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EMPIRICAL ARTICLE

Computational modeling of social evaluative decision-making elucidates individual differences in adolescent anxiety

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Abstract

Adolescents experience significant developmental changes during a time of heightened sensitivity to social cues, particularly rejection by peers, which can be especially overwhelming for those with elevated levels of social anxiety. Social evaluative decision-making tasks have been useful in uncovering the neural correlates of information processing biases; however, linking youths' task-based performance to individual differences in psychopathology (e.g., anxiety symptoms) has proven more elusive. Here, we address this weakness with drift diffusion modeling to decompose youths' performance on the social judgment paradigm (SJP) to determine if this approach is useful in discovering individual differences in anxiety symptoms, as well as puberty, age, and sex. A sample of 103 adolescents (55 males, M_{age} = 14.49, SD = 1.69) completed the SJP and self-report measures of anxiety, as well as self- and parent-reported measures of puberty. The decision threshold parameter, reflecting the amount of evidence needed to make a social evaluative decision, predicted youth self-reported anxiety, above and beyond typical metrics of SJP performance. Our results highlight the potential advantage of parsing task performance according to the underlying cognitive processes. Future research would likely benefit from applying computational modeling approaches to social judgment tasks when attempting to uncover performance-based individual differences in psychopathology.

KEYWORDS
adolescence, anxiety, drift diffusion, social anxiety, social evaluation, social judgment paradigm

INTRODUCTION

Adolescence is widely understood as a unique period in development with significant changes in social environment and brain maturation (e.g., increased independence from parents and more time spent with peers; Blakemore & Mills, 2014; Guyer et al., 2016; Schriber & Guyer, 2016). Given the significant social changes, adolescent anxiety is of particular interest as it is characterized by an overestimation of the probability and cost of potential social threats (Grupe & Nitschke, 2013). Importantly, these changes materialize during a time of heightened sensitivity to social cues, particularly rejection by peers (Gunther Moor et al., 2014). Peer rejection appears to both precede and maintain anxiety symptoms (LoParo et al., 2023), which is especially devastating for those with elevated levels of social anxiety (Festa & Ginsburg, 2011; Pickering et al., 2020).

Social evaluation

Peer rejection is associated with deficits in social information processing (Lansford et al., 2010), which can be exacerbated by anxiety (e.g., Blöte et al., 2015). For instance, anxiety is associated with perturbed anticipatory processes (e.g., heightened sensitivity) during perceived social evaluative threats and ambiguous situations (Grupe & Nitschke, 2013; Hinrichsen & Clark, 2003; Wells et al., 1995). An extension of previous maintenance models of anxiety (e.g., Hofmann, 2007; Moscovitch, 2009; Rapee & Heimberg, 1997; Wells et al., 1995), the integrated etiological and maintenance model posits four cognitive facets of social-evaluative threat detection: anticipatory processing, attention to the self, attention to threat in the environment, and post-event processing (Wong & Rapee, 2016). Substantial literature supports the association between anxiety and attentional biases (e.g., Schultz & Heimberg, 2008), anticipatory event processing biases (e.g., Wong et al., 2019), and post-event processing biases (e.g., Brozovich & Heimberg, 2008) during social evaluation. However, there is limited research exploring how these cognitive biases during social evaluation affect decision-making processes during peer rejection nor their potential relation to individual differences in anxiety symptoms.

Social judgment paradigm

Several studies have examined responses to social evaluative feedback using ecologically valid social tasks, in particular the social judgment paradigm (SJP; Gunther Moor et al., 2010; Somerville et al., 2006; van der Molen et al., 2014). Participants performing the SJP are led to believe that they are participating in a study on first impressions. Participants provide their portrait photograph and are told that a panel of peers will evaluate whether they liked or disliked the participant based on their photograph. Participants are then shown photographs of the peers who evaluated them and indicate whether they thought each peer liked or disliked them. Following the participants' responses, fictitious peer feedback is presented for each trial with a 50% rate of acceptance. Used in conjunction with functional magnetic resonance imaging (Birk et al., 2019; Jarcho et al., 2013; Lau et al., 2011) and electrophysiological measures (e.g., event-related potentials; Cao et al., 2015; Kujawa et al., 2014; van der Molen et al., 2018), the SJP is useful for investigating the neural correlates of information processing biases (e.g., anticipatory event and post-event processing biases, see Wong & Rapee, 2016) in emotional reactivity to social evaluation. Importantly, several studies report that the degree of neural anticipatory reactivity exhibited prior to receiving peer feedback is related to social anxiety symptom severity in adolescence (Topel et al., 2021). In contrast to the productive electrophysiological (e.g., van der Molen et al., 2018) and neuroimaging (e.g., Lau et al., 2011), findings from social evaluative tasks, literature attempting to link adolescent anxiety with behavioral differences in response to social-evaluative threat stimuli, such as social rejection cues from peers, remain largely equivocal (Harrewijn et al., 2018; Topel et al., 2021). The purpose of the current study is to leverage computational modeling to explore whether this approach aids in linking task-based behavior during the SJP to individual differences in adolescent anxiety.

Computational modeling

Previous research exploring behavioral responses during the SJP has relied on reaction times averaged across trials and within groups, which has been inconsistent in uncovering links to anxiety symptoms or related constructs (Harrewijn et al., 2018; Somerville et al., 2006; Topel et al., 2021; van der Molen et al., 2014, 2018), potentially because it disregards variability in the processes underlying reaction time latency data. Computational modeling can be used to increase precision by combining cognitive tasks, such as the SJP, with computational models to capture clinically relevant (e.g., anxiety symptoms) individual differences (Stephan & Mathys, 2014). Computational models provide parameter estimates that are thought to reflect latent cognitive processes that shape brain activity and behavior governing an individual's task performance (Karvelis et al., 2023). These task-based parameter estimates are often found to outperform typical metrics of task performance (e.g., reaction time) when predicting clinically relevant outcomes (e.g., Castagna et al., 2023).

