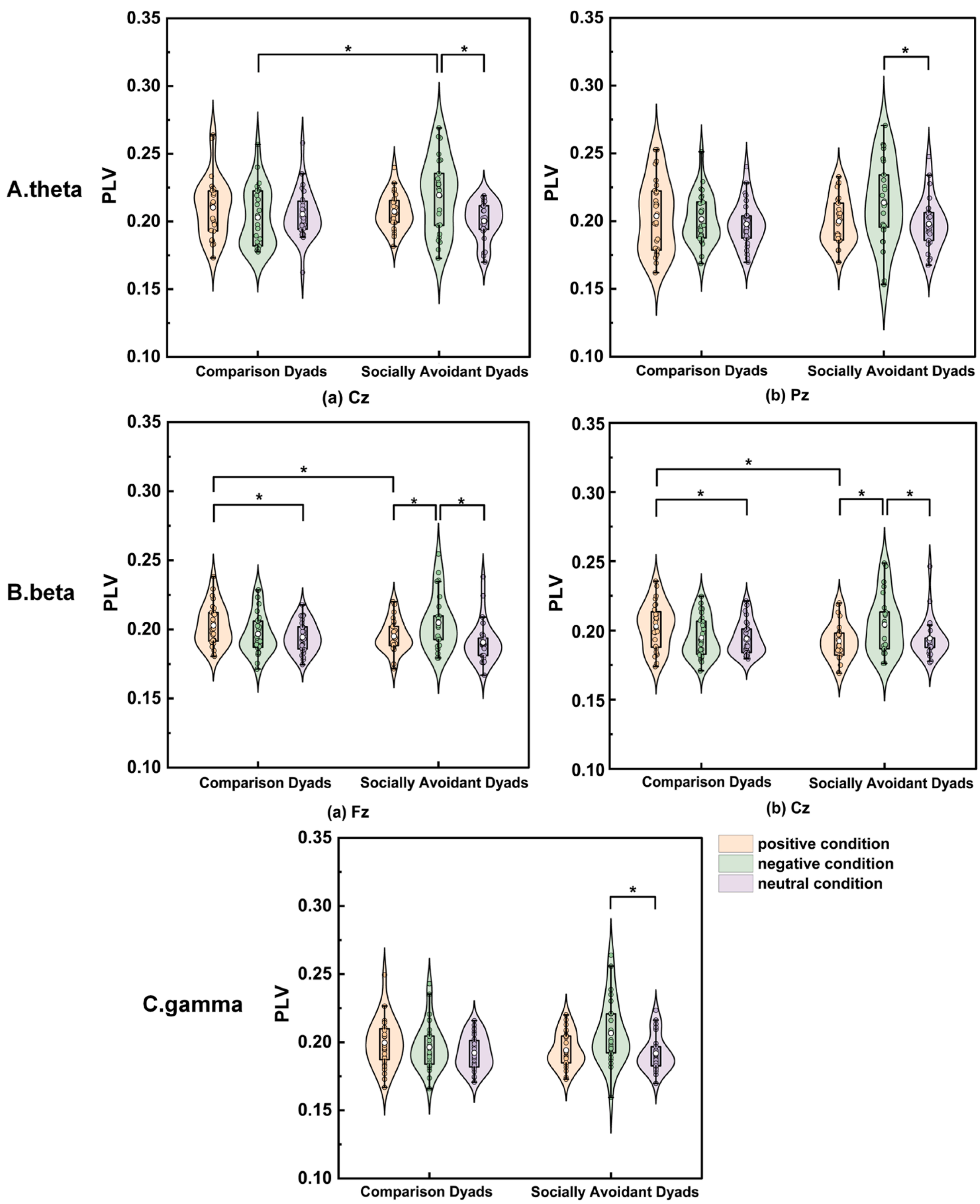

Fig. 3. PLVs between the comparison group and socially avoidant group in different conditions.

difference in the IBS between socially avoidant and non-avoidant group in the central ($p = .061$) and frontal regions ($p = .098$) in the negative condition ($p = .061, p = .098$) and neutral condition ($p = .972, p = .308$). No other significant effect was found ($p = .164\sim.991$; $F = 0.001\sim1.84$; $\eta_{p^2}= 0.001\sim.03$).

