I Like Them...Will They Like Me? Evidence for the Role of the Ventrolateral Prefrontal Cortex During Mismatched Social Appraisals in Anxious Youth

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Abstract

Objective: Socially anxious adolescents report distress during social decision-making, wherein their favorable view of peers directly conflicts with their expectation to be viewed negatively by peers; a phenomenon we refer to as “mismatch bias.” The present study utilizes a novel paradigm with dynamic social stimuli to explore the correlates of mismatch biases in anxious and healthy youth.

Method: The behavioral and neural correlates of mismatch biases were assessed in healthy ($N=17$) and anxious ($N=14$) youth during functional MRI. Participants completed a novel task where they viewed silent videos of unknown peers. After viewing each video, participants appraised the social desirability of the peer (“How much do you think you would like them [if you met them]”) or predicted how socially desirable the peer would find them (“How much do you think they would like you [if you met them]”). Each participant’s mismatch bias was calculated as the difference between their appraisal of peers and their prediction of peers’ appraisal of them.

Results: We found that anxious youth exhibited mismatch bias: they rated unknown peers as more desirable than they predicted peers would rate them. This effect was not present in the healthy group. Mismatch biases were associated with increased engagement of the ventrolateral prefrontal cortex (vlPFC), a region broadly involved in flexible cognitions and behavioral selection. In addition, greater mismatch biases and vlPFC activation during mismatch biases were associated with more severe anxiety symptoms.

Conclusions: The findings highlight the importance of understanding mismatch biases to inform treatments that target distress elicited by discrepant social appraisals in anxious youth.

Keywords: adolescence, fMRI, social anxiety, social cognition

Introduction

ADOLESCENCE INVOLVES NUMEROUS physical, social, and psychological changes. During this period, the relative importance of peers is at its highest (Larson and Richards 1991). Rapidly changing social dynamics paired with the reorganization of neural structures may help explain age-related increases in anxiety, including social anxiety disorder (SAD) (Wittchen and Fehm 2003; Beesdo et al. 2010; Knappe et al. 2011; Caouette and Guyer 2014). SAD involves extreme fear of negative evaluation (FNE) and avoidance of social situations (American Psychiatric Association

2013). Patients with SAD and individuals with high trait anxiety have biased interpretations of social signals and make more negative predictions about forthcoming social encounters (Miranda and Menon 2007; Heimberg et al. 2010; Cabeleira et al. 2014). Although most anxious youth have normative desires for peer-based interactions, negative prediction biases and extreme FNE conflict with the motivation for social engagement. This motivational conflict may be a source of distress in anxious youth (for a recent conceptual model, see Caouette and Guyer 2014).

Motivational conflicts have been discussed in the context of risky decision-making (for review, see Aupperle and Paulus 2010)

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and adolescent vulnerability to SAD (Caouette and Guyer 2014). Nevertheless, few social-processing paradigms test anxiety in the context of motivational conflicts. The current study quantifies a form of motivational conflict we call mismatch bias. Mismatch bias occurs when one's appraisal of the *desirability of a peer* is inconsistent with one's *prediction of how desirable a peer views them*. Ideally, motivational appraisals regarding desirability of a peer match predictions of reciprocal interest from the peer. However, with mismatch bias the adolescent expects a desirable peer to view the adolescent as relatively undesirable. Motivational conflicts related to such appraisals, emphasized in theory from Caouette and Guyer (2014), raise an expectation of enhanced mismatch bias and distress in SAD relative to healthy adolescents during social appraisal. Extending this theory, an emphasis on mismatch bias aligns with theories of adolescent SAD regarding conflicts between a heightening of social salience and anxiety about potential negative outcomes. The present study focuses on mismatch between a participant's assessment of a peer's desirability and predictions about a peer's assessment of the participant's desirability to test hypotheses linking these two appraisals to brain function in pediatric anxiety.

Previous studies have demonstrated negatively biased social predictions in anxious youth (Miles et al. 2004; e.g., Guyer et al. 2008; Haller et al. 2016). By considering mismatch between two appraisals, the current study attempts to more closely mimic complex features of social decision-making where individuals simultaneously weigh potential positive and negative aspects of peers. Importantly, discrepancies between these two appraisals, rather than a singular focus on predicted negative outcomes, may generate distress in the anxious adolescent. In the present study we directly assess and contrast these two appraisals to map their relations with anxiety symptom severity.

