Negative Bias Mechanisms of Emotion Processing and Social Intention Understanding in Socially Anxious Individuals Based on Biological Motion

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Abstract

Individuals with social anxiety may exhibit abnormalities in both emotional processing and social intention understanding, manifested as negative cognitive biases; however, there is currently a lack of research on the common mechanisms underlying emotional and social intention understanding in social anxiety, as well as clinical prediction models. This project intends to comprehensively utilize behavioral experiments, functional magnetic resonance imaging, and computational modeling, based on biological motion paradigms for emotion recognition and social intention inference, combined with facial expression recognition tasks, to systematically investigate the mechanisms of negative cognitive bias in emotional and social intention processing among individuals with social anxiety, construct a predictive model for social anxiety symptoms, examine multidimensional data associations underlying mental disorders, and assess the role of multidimensional data in the objective classification and prediction of clinical symptoms of social anxiety.

Full Text

The Mechanism of Negative Bias in Emotion Processing and Social Intention Understanding in Socially Anxious Individuals: A Biological Motion Approach

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Abstract
Socially anxious individuals exhibit abnormalities in both emotion processing

and social intention understanding, characterized by negative cognitive biases. However, research on the shared mechanisms underlying emotion and social intention processing in social anxiety remains scarce, and clinical predictive models are lacking. This project will integrate behavioral experiments, functional magnetic resonance imaging (fMRI), and computational modeling to systematically investigate the mechanisms of negative cognitive bias in social anxiety. Using biological motion paradigms that tap into both emotion recognition and social intention inference, combined with facial expression recognition tasks, we will examine how negative biases manifest in emotional and social intention processing among socially anxious individuals. We will also construct predictive models for social anxiety symptoms, test multidimensional data associations underlying mental disorders, and evaluate how multidimensional data can contribute to objective classification and clinical prediction of social anxiety.

Keywords: emotion recognition, social anxiety, social intention understanding, biological motion, brain imaging, cognitive computing
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1. Problem Statement

Social anxiety disorder is a prevalent anxiety condition characterized by intense fear and avoidance of social situations and behaviors. It severely impairs patients' quality of life and creates substantial barriers to seeking treatment, forming a vicious cycle [**?**, **?**, **?**]. Social anxiety has become the third most common mental health problem worldwide, with 13% of individuals receiving a clinical diagnosis of social anxiety disorder at some point in their lives, while subclinical social anxiety is nearly universal [**?**, **?**]. Due to the heterogeneity and comorbidity of mental disorders, traditional diagnostic methods based on subjective reports from DSM and ICD criteria suffer from limitations such as misdiagnosis and missed diagnosis. There is an urgent need for research that validates the neurobiological mechanisms underlying clinical symptoms and establishes objective diagnostic and predictive indicators based on behavioral and brain activity patterns. Social anxiety disorder, with its high comorbidity with depression and other anxiety disorders, provides an effective entry point for parsing the comorbidity and heterogeneity of mental illnesses. Moreover, unlike generalized anxiety disorder, panic disorder, or specific phobias, social anxiety features both a clear stressor and a stress process closely linked to cognitive processing of social information, making it ideal for investigating how mental disorders affect daily social interactions [**?**, **?**].

Social cognition refers to the process by which individuals understand and think about others, forming inferences about others' states based on social information (e.g., faces, body postures, language) in the environment [**?**, **?**, **?**]. Specifically, social cognition involves inferring and judging others' mental states, behavioral motivations, and intentions. Emotion processing and intention inference repre-

sent distinct yet closely related dimensions of social cognition. Emotion recognition involves interpreting and judging others' emotional states—determining whether someone is happy or angry, cheering enthusiastically or shouting in rage. Intention inference involves deducing others' social intentions and imminent actions—judging whether someone is waving in greeting or preparing to strike. Thus, emotions and intentions can be distinguished as states at the level of feeling versus behavior, with different manifestations, yet both can convey threat signals in social cognitive processing.

Socially anxious individuals may show abnormalities in both emotion processing and social intention inference, yet existing evidence focuses on single domains and single data dimensions, failing to integrate common mechanisms across both dimensions or establish multimodal clinical prediction models for social anxiety. Therefore, systematically examining the shared cognitive-neural mechanisms of negative bias in emotion recognition and intention inference among socially anxious individuals holds important theoretical significance for advancing our understanding of the pathological mechanisms of social anxiety. Practically, constructing predictive models for social anxiety symptoms based on behavioral and neuroimaging data, testing associations among multidimensional data underlying mental disorders, and evaluating the role of multidimensional data in objective classification and prediction of social anxiety symptoms will be crucial for establishing objective diagnostic and predictive criteria.