For the gamma IBS, the main effect of Valence was significant, F (2102) = 5.62, $p = .005$, $\eta_{p^2}= 0.10$. The IBS in the negative condition was significantly greater than that in the neutral condition ($p = .007$). The interaction between Valence and Group was significant, F (2102) = 4.07, $p = .020$, $\eta_{p^2}= 0.07$. As shown in Fig. 3, the IBS of socially avoidant group in negative conditions was significantly greater than that under neutral conditions ($p = .003$) and positive conditions ($p = .013$). The interaction of Electrode, Valence and Group was not significant, F (4204) = 0.13, $p = .971$, $\eta_{p^2}= 0.00$. No other significant effect was found ($p = .484\sim.924$; $F = 0.63\sim1.84$; $\eta_{p^2}= 0.001\sim.01$).

Correlations between the ERPs in the emotional processing stage and the IBS in the emotional communication stage

As shown in Fig. 4, for the socially avoidant group, results of the correlation analyses showed that the N1 amplitude in the emotional processing stage was negatively correlated with the beta IBS in the communication stage in positive condition for the socially avoidant group (Fz: $r = -0.46, p = .021$; Cz: $r = -0.47, p = .019$). The amplitude of LPP_{300} in the emotional processing stage was negatively correlated with the gamma IBS in the communication stage ($r = -0.42, p = .038$).

For the non-avoidant group, the N2 amplitude in the emotional processing stage was positively correlated with the beta IBS in the communication stage under negative condition ($r = 0.41, p = .030$). In positive condition, the LPP_{600} amplitude in the emotional processing stage was significantly positively correlated with the theta IBS in the communication stage ($r = 0.46, p = .014$). The LPP_{600} amplitude in the emotional processing stage was significantly positively correlated with the gamma IBS in the communication stage ($r = 0.41, p = .032$).

Discussion

This study examined IBS in socially avoidant dyads during an emotional communication task in a realistic environment. It also explored the relationship between ERP amplitudes during emotional processing and IBS in communication. Interbrain synchrony unveils the cognitive neural characteristics of individuals engaged in social interactions. In this study, we observed an increased beta, theta, and gamma IBS among socially avoidant dyads under negative compared to positive and neutral communication conditions. Beta and theta oscillatory activity, typically linked to attention allocation (Baumeister et al., 2008). Our finding aligns with the previous research suggesting that socially avoidant individuals allocate greater attentional resources to negative stimuli to avoid negative social consequences, resulting in higher sensitivity towards negative stimuli (Jetha et al., 2013).

Gamma oscillatory activity, associated with cognitive functions like emotion and intention (Barraza et al., 2020). The greater gamma IBS during negative emotional communication suggest the tendency of socially avoidant individuals to evaluate and interpret negative stimuli as more negative during emotional interaction (Sloan, 2004). This is in line with the previous finding that individuals with social avoidance motivations are more likely to interpret the meaning of facial expressions negatively (Nikitin & Freund, 2015). Due to the negative bias in the processing of emotional stimuli, socially avoidant individuals tend to process, interpret, and experience negative stimuli stronger and more negatively during social interaction (Sloan, 2004), resulting stronger emotional expression (Deng et al., 2023). The overreaction and expression to negative emotions of socially avoidant individuals during emotional interaction may trigger higher level of empathy of the partners and the emotional transmission within the dyads, resulting greater interbrain synchrony.

The current study further revealed that socially avoidant dyads exhibited reduced beta IBS compared to non-avoidant dyads during positive emotional communication. This diminished beta IBS is attributed to the negative bias in emotional processing among socially avoidant individuals, who are less responsive to positive stimuli and experience fewer positive emotions (Pickett & Kurby, 2010). Consequently, their limited comprehension of positive emotions and diminished positive experiences likely impede the expression of such emotions, resulting in lower IBS during emotional communication with their partners.