The current study generates a measure of mismatch bias in the context of a brain imaging study to map the neural circuits involved in mismatch bias. Prior studies have mapped differences between healthy and anxious youth as they estimate a peer's appraisal of their desirability. Much of the functional magnetic resonance imaging (fMRI) literature on peer relations in anxious youth has focused on biased predictions regarding peers' desire to interact or consequences of feedback (Lau et al. 2012; e.g., Jarcho et al. 2015). The current study assesses brain functions engaged when youth predict peers' desire for interaction. However, we specifically extend this work by also assessing functions engaged when youth appraise the desirability of the same peers.

Considerable work finds that socially anxious youth report more negative predictions about social interactions than their healthy peers (e.g., Guyer et al. 2008; Haller et al. 2016), one component of mismatch bias. In particular, more negative predictions are associated with more severe anxiety symptoms (Caouette et al. 2014; Haller et al. 2016), lower self-esteem (Guyer et al. 2008; Somerville et al. 2010), and self-reported avoidance (Miers et al. 2014). One study contrasted brain response in anxious and healthy youth as they anticipated how interested unknown peers would be in interacting with them (Guyer et al. 2008). The study found greater amygdala-ventrolateral prefrontal cortex (vlPFC) connectivity in anxious relative to healthy participants while anticipating feedback from unknown peers. Moreover, the extent of coactivation between regions was positively correlated with social anxiety severity. However, this past study did not relate activation to levels of predicted peer interest nor did it assess brain function engaged when youth appraised the desirability of these peers. Thus, prior data suggest that anxiety influences brain function during anticipation of

social outcomes; neural mechanisms implicated during the decision-making process in which different appraisals are integrated (i.e., mismatch biases) are yet to be tested.

In the current study, the behavioral and neural correlates of mismatch biases were assessed in anxious and healthy youth during fMRI. Participants completed a novel task where they viewed short videos of unknown peers. After viewing each video, participants appraised the social desirability of the peer (i.e., rated how much they think they will like that peer) or predicted how socially desirable the peer would find the participant (i.e., rated how much they think that peer will like them). Mismatch biases were defined as the difference between these ratings. We expected anxious participants to exhibit greater mismatch bias than healthy participants. More specifically, we posited that anxious, but not healthy, participants would expect peers to rate them as less socially desirable than they, in turn, rated peers. Importantly, we hypothesized that the magnitude of the mismatch bias would positively correlate with anxiety-symptom severity. Finally, we predicted that mismatch biases in the anxious youth would be associated with greater activation in brain regions previously implicated in affect and decision making (e.g., vlPFC, amygdala, and striatum).

Methods

Participants

Thirty-five youth (19 females) ages 8–17 participated in the current study. Of the participants who completed the task, 4 (1 female, 2 anxious) were excluded due to excessive head motion during the scanning session (> 20% censoring rate). Of the 31 remaining participants, 14 (6 females) met DSM-5 criteria for at least one anxiety disorder (anxiety group, see Table 1 for diagnoses) as assessed by a clinician in a semistructured clinical interview (KSADS, Kaufman et al. 1997), and 17 (12 females) were free of psychiatric illness (control group). Compared with healthy youth, anxious youth had more severe anxiety symptoms (averaged self- and parent-report) as assessed by the total score on the Screen for Child Anxiety Related Disorders (SCARED) ($t(28)=7.07$, $p<0.001$) and the Social Anxiety subscale ($t(28)=4.43$, $p<0.001$) (Table 2). The anxiety group also reported higher FNE (Watson and Friend 1969), ($t(24)=3.48$, $p<.005$)*, a hallmark characteristic of SAD. The two groups did not differ in age ($t(29)=-0.15$, $p=0.88$), gender ($\chi^2(1)=2.43$, $p=0.16$), or intelligence quotient (IQ) ($t(29)=0.34$, $p=0.74$). For means and standard deviations see Table 2.

Procedure

All procedures were approved by the National Institute of Mental Health Institutional Review Board. Parents and participants provided written consent/assent. All participants were paid for their participation. Anxious participants also received treatment following the completion of the study. Before undergoing fMRI, we explained to participants that a great deal of information is conveyed in facial expressions and that we were interested in how individuals make judgments about other people based on short silent video clips. Participants then underwent fMRI while viewing a series of 5-second silent videos ($N=40$) of unfamiliar adolescents. This was composed of one set of videos where adolescents discussed their anxiety ($N=20$ videos) and a different set of videos where another group of unfamiliar adolescents discussed a

*Five participants (three anxious, two healthy) were missing Fear of Negative Evaluation scores.