2.1 Cognitive-Neural Mechanisms of Social Anxiety

The cognitive and emotional processing mechanisms underlying social anxiety disorder remain unclear, though multiple abnormal factors may be involved. As shown in Figure 1 [Figure 1: see original paper], negative cognitive bias toward social information represents a key manifestation of these mechanisms—socially anxious individuals tend to generate negative emotional perceptions and interpretive biases when processing social information, leading to excessive fear responses [**?**, **?**, **?**, **?**]. For example, a socially anxious person might interpret an acquaintance' s inadvertent frown as a sign of disapproval. Numerous studies have documented negative cognitive biases toward facial expressions in social anxiety [**?**, **?**, **?**, **?**, **?**].

Neuroimaging studies have validated these negative biases in social anxiety. During emotion processing tasks, social anxiety is associated with abnormal activity in threat-fear circuits, primarily involving the amygdala, insula, parahippocampal gyrus, and medial prefrontal cortex [**?**, **?**, **?**, **?**, **?**]. For instance, a meta-analysis by Etkin and Wager (2007) concluded that social anxiety involves abnormal activity in threat-fear circuits, characterized by significant hyperactivation of bilateral amygdala and insula during negative emotional responses. The amygdala is widely recognized for its role in emotional processing and arousal under fear conditions, while the insula—intrinsically connected to the amygdala [**?**, **?**]—participates in both emotional processing and interoceptive awareness [**?**, **?**]. Additionally, hyperactivation in regions responsible for emotional reg-

ulation and contextual processing, such as the medial prefrontal cortex and parahippocampal gyrus, is significantly associated with social anxiety [?, ?, ?].

Furthermore, evidence from both task-based and resting-state functional connectivity studies indicates that social anxiety involves abnormal activity in brain regions processing social information. Gentili et al. (2009, 2016) found that during face recognition tasks, socially anxious individuals showed stronger activation in default mode network regions including the precuneus, posterior cingulate cortex, and superior temporal sulcus—key areas of the theory-of-mind system responsible for self-state awareness, other-state inference, and social meaning processing. In social scenario tasks, socially anxious individuals also exhibited abnormal activation in default mode network regions like the precuneus and posterior cingulate cortex [?, ?]. Resting-state functional connectivity studies have similarly revealed reduced connectivity between the left precuneus and medial prefrontal cortex, and between the right precuneus and inferior temporal gyrus in social anxiety patients compared to controls [?, ?]. As illustrated in Figure 2 [Figure 2: see original paper], socially anxious individuals show not only task-specific activation in fear and emotion networks but also distinct brain activity in theory-of-mind and social cognition regions compared to healthy controls [?, ?].

However, no studies have effectively integrated the common mechanisms across emotional and social-cognitive brain networks in social anxiety—specifically, how emotion processing and social intention understanding interact. We propose a theoretical hypothesis that negative cognitive bias in social anxiety may be implemented through dual pathways: a ventral emotional pathway from visual cortex to limbic system generating negative emotion processing, and a dorsal social intention pathway from visual cortex to theory-of-mind and motor networks generating negative intention inference, with both pathways converging in the prefrontal cortex to produce a negative cognitive bias toward social information.

2.2 Social Anxiety and Biological Motion

Biological motion paradigms offer a promising approach to investigate shared mechanisms underlying emotion processing and social intention understanding in social anxiety. While facial expressions convey important emotional information in daily social communication, human biological motion contains not only rich emotional information but also crucial social intention signals. A classic method presents body movements as point-light displays [?, ?]. Humans can rapidly extract diverse social information—such as identity, emotion, gender, and causality—from point-light biological motion stimuli without any learning [?, ?, ?, ?, ?, ?, ?, ?, ?, ?, ?, ?, ?, ?]. Previous research has linked atypical biological motion processing to various mental disorders, including autism [?, ?] and schizophrenia [?, ?]. Indirect evidence suggests that socially anxious individuals show a stronger facing-the-viewer bias—interpreting ambiguous biological motion stimuli more often as approaching rather than receding [?, ?, ?]. Since "approaching" carries greater potential threat than "receding" [?, ?], enhanced

facing-the-viewer bias may indicate heightened sensitivity to threat information in social anxiety. However, no direct evidence has examined whether socially anxious individuals exhibit negative cognitive biases in emotion processing and social intention understanding when observing biological motion, or whether such biases can predict more severe social anxiety symptoms.