Furthermore, we examined the relationship between sender's emotion-related ERPs during the emotional processing stage and the IBS within the sender and the receiver during the emotional communication stage. Results found that the non-avoidant dyads exhibited positive

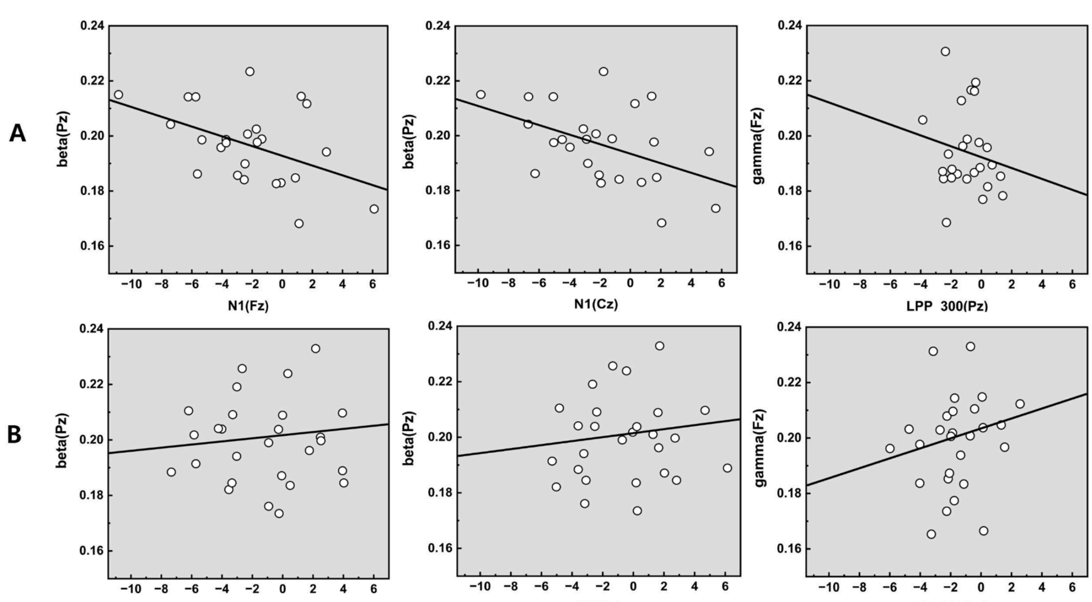

Fig. 4. Graphs of the correlation analysis between different groups in the positive condition. A) Graphs of the correlation analysis of the socially avoidance group; B) Graphs of correlation analysis of the non-avoidance group.

correlations between the emotion-related ERPs during the emotional processing stage (i.e., N2 and LPP) and the IBS during the emotional communication stage in both positive and negative conditions. It is suggested that deep emotional processing enhances later emotional expression and communication (Van Kleef, 2009). Conversely, socially avoidant dyads exhibited negative correlations between N1/LPP ERPs and IBS during positive communication. This indicates that socially avoidant individuals' higher psychophysiological activation in response to the positive stimuli during the emotional processing stage is associated with impaired emotional interaction. The stronger ERP amplitudes indicate that socially avoidant individuals are more strongly influenced by the positive emotions (Guney et al., 2009; Murata et al., 2013). However, the negative bias of socially avoidant individuals during emotional processing leads them to process and interpret positive stimuli in a more negative manner (Sloan, 2004). Moreover, socially avoidant individuals, due to their paucity of positive emotional experiences, struggle to express their positive emotions appropriately (Coplan et al., 2021; Deng et al., 2023; Watson & Naragon-Gainey, 2010). This discrepancy between neural activation triggered by positive stimuli and their limited emotional knowledge hinders positive emotional expression, leading to reduced interbrain synchrony. Additionally, prior research suggests that socially avoidant individuals' overreaction to emotional stimuli may contribute to their adjustment difficulties (Deng et al., 2023). The negative correlation between neural activation during emotional processing and neural synchrony during communication underscores potential mechanisms underlying dysfunctional interpersonal interactions in socially avoidant individuals.

The findings of this study have important practical implications for the intervention of socially avoidant individuals. In the future, it would be valuable to consider the negative bias characteristics of individuals with social avoidance and develop intervention programs aimed at reducing such negative bias. One potential approach in future interventions could be the utilization of attention bias correction training (Kunecke et al., 2017) to redirect the attention of socially avoidant individuals towards positive events. By increasing their attention and understanding of positive experiences, individuals may become more skillful to express positive emotions during social interactions. Thus, in daily interpersonal interactions, individuals with social avoidance may benefit from engaging in appropriate communication about emotional experiences to foster the development of positive social relationships.