TABLE 1. ANXIETY DIAGNOSES

Diagnosis	N
Social anxiety disorder	2
+ Generalized anxiety disorder	7
+ Specific phobia	4
+ Panic disorder	1
+ Selective mutism	1
Generalized anxiety disorder	2
+ Specific phobia	2

+ specifies comorbid anxiety diagnoses.

nonanxiety-related topic ($N=20$ videos). Participants were not explicitly told that the adolescents in the video would be discussing their anxiety or a nonanxiety-related topic. Instead they were simply told that adolescents in the videos would be discussing a variety of topics. We used silent videos for several reasons. Given the short duration of clips (5 seconds), the content of the few words that were spoken did not necessarily contain meaningful information or complete sentences/thoughts. In addition, including language in the clips would have required balancing their content across all videos. Most importantly, the absence of linguistic content is consistent with most fMRI-based studies of peer evaluation (e.g., Guyer et al. 2008; Lau et al. 2012; Jarcho et al. 2015).

Immediately following each video, participants had 3 seconds to answer a question (described below) using a 7-point Likert scale from 0 (Not Very Much) to 6 (Very Much), see Figure 1. Two of the runs probed participant ability to detect naturalistic expressions of anxiety;[†] the two other runs probed mismatch bias. Since the focus of the present article is on mismatch biases we will only discuss those runs in this article. The order of runs was counterbalanced across participants.

Behaviorally, the mismatch bias was quantified by measuring the discrepancy between participant responses to two questions. One question asked participants to appraise the social desirability of the peer ("How much do you think you would like them [if you met them]?"), while the other question required the participant to predict how socially desirable the peer would find them ("How much do you think they would like you [if you met them]?"). Each participant's mismatch bias was calculated as the difference between their appraisal of peers ("I like them") and their prediction of peers' interest in them ("They like me"). Participants viewed all 40 silent videos during each of the two 9-minute runs. Each run was composed of 4 total blocks (10 videos each), including 2 blocks of each appraisal question (2 blocks of 2 questions for 4 total blocks each with 10 videos). The start of every block included the appraisal question the participant was to answer for each of the 10 subsequent videos. This allowed participants to appropriately evaluate each peer while watching their video. Participants rated each video twice: during one run ratings were based on their appraisal of their peer; and during the other run ratings were based on their prediction of each peers' appraisal of the participant. The order of videos within each block was randomly determined, while block order was counterbalanced across participants.

[†]Another research question we hoped to address using these stimuli was whether verbal expressions of anxiety generated detectable facial displays. However, participants were not able to discriminate between video type. Since this was a systematic feature of the stimuli presented we wanted to document it and maintain the variable in our analyses.

TABLE 2. DEMOGRAPHICS

Variable	Healthy youth (n = 17)		Anxious youth (n = 14)		t-statistic
	M	SD	M	SD	
Age (years)	13.35	2.94	13.18	3.32	-0.15
Intelligence (WASI)	113.76	10.88	115.14	11.54	0.11
SCARED-social anxiety ^{a,b}	2.56	3.11	7.93	3.29	4.43**
SCARED-total ^{a,b}	8.04	6.87	31.98	11.14	7.07**
Fear of negative evaluation ^c	8.29	5.63	17.58	7.96	3.48*

** $p < 0.001$.

* $p < 0.005$.

^aCurrent anxiety symptoms were assessed by the Screen for Child Anxiety Related Disorders questionnaire (Muris et al. 1998) and were averaged from the child and parent reports.

^bSCARED data from one healthy subject were missing.

^cFear of Negative Evaluation data was missing from five subjects (three anxious youth and two healthy youth).

Behavioral data analysis plan

To compare mismatch bias between groups we ran a repeated-measures ANOVA where group (anxious, healthy) was the between-subject variable and question ("I like them," "They like me") was the within-subject variable. To examine potential relations between the mismatch bias and the severity of anxiety symptoms across the entire sample, we ran Pearson correlation analyses between mismatch bias scores ("I like them" - "They like me") and SCARED total and social anxiety scores (Muris et al., 1998). We also included a secondary analysis comparing mismatch bias scores with self-reported FNE, a hallmark characteristic of SAD (FNE Scale; Watson and Friend 1969). This analysis served as an additional measurement of social anxiety to validate any potential findings.

For completeness we ran a second set of analyses (independent samples t -tests) to examine group differences in rating of each question separately, as opposed to contrasted with each other in the mismatch bias. We also included Pearson correlation analyses with the individual question rating and anxiety symptoms (SCARED and FNE scores) to compliment the mismatch bias analyses.