Moreover, the neural mechanisms of biological motion processing involve multiple networks related to social intention understanding and emotion processing, providing a solid foundation for investigating shared neural mechanisms in social anxiety. Numerous studies have found that the temporoparietal junction (TPJ), particularly the posterior superior temporal sulcus (pSTS), participates in biological motion processing and shows consistent activation during biological motion recognition tasks [**?**, **?**, **?**]. Van Overwalle and Baetens (2009) further expanded this framework, proposing that biological motion understanding involves both a mirror system (comprising pSTS, anterior intraparietal sulcus, and premotor cortex) that matches others' movements to self-movements to facilitate intention understanding, and a theory-of-mind system (comprising precuneus, temporoparietal junction, and medial prefrontal cortex) that identifies and infers others' intentions. Additionally, emotion-related regions such as the amygdala participate in visual analysis of human movement [**?**, **?**]. However, current biological motion research has focused primarily on healthy individuals and brain-damaged patients, with limited evidence regarding abnormal brain activity during biological motion processing in social anxiety.

2.3 Cross-Modal Data Association in Mental Disorders

Traditional psychiatric diagnosis relies on criteria from the Diagnostic and Statistical Manual of Mental Disorders (DSM) or International Classification of Diseases (ICD), classifying disorders based on symptom presence, number, and duration. Due to comorbidity and heterogeneity issues, these traditional methods suffer from misdiagnosis, missed diagnosis, and labeling problems. The field urgently needs research validating neurobiological mechanisms underlying clinical symptoms and establishing objective behavioral and neuroimaging indicators for diagnosis and prediction. However, previous studies have found weak associations between different measurement methods (e.g., behavioral experiments and questionnaire measures) and experimental paradigms [**?**, **?**, **?**]. Large-scale behavioral and neuroimaging studies have similarly failed to demonstrate strong cross-modal correlations across different tasks, even when all modalities target depression and anxiety disorders [**?**, **?**, **?**, **?**]. This does not mean we cannot identify neurobiological markers for mental disorders. A longitudinal study using targeted neuroimaging tasks successfully identified predictive associations between clinical symptom dimensions and brain activity in depression and anxiety disorders [**?**, **?**, **?**, **?**]. Therefore, to parse cross-modal data associations in mental disorders, we urgently need targeted experimental paradigms that explore neurobiological mechanisms from multiple dimensions. Social anxiety spans theoretical dimensions of both emotion and social intention, while bio-

logical motion paradigms can conveniently measure both processes, providing an excellent perspective for empirically testing cross-modal data associations underlying mental disorders.

3. Brief Review

In summary, previous research on social anxiety has identified tendencies in emotion processing and social intention processing, but several limitations remain:

(1) Most previous paradigms have focused on facial expression processing while neglecting equally important body movements and postures. As Darwin (1872) noted in his classic work: "Movement expresses others' intentions and emotions far better than pictures." Biological motion contains rich emotional and social intention information and constitutes an important component of social interaction. For socially anxious individuals, biological motion may hold special significance. Due to fear and avoidance of social situations, they may avoid eye contact or direct face viewing, instead focusing attention on non-facial regions. Additionally, while many studies have reported amygdala effects, these effects in face recognition paradigms may stem from face processing itself rather than social anxiety-specific emotion processing or social cognition mechanisms. Furthermore, previous paradigms for constructing social scenarios have primarily relied on imagined public speaking tasks. Although this approach can tap into social anxiety, it depends on participants' imagination and cannot be extended to more realistic interactive processes. Adopting biological motion paradigms facilitates development of richer interactive scenarios and future extension to complex virtual reality interactions. Therefore, the field urgently needs paradigms based on biological motion and multi-person social interaction to deepen understanding of the cognitive-neural mechanisms of social anxiety.

(2) Previous research has typically been limited to emotion processing, lacking exploration of shared mechanisms between emotion processing and social cognition in social anxiety. The complex and diverse neural mechanisms underlying emotion processing require further investigation, and Pessoa (2019) calls for researchers to examine interactions between emotion and cognition rather than studying single domains in isolation. While emotion processing represents an important factor in understanding social anxiety mechanisms, social intention also significantly influences our interpretation of social scenes and directly affects physiological and behavioral responses. Moreover, evidence demonstrates close associations between emotion processing and movement processing [**?**, **?**]. Previous paradigms for studying social anxiety (e.g., face recognition, imagined social scenarios) cannot effectively integrate common mechanisms across emotion and social cognition processing. Biological motion paradigms can effectively fill this gap.