However, limitations should be acknowledged. First, the sample size of the study is relatively small. It recruited participants aged 17–25, overlooking the potential age-related variations in avoidance behaviors among socially avoidant individuals. Future research should explore emotional interactions across age ranges to enhance theoretical understanding and generalizability. Second, while the emotional communication task provided a realistic simulation, it failed to fully capture real-life interpersonal dynamics. Future studies should investigate neural mechanisms in more naturalistic settings. Third, Compared to EEG-based hyperscanning approach, functional near-infrared spectroscopy (fNIRS) provides higher spatial resolution and less interference from body movement, which has advantages for assessing the functional localization in relevant brain regions in real-world situations. In the future, fNIRS hyperscanning technology can be utilized to explore the neural mechanisms of emotional communication in socially avoidant individuals with greater depth, thus getting more effective brain function information.

Notwithstanding these limitations, this is the first study to explore the neural mechanisms underlying emotional interactions in socially avoidant individuals. Our findings deepen the understanding of the neural mechanisms involved in emotional communication among those with social avoidance, offering practical insights for improving social interaction among individuals with social maladjustment. Tables A1-A2.

Data availability

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

Funding information

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Author contributions

Conceptualization, X.D.; datacuration, X.C.; formal analysis, X.C. and J.W.; funding acquisition, X.D.; investigation, X.C.; methodology, X. D.; project administration, X.D.;original draft-writing, X.D. and X.C.; visualization Writing, J.W.; writing review & editing, X.D. and J.W. All authors read and approved the final manuscript.

Ethical approval

The research protocol was reviewed and approved by the Institutional Review Board of Shenzhen University (PN-202200010). All procedures performed in studies involving human participants were conducted in accordance with the ethical standards of the Institutional Review Board of Shenzhen University and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

Declaration of competing interest

The authors declare no conflict of interest.

Acknowledgments

We wish to thank all participants in this study as well as all members of the research team.

Appendix 1

Table A1
Results of the ANOVAs on the Delta, Alpha Interbrain Phase-locking-value (PLV).

PLV	Factor	df	F	p	Partial η^2
Delta	Electrode	2102	7.38	.063	.13
	Valence	2102	3.63	.071	.07
	Group	1,51	.21	.650	.00
	Electrode*Group	2102	.02	.973	.00
	Valence *Group	2102	2.15	.128	.04

(continued on next page)

Table A1 (*continued*)

PLV	Factor	df	F	p	Partial η^2
	Electrode*Valence	4204	1.20	.358	.02
	Electrode*Valence*Group	4204	2.01	.094	.04
Alpha	Electrode	2102	2.24	.112	.04
	Valence	2102	4.29	.058	.08
	Group	1,51	.00	.954	.00
	Electrode*Group	2102	.39	.677	.01
	Valence *Group	2102	2.64	.084	.05
	Electrode*Valence	4204	.53	.712	.01
	Electrode*Valence*Group	4204	.75	.557	.02

Appendix 2

Table A2
Correlation between the ERPs in the Emotional Processing Stage and the IBS in the Emotional Communication Stage between Different Groups.

Emotional Processing Stage	Emotional Communication Stage	Condition	Socially Avoidant Group		Non-avoidant Group	
			r	p	r	p
N1 (Fz)	beta IBS	Positive	−0.46	.021	.11	.587
		Negative	.10	.651	−0.01	.950
		Neutral	−0.03	.896	.17	.400
N1 (Cz)	beta IBS	Positive	−0.47	.019	.12	.533
		Negative	.14	.493	.08	.673
		Neutral	−0.06	.777	.14	.465
N2 (Cz)	beta IBS	Positive	.20	.342	.05	.800
		Negative	.07	.731	.41	.030
		Neutral	.06	.781	−0.04	.853
LPP_{300} (Pz)	gamma IBS	Positive	−0.42	.038	.20	.316
		Negative	−0.27	.198	.36	.063
		Neutral	−0.06	.776	.22	.253
LPP_{600} (Pz)	gamma IBS	Positive	−0.25	.235	.41	.032
		Negative	.18	.381	.17	.394
		Neutral	−0.36	.073	.29	.132
LPP_{600} (Pz)	theta IBS	Positive	.04	.855	.46	.014
		Negative	.11	.598	−0.12	.542
		Neutral	.06	.776	.37	.054

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