Imaging

Neuroimaging was completed on a 3T GE Scanner using an 8-channel head coil. Each functional imaging run consisted of 230 whole-brain (39, 2.6-mm axial slices) T*2-weighted echoplanar images (TR = 2300 ms, TE = 30, flip = 70°, 24 FOV, 96 × 96 matrix). A structural magnetization-prepared rapid acquisition gradient echo (MPRAGE) sequence was acquired for coregistration. A structural scan was collected in the axial direction (TR/TI/TE = 7.7 ms/725, min full, 1-mm slices, 6° flip angle, 256 × 256 matrix, 22.0 cm field of view). A short distortion correction scan (Holland et al. 2010) was obtained to correct for echoplanar uniformity distortions.

Imaging analyses

All imaging analyses were conducted using AFNI v.17.3.09 (Cox 1996). Standard preprocessing procedures were used (afni.proc.py), including: despiking, slice time correction, distortion correction, coregistration, spatial smoothing with a 6-mm full-width half maximum smoothing kernel, and warping to standardized Talairach space. TRs with greater than 1 mm of movement were censored. All participants included in analyses had more than 80% of TRs in each

FIG. 1. Social Appraisal Task. Participants view a series of silent videos (5 seconds) of unknown youth discussing either their anxiety or a nonanxiety-related topic. After each video participants then make one of two social appraisals (3 seconds) regarding the person in the video. This decision is then followed by a jittered interval (0–8 seconds) before the beginning of the next trial. Participants complete 2, 9-minute runs of the social appraisal task. Photo used with permission.

run following censoring. Overall, censoring rates among the included participants were low ($M=4.9\%$, $SD=4.8\%$), but the anxious group ($M=6.6\%$, $SD=5.1\%$) had marginally more censoring than the healthy group ($M=3.5\%$, $SD=4.1\%$), ($t(29)=1.87$, $p=0.07$). At the individual subject level, we applied a general linear model (GLM) with two regressors of interest reflecting the specific question block ("I like them," "They like me") time-locked to each video onset and convolved with a 5-second duration. Regressors of noninterest included video topic (anxiety, nonanxiety related), the instruction page, response period (i.e., button press), and motion parameters.

Whole-brain group level analyses utilized a mixed-effects model (AFNI's 3dMVM) where question block ("I like them" versus baseline and "They like me" versus baseline) was entered as the within-subjects variable and diagnosis group (anxious, healthy) was the between-subjects variable. Again, video type was entered as a within-subjects regressor of noninterest. Given the wide age range of participants, age was included as a covariate. Group differences in the mismatch bias were assessed with a diagnosis group $\times$ question interaction. Given the novelty of this paradigm we also used this model to examine brain regions engaged by the main effects of task-dependent effects (i.e., overall activation elicited by the task and question type). Youth with and without anxiety diagnoses exhibit a range of anxiety symptoms. Thus, to explore potential effects of anxiety severity on brain function, rather than group differences based on DSM diagnoses, we ran a second, identical group analysis that replaced diagnosis group with SCARED total scores as a continuous variable (collapsed across groups).

All output maps were masked to only include gray matter and voxels where at least 90% of the participants had signal. Significance for all output maps was determined based on 10,000 Monte Carlo simulations in AFNI's 3dClustSim program. The spatial autocorrelation function (two-sided thresholding) was utilized to give an accurate estimate of spatial smoothing across the brain (Cox et al. 2017). Using the autocorrelation option in AFNI FWHM of the current dataset was estimated at $a=0.43$, $b=5.56$, and $c=13.20$. With a voxel-wise probability threshold of $p<0.005$ and family-wise error rate of $p=0.05$ simulations resulted in a cluster contiguity threshold of 126 voxels.

Results

Task behavior

A repeated-measures ANOVA confirmed group differences in mismatch bias, $F(1, 29)=7.84$, $p=0.009$, $\eta_p^2=0.21$. As expected,