(3) Most studies have focused on single data dimensions, lacking integration of multimodal data. Some research has concentrated on behavioral cognitive mechanisms [**?**, **?**, **?**], while others have focused on neuroimaging foundations [**?**, **?**, **?**, **?**]. Previous research has lacked integration of multimodal data, preventing examination of associations among behavior, brain activity, and clinical symptoms, and hindering construction of predictive models for psychiatric classification and diagnosis based on multimodal data. This study will parallelly investigate behavioral and neuroimaging mechanisms, explore correlations across multimodal data, and use multimodal data to classify subtypes of social anxiety disorder and enable clinical prediction.

(4) Previous research has typically focused on single psychiatric categories, with relatively few studies across diagnostic categories. Depression, anxiety, and other mental disorders exhibit severe comorbidity, while emotion processing and social intention understanding also share many commonalities (e.g., how emotion processing influences social intention perception). These shared features have been confirmed by neuroimaging research [**?**, **?**]. This study will examine associations between social anxiety and depression/anxiety disorders while parsing the cognitive and emotional processing mechanisms of social anxiety.

Addressing these challenges and critical research needs, this project will integrate behavioral experiments, questionnaire measures, neuroimaging techniques, cognitive computation, and machine learning. Based on classic biological motion paradigms, we will construct emotion recognition and social intention inference tasks to systematically parse the cognitive-neural mechanisms of negative cognitive bias in emotion processing and social cognition among socially anxious individuals, and analyze associations among multimodal data and clinical symptoms. This research is expected to lead future efforts in objective classification and prediction of mental disorders based on multimodal signals from behavior and neuroimaging.

4. Research Framework

The core content of this project concerns the cognitive-neural mechanisms of emotion processing and social intention understanding in socially anxious individuals. We will adopt classic biological motion paradigms to explore negative cognitive biases in both emotion recognition and social intention inference tasks among clinical and subclinical populations with social anxiety. By combining behavioral experiments, functional magnetic resonance imaging (fMRI), computational modeling, and machine learning, we will progressively reveal the cognitive-behavioral and brain mechanisms of social anxiety, as well as how multimodal data can classify subtypes and predict clinical outcomes.

Study 1 will systematically test emotion recognition characteristics in social anxiety using classic single-person and two-person biological motion paradigms

combined with facial expressions. Study 2 will investigate the cognitive-neural mechanisms of social intention inference in social anxiety based on two-person biological motion paradigms and facial emotion recognition. Study 3 will combine behavioral and neuroimaging data from Studies 1 and 2 to explore common mechanisms of emotion recognition and social intention inference in social anxiety, test whether multimodal data show robust associations, whether they reflect different subtypes of social anxiety, and construct clinical prediction models. Through these studies, we aim to promote objective classification and diagnosis based on neurobiological signals in China' s mental health field. The overall research framework is shown in Figure 3 [Figure 3: see original paper].

4.1 Study 1: Emotion Recognition from Biological Motion and Facial Expressions in Social Anxiety

Study 1 will investigate the cognitive and brain mechanisms of emotion recognition from biological motion and facial expressions in social anxiety. The behavioral paradigm uses motion capture to construct point-light displays of single-person and two-person biological motion stimuli. We will select motion stimuli expressing different emotions from multiple motion capture databases, such as happy, sad, and angry walking movements, and two-person social interactions expressing emotions like "A expressing happiness/anger to B." This study will simultaneously employ classic facial expression recognition paradigms. By examining accuracy and reaction times for different emotions across social anxiety levels in both biological motion and face emotion recognition tasks, we will obtain sensitivity curves for various emotions as a function of social anxiety severity. Additionally, as shown in Figure 4 [Figure 4: see original paper], we will use drift-diffusion modeling to further parse the relationship between underlying cognitive processes and social anxiety. Finally, fMRI will be used to reveal the brain mechanisms underlying these behaviors, and we will build predictive models for social anxiety levels based on multimodal behavioral and neuroimaging data combined with machine learning.

The experiment will recruit participants with high and low scores on the social anxiety continuum, while collecting relevant anxiety and depression measures for comorbidity analysis. The hypothesis is that, compared to low social anxiety individuals, those with high social anxiety will show stronger negative emotion cognitive biases and exhibit distinct brain activity and network connectivity in emotion-processing regions.

4.2 Study 2: Social Intention Inference from Biological Motion and Facial Expressions in Social Anxiety

Building on Study 1, Study 2 will systematically examine the cognitive-neural mechanisms underlying social intention inference in social anxiety using behavioral and neuroimaging experiments with similar analytical approaches. The experimental paradigm will be based on two-person biological motion stimuli

for social intention inference tasks. The hypothesis is that, compared to low social anxiety individuals, those with high social anxiety will show stronger negative biases toward social intentions and exhibit distinct brain activity and network connectivity in theory-of-mind regions.

4.3 Study 3: Cross-Task Multidimensional Data Correlation in Social Anxiety

Studies 1 and 2 investigate the cognitive and neural mechanisms of social anxiety disorder from the perspectives of emotion perception and social intention inference, respectively. Study 3 will combine behavioral and neuroimaging data from both studies to examine cross-task consistency across multiple dimensions and establish predictive models for clinical symptoms of social anxiety.

Study 3 will compile cognitive-behavioral data, neuroimaging data, and self-report questionnaire data from Studies 1 and 2 focusing on emotion processing and social intention inference. Based on these multidimensional data, we will conduct three types of analyses: latent factor modeling [**?**, **?**, **?**, **?**], machine learning clustering algorithms, and support vector regression to examine data consistency across tasks, conduct cluster analysis, and build clinical prediction models.

Additionally, we will explore common mechanisms across different psychiatric diagnostic categories based on participants' self-reported depression, anxiety, and social anxiety traits.

Figure 4 illustrates the integration of facial expression and biological motion paradigms to collect multidimensional data for building drift-diffusion models, parsing common mechanisms of emotion and social processing underlying social anxiety, and constructing predictive models. ACC: accuracy; RT: reaction time.

5. Theoretical Construction and Innovation

Socially anxious individuals show abnormalities in both emotion processing and social intention inference, providing an excellent perspective for validating associations among multidimensional data underlying mental disorders. However, existing evidence cannot effectively integrate the shared mechanisms of emotion processing and social intention understanding in social anxiety, nor has it established clinical prediction models based on multimodal data. Therefore, this study will adopt classic biological motion paradigms, integrating behavioral experiments, fMRI, clinical questionnaires, computational modeling, and machine learning to systematically examine the shared cognitive-neural mechanisms of negative bias in emotion recognition and social intention inference, and construct multimodal predictive models for social anxiety.

(1) **Constructing a theoretical model of cognitive bias mechanisms in social anxiety**
This study will employ classic biological motion paradigms to construct

emotion recognition and social intention inference tasks, extending beyond facial expression recognition paradigms. While previous research on cognitive bias in social anxiety has focused on facial expression recognition tasks [**?**, **?**], socially anxious individuals often avoid direct eye contact or face viewing in social situations, instead focusing on non-facial regions. Biological motion contains rich emotional and social intention information and represents a primary source for socially anxious individuals to judge others' emotions and intentions. Combining both paradigms will facilitate investigation of cognitive bias processes in emotion recognition and social intention inference. Furthermore, computational modeling can quantify cognitive biases in emotion and social intention processing, contributing to objective diagnostic indicators.

(2) **Exploring shared mechanisms of emotion recognition and social intention understanding through social anxiety**
Cognitive biases in social anxiety are multifaceted and complex. Taking emotion recognition and social intention as examples, although previous research has extensively studied each domain separately, integrating findings is not simply additive. Pessoa (2019) calls for researchers to examine emotion-cognition interactions and embrace complexity. However, current evidence cannot effectively integrate common mechanisms across emotion processing and social cognition. Leveraging the characteristic that neural mechanisms of biological motion processing involve both emotion and social cognition networks, this study will explore shared mechanisms of emotion recognition and social intention from an integrated perspective, establishing an exploratory framework for common neural mechanisms across multiple cognitive functions. By combining biological motion paradigms with classic facial expression recognition and social intention inference tasks, we will compare processing mechanisms across tasks to establish generalizability of findings.

(3) **Constructing multimodal data for emotion recognition and social cognition in social anxiety**
This study will integrate behavioral experiments, fMRI, clinical questionnaires, computational modeling, and machine learning to systematically examine shared cognitive-neural mechanisms of negative bias and build multimodal predictive models for social anxiety. This research will promote empirical testing of associations among multimodal data underlying mental disorders and advance classification and diagnosis based on neurobiological indicators in China. It is expected to lead future efforts in objective classification and prediction of mental disorders based on multimodal signals from behavior and neuroimaging, contributing to the "Healthy China 2030" initiative' s goal of "significantly improving the prevention and treatment of common mental disorders and the identification and intervention of psychological and behavioral problems by 2030."

References (included in original text)

Note: Figure translations are in progress. See original paper for figures.