anxious youth appraised *the social desirability of peers* as higher than their predictions of *peers' rating of their own social desirability* ($t(13)=2.26$, $p=0.04$, $d=1.25$), while healthy youth demonstrated a trend in the opposite direction ($t(16)=-1.72$, $p=0.10$, $d=0.86$; See Fig. 2a). A second set of analyses considered the appraisals separately, as opposed to contrasted with each other in the mismatch bias. This second set revealed no group differences in ratings of *the social desirability of peers* ($t(29)=0.54$, $p=0.59$, $d=0.20$) or predictions of *peers' rating of their own social desirability* ($t(29)=-0.75$, $p=0.46$, $d=0.27$, see Fig. 2b). In addition, across all participants a larger mismatch bias was related to higher total SCARED scores ($r=0.50$, $p=0.005$; See Fig. 3a) with a trend toward higher SCARED social anxiety scores ($r=0.35$, $p=0.059$; See Fig. 3b). To corroborate these findings, additional analyses examined ratings on the FNE scale. This revealed that participants with higher FNE also showed a larger mismatch bias ($r=0.59$, $p=0.001$, Supplementary Fig. S1a; Supplementary Data are available online at www.liebertpub.com/cap).

A third set of analyses considered associations between each appraisal rating and anxiety severity (scores on the SCARED and FNE). In this study, more negative predictions regarding how peers would rate the participant's social desirability ("They like me") were associated with higher SCARED social anxiety scores ($r=-0.44$, $p=0.019$) and FNE scores ($r=-0.45$, $p=0.022$) but not SCARED total ($r=-0.24$, $p=0.21$). There were no significant relations between appraisals of the desirability of peers ("I like them") and self-reported anxiety (SCARED total: $r=0.01$, $p=0.98$; SCARED social anxiety: $r=-0.29$, $p=0.11$) or FNE ($r=-0.15$, $p=0.47$).

Functional magnetic resonance imaging

An initial analysis examined overall task effects, collapsed across both conditions and diagnostic groups. This revealed robust activations throughout regions known to support social processing. This included ventral temporal-occipital cortex, the posterior superior temporal sulcus, temporal parietal junction, inferior frontal gyrus, posterior cingulate (extending into the mid and anterior cingulate), and superior frontal gyrus when participants were actively assessing social desirability (Table 3). There were no significant main effects of group or question type.

Critically, a significant diagnosis group $\times$ question interaction was found in the left inferior frontal gyrus (MNI: $-42, 37, -14$; $k=219$, $p<0.005$), a region within the vlPFC (Fig. 4a). This finding indicated that BOLD activity was differentially expressed across the two

FIG. 2. Mismatch bias by Group. **(a)** Anxious participants demonstrated a significantly greater mismatch bias (i.e., higher appraisal of interest in peers compared to their prediction of peers' appraisal of them) compared with healthy participants ($p < 0.05$). **(b)** There were no group differences in appraisal ratings of the social desirability of peers ($p > 0.05$) or predictions of peers' ratings of the participant's social desirability ($p > 0.05$). ** $p < 0.01$, * $p < 0.05$, asterisks within bars represent significant differences from zero as determined by a one-sampled t -test.

question contexts as a function of diagnosis group. To decompose the interaction, data were extracted from the functional cluster, and the mismatch bias was plotted. This bias was quantified as the difference in activation while appraising the social desirability of peers ("I like them") relative to predicting the peers' rating of their own social desirability ("They like me"). Once extracted, follow-up tests showed that vIPFC engagement in anxious youth was significantly greater during the "I like them" than the "They like me" (i.e., mismatch bias) question blocks ($t(13) = 4.17$, $p < 0.001$, $d = 2.31$), whereas the opposite pattern emerged in the healthy group such that there was significantly greater activation during the "They like me" than the "I like them" question blocks ($t(16) = -4.23$, $p < 0.001$, $d = 2.12$; $F(1, 28) = 35.60$, $p < 0.001$, $\eta_p^2 = 0.56$; Fig. 4b). *Post hoc* analyses showed that there were significant group differences in vIPFC activation during both "I like them" ($t(29) = 2.90$, $p = 0.007$, $d = 1.07$) and "They like me" question blocks ($t(29) = -3.91$, $p = 0.001$, $d = 1.45$, Fig. 4c). During "I like you" blocks, anxious participants showed greater vIPFC activation than their healthy

counterparts, who showed significant deactivation in this region. The opposite pattern emerged during "They like me" blocks, where anxious participants showed significant deactivation in this region compared with healthy participants.

To explore continuous, rather than categorical, relations between activation in this region and anxiety severity, data extracted from the vIPFC were correlated with symptom severity as measured by the SCARED. Across all participants, vIPFC activation associated with the mismatch bias (i.e., difference in activation during "I like them" - "They like me" appraisals) was more pronounced in individuals with more severe anxiety symptoms in general, $r = 0.56$, $p = 0.001$ (Fig. 5a), and with social anxiety symptoms in particular, $r = 0.53$, $p = 0.003$ (Fig. 5b). Similar to the behavioral findings, additional analyses revealed that participants with higher FNE also showed greater vIPFC activation associated with mismatch bias ($r = 0.41$, $p = 0.04$, See Supplementary Fig. S1b). When the appraisals were examined separately (not as mismatch bias), lower vIPFC activation during predictions about one's social desirability ("They like me")

FIG. 3. The relationship between mismatch bias and SCARED total **(a)** and SCARED social anxiety **(b)**. Across all participants a larger mismatch bias was related to higher self-reported anxiety (total SCARED scores; $r = 0.50$, $p < 0.05$) with a trend toward higher self-reported social anxiety (SCARED social anxiety scores; $r = 0.35$, $p = 0.059$).

TABLE 3. FUNCTIONAL MAGNETIC RESONANCE IMAGING WHOLE-BRAIN RESULTS

Region	K (# voxels)	MNI coordinates			F-statistic	η_p^2
		x	y	z		
Main effect of task						
Declive	20527	33	-66	-13	100.00	
Superior frontal gyrus	173	-28	44	28	20.16	
Main effect of group						
—	—	—	—	—	—	
Main effect of question						
—	—	—	—	—	—	
Group $\times$ Question						
Inferior frontal gyrus/vIPFC	219	-42	37	-14	33.29	0.56

All results are from a whole-brain mixed-effects ANOVA with Group (anxious, healthy) and Question (“I like them,” “They like me”) controlling for video type, age, and motion. Maps were corrected at $p < 0.005$ with a cluster threshold of $k > 126$.

vIPFC, ventrolateral prefrontal cortex.

was related to higher overall anxiety symptoms ($r = -0.49, p = 0.006$) and social anxiety symptoms ($r = -0.40, p = 0.028$) on the SCARED. Predictions about one’s own social desirability were not related to FNE scores ($r = -0.27, p = 0.18$). Relationships between vIPFC activation and anxiety symptoms during appraisals of peers social desirability did not reach significance (SCARED total: $r = 0.34, p = 0.07$; SCARED social anxiety: $r = -0.33, p = 0.07$; FNE: $r = 0.27, p = 0.18$).

These results were further corroborated by the secondary whole-brain analysis that utilized continuous SCARED scores, as opposed to DSM-5 grouping. A SCARED total $\times$ question type interaction emerged in an overlapping region of the left vIPFC ($-44, 37, -14$; $k = 25$, See Supplementary Fig. S2). Although this result did not survive the whole-brain cluster threshold, it supports evidence from our primary analysis. No other main or interaction effects were observed. Neither the amygdala nor striatum emerged in either whole-brain analysis.

Discussion

Using a novel task with dynamic social stimuli, anxious, but not healthy, youth exhibit a behavioral mismatch bias. This bias manifested such that anxious participants’ appraisal of *peers’ social desirability* was higher than their prediction of *the peers’ rating of their own social desirability*. An important aspect of this study is that we used the same set of dynamic social stimuli to assess how participants believed they would be viewed by peers and how much interest the participants expressed in these peers. This enabled us to examine behavioral and neural correlates engaged during the critical decision-making period when mismatch bias likely influences motivation conflicts. Isolating relationships between anxiety and mismatch biases may, therefore, shed light on potential brain-based mechanisms that promote distress in anxious youth.

Anxious participants demonstrate a mismatch bias—they appraised peers as *more* desirable than they predicted peers would

FIG. 4. vIPFC activation from a Group $\times$ Question interaction. (a) Results of a whole-brain group-level analysis indicated a significant group $\times$ question interaction ($p < 0.005$; $k = 219$) in the vIPFC. (b) Follow-up tests revealed significantly greater vIPFC activation during the “I like them” than the “They like me” appraisal blocks in anxious participants, whereas healthy participants showed the opposite effect ($p < 0.001$). (c) Furthermore, during “I like you” blocks, anxious participants showed greater vIPFC activation than healthy participants. The opposite pattern emerged during “They like me” blocks, where anxious participants showed significant deactivation in this region compared with healthy participants. $**p < 0.01$, asterisks within bars represent significant differences from zero as determined by a one-sampled t -test. vIPFC, ventrolateral prefrontal cortex.

FIG. 5. The relationship between mismatch bias in the vLPFC and SCARED total (a) and SCARED social anxiety (b). Across all participants, those with higher vLPFC activation during mismatch bias reported more anxiety symptoms ($r=0.56$, $p<0.005$) and more social anxiety symptoms ($r=0.53$, $p=0.005$).

appraise them. Moreover, healthy participants showed a trend toward the opposite effect. That is, healthy youth appraised peers as *less* desirable than they predicted peers would appraise them. Importantly, no group differences emerged when appraisal ratings were examined separately. However, participants with higher self-reported social anxiety predicted that peers would find them less desirable (i.e., negative prediction bias) than participants with lower social anxiety. As such, categorical analyses in the current study did not replicate group differences in negative prediction biases; nevertheless, continuous analyses revealed the expected relation between negative biases and social anxiety symptoms. Inconsistencies between the current and prior results could be due to many factors. For example, weighing these two appraisals in the same experimental context, as done in the current study, could engage different psychological processes than when weighing one of these appraisals in isolation, as done in prior work. Furthermore, failure to replicate group differences in negative biases (Miles et al. 2004; e.g., Jarcho et al. 2015) highlights the importance of considering individual differences in discrepancies between how an individual appraises peers and predictions of one's own desirability (i.e., mismatch bias), rather than examining these components separately.

Unlike the analyses of prediction bias, mismatch bias effects emerged in analyses that treated anxiety as a categorical variable based on diagnosis, but also when severity of overall anxiety symptoms was considered continuously. Specifically, youth with more severe anxiety symptoms demonstrated a larger mismatch bias than those with fewer anxiety symptoms. Severity of social anxiety was not related to behavioral mismatch bias. However, self-reported FNE, a hallmark characteristic of SAD, was strongly related to mismatch biases. This supports the idea that mismatch biases relate to the distress that promotes or sustains overall anxiety symptoms in youth.

Mismatch biases elicited greater engagement of the vLPFC in anxious, compared with healthy, youth during social appraisals. More specifically, anxious participants more strongly activated the vLPFC when appraising their social desirability for peers compared to when predicting peers' appraisal of them. Healthy participants showed the opposite effect. Across all participants, anxiety severity was correlated with greater vLPFC activation during "I like them" compared to "They like me" decisions (i.e., mismatch bias). Thus,

differential recruitment of the vLPFC during social appraisals may play a role in the conflict anxious youth experience as they estimate their relative social worth.

Behavioral data extend the literature on social biases in anxious youth in two ways. First, we showed that a negative prediction of one's self is paired with a favorable appraisal of others in anxious youth; this has rarely been assessed, particularly when using the same stimuli for both forms of social appraisal. While such a mismatch is often assumed, little to no data in the extant literature quantify this phenomenon, its relation to pediatric anxiety, or its underlying neural mechanisms. We demonstrated a greater mismatch bias in anxious, compared with healthy, youth, which suggests a discrepancy between desirability ascribed to peers and their expectation to receive negative evaluations from those peers. This mismatch may increase social distress in anxious youth and should be addressed in future studies. Second, we showed that magnitude of the mismatch bias was positively related to the severity of anxiety symptoms. This suggests that the mismatch bias may be one mechanism by which anxiety symptoms are supported. These findings highlight the importance of mismatch biases in pediatric anxiety and the need for further research aimed at understanding relations among the mismatch bias, distress, and potential treatments. Therapeutic approaches that address an individual's desire to engage with peers, their negative expectations of those interactions, and the discrepancy between those two components may guide the development of more targeted interventions. Specifically, such interventions could address both the tendency to predict negative peer-related outcomes and the potential tendency to overvalue those same peers. Addressing only one of these biases, namely the tendency to predict negative outcomes, may result in reduced efficacy of treatment aimed at minimizing distress during the social decision-making process. Treatment that addresses both biases and the mismatch between the two may prove to be more efficacious.

In healthy participants, the opposite pattern emerged such that they believed peers would rate them as more desirable than they would rate their peers. While this pattern did not reach significance, potentially due to small sample size, it may reflect a phenomenon in the social psychology literature that suggests that healthy adults and adolescents often exhibit "comparative optimism" when making various appraisals about the self and others (Elkind 1967; Sherman

1980; Weinstein 1980; e.g., Chambers and Windschitl 2004), including social desirability (Alicke, 1985; although see Gunther et al. 2010). Comparative optimism is the tendency for individuals to believe that they will experience more positive events or be viewed more positively than others (Sherman 1980; Alicke 1985; Diener and Fujita 1997). This may be a particularly adaptive strategy during a phase of development when social evaluation becomes increasingly salient and meaningful. The present findings paired with the well-established negative bias among anxious patients suggest that anxious individuals may not experience comparative optimism, which may play a role in adaptive social functioning across this period of life.

In the current study, the vIPFC uniquely accounted for group differences in the mismatch bias. The vIPFC is a region broadly involved in attention and self-regulation, as shown through research on emotional judgments, appraisals, and updating rule contingencies (Ochsner et al. 2004; e.g., Goldin, et al. 2008; Guyer et al. 2012). Differential vIPFC activation in healthy and anxious youth, as demonstrated in the current study, may reflect anxiety-related discrepancies in the use of one or more of these vIPFC-related cognitive processes (i.e., attention, rule updating, behavioral selection) (Nelson and Guyer 2011). It is notable that a similar region in the vIPFC was engaged in prior studies using a different social evaluation task (Guyer et al. 2008, 2012) where anxious youth anticipated social feedback from peers who were most likely to provoke concern about social retribution (Guyer et al. 2008) and when nonanxious adolescents appraised their affective responses to social feedback (Guyer et al. 2012).

One conceptualization of the vIPFC suggests that the region sustains pediatric anxiety (Monk et al. 2006; e.g., Guyer et al. 2008; Maslowsky et al. 2010), potentially as part of its role in the acquisition or deployment of rule-based behaviors (Nelson and Guyer 2011). Within this framework, activation differences in anxious and healthy youth may reflect the need for different calculations related to social appraisals. For instance, heightened vIPFC activation in anxious youth when appraising the social desirability of peers may support flexible selection of the appropriate appraisal. In contrast, less engagement of the vIPFC in anxious youth when making predictions about their own social desirability may reflect an automatic tendency to predict negative social outcomes. Such habit-based cognitions may require fewer value-based calculations than more flexible cognitive processes. This interpretation is supported by research demonstrating that the vIPFC is not necessary for processing pre-established rules or habitual social constructs (Bunge 2004; Gozzi et al. 2009; Rygula et al. 2010). While further work is needed to test these specific relations, and to determine if brain function associated with mismatch bias predicts subsequent social decisions, the present results support the notion that differential engagement of the vIPFC during social appraisals is an important characteristic of pediatric anxiety.

The current study is not without its limitations. One notable limitation of the present study is our small sample size. The novelty of both the mismatch bias and vIPFC findings requires replication in a larger sample. Replication in a larger sample would also allow for the examination of age- and sex-related effects (i.e., Guyer et al. 2009; Guyer et al. 2012; Silk et al. 2012), as well as diagnosis-specific effects during social appraisals and mismatch bias. The relation between mismatch bias and social anxiety symptoms is not consistent across our analyses. Given the overlap of anxiety symptoms in our small sample, replication in a larger sample should provide the variability needed to examine diagnosis-specific effects. In addition, future studies may also consider altering the paradigm. For instance, the participants in the current task had no

expectation of meeting or receiving social feedback from their peers. A more ecologically valid social manipulation may increase participant engagement in the task, thereby eliciting the strong negative expectancy bias typically found in anxious individuals (for review, see Miranda and Menon 2007). With these modifications, diagnosis-related differences in the ability to discriminate between anxious and nonanxious youth, and how this discrimination translates into social biases, could be better assessed.

Despite these limitations this first study to examine the neural correlates of the mismatch bias provides important clues about the neurocognitive mechanisms that support anxiety symptoms in youth. It highlights the potential role of the vIPFC in social appraisals that may underlie distress during social decision-making, a critical aspect of SAD.

Conclusions

In conclusion, we used dynamic social stimuli to examine the behavioral and neural correlates of social appraisals in anxious and healthy youth. To our knowledge this is the first study to map neural processes differentially engaged when participants contrast their appraisal of peers compared to their estimate of their peers' appraisal of them. These findings provide new insight into how youth with anxiety make social appraisals. While these results need to be replicated, we hope to extend our findings to understand how anxious youth make decisions to approach or avoid social interactions in the real world. Together, these findings highlight the importance of mismatch biases in pediatric anxiety and the need for further research aimed at understanding relationships among mismatched social appraisals, distress, and potential treatments.

Clinical Significance

Adolescence is a critical time for establishing and maintaining healthy peer relationships, as well as adaptive social strategies. However, it is also a critical point for the onset of anxiety disorders, particularly social anxiety. Research aimed at understanding how anxious youth process social information, which is crucial for informing prevention and treatment programs aimed at reducing social avoidance during this critical period of development. Hopefully these findings will aid in the design of novel treatments by providing behavioral- and brain-based targets for interventions.

Disclosures

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