Process models, such as the drift diffusion model, were developed to provide additional information about underlying cognitive processes during binary decision-making tasks by capturing intraindividual variability across experimental trials (Ratcliff & McKoon, 2008). It is feasible that leveraging computational modeling in the context of the SJP may elucidate relations between decision-making processes during social evaluation and individual differences in adolescent anxiety. In fact, reinforcement learning models have previously proven useful in decomposing task-based behavior during repeated social interactions (e.g., Jones et al., 2011, 2014; Koban et al., 2017; Will et al., 2020). Despite promising advances in computational modeling of cognitive processes, no published research to date has applied decision-making computational models to the SJP to aid in linking performance to real-world psychopathology. Thus, here we apply the drift-diffusion model to the SJP to evaluate whether this more nuanced approach can uncover linkages between drift diffusion model parameters and individual differences in anxiety symptoms.

Drift diffusion modeling

Evidence accumulation models, such as the drift diffusion model (DDM), are a widely applied class of algorithms used to jointly predict subjects' choices and reaction times during two-choice decision-making (Ratcliff, 1978, 1985; Ratcliff & McKoon, 2008). The model posits that during the time it takes for an individual to make a binary decision, evidence accumulates toward a decision threshold, following a stochastic or random process, until it reaches one of two independent decision thresholds, at which point the individual makes the response that corresponds to that threshold (see Figure 1). The DDM, which is routinely applied to binary decision-making tasks in adolescents (e.g., Castagna et al., 2023; Castagna & Crowley, 2021; Liu et al., 2022; Pitliya et al., 2022), estimates four key parameters: drift rate, decision threshold, bias, and nondecision time (see Table 1) (Ratcliff & McKoon, 2008).

Regarding the SJP, where participants make decisions as to whether they expect acceptance or rejection by putative others, the model can be structured such that the modeling parameters (e.g., processing efficiency and drift rate) are affected by the feedback previously received (e.g., rejection). In this context, it may be suspected that youth with elevated anxiety will demonstrate decreased decision-making efficiency (drift rate) following rejection (relative to increased processing efficiency following acceptance). While the DDM has not been applied to social evaluation tasks, past research finds that the social influence (i.e., being aware of other participants' decisions) reduces processing efficiency (drift rate) during decision-making (Germar et al., 2013).

The decision threshold may also hold promise in linking SJP task performance and anxious symptomatology. Past research demonstrates that highly anxious individuals exhibit atypical emotional reactivity in social contexts perceived as threatening (e.g., Chen et al., 2017; Howell et al., 2016). Within a DDM, the tendency to engage in generalized avoidance (disengagement) could be expected to manifest in highly anxious individuals exhibiting a lower threshold separation, as the model was structured such that the modeling parameters (e.g., decision threshold) are affected by the feedback previously received (e.g., rejection). That is, they may be expected to require less information to determine whether they expect to be accepted or rejected by someone else as a function of the feedback they just received due to avoiding elaborative deliberation (e.g., larger decision thresholds) disengaging from the task, thus, requiring less processing and evidence to make either decision.

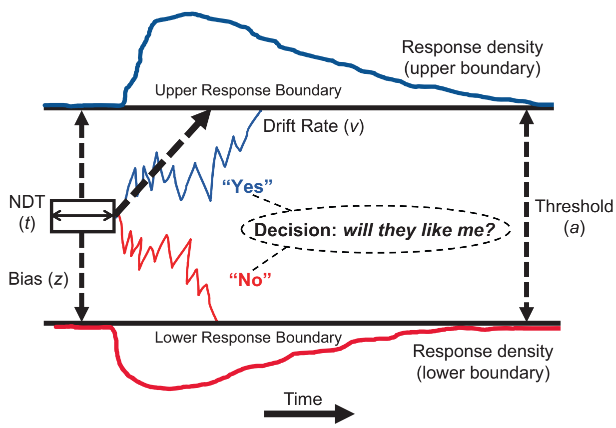

FIGURE 1 Simulated trajectories of the two drift processes (blue and red lines). Evidence is noisily accumulated over time (x-axis) where the (average) drift rate (v) continues until it reaches one of two boundaries, with a degree of separation defined by threshold (a), is crossed, and a response is initiated. An individual's starting point along the y-axis is defined by the bias (z) parameter. Upper (blue) and lower (red) panels refer to density plots for the two responses. The flat, solid line at the beginning of the drift processes indicates the nondecision time (t), NDT, where no accumulation happens. Dashed lines indicate parameters allowed to vary as a function of condition (i.e., responding "yes" vs. "no") within the full model in the current study. Colored lines within the boundaries indicate two hypothetical trials. While simulation data are depicted here, HDDM uses a closed-form likelihood function.

Current study

It is possible that past research has struggled to uncover individual differences in psychopathology related to SJP performance due to their reliance on the noisy amalgamation of a number of overlapping cognitive processes. We aim to fill this gap in the literature by exploring whether DDM parameters of SJP performance are useful in elucidating relations between SJP performance and youths' anxiety symptoms (i.e., social anxiety, physical symptoms, harm avoidance, and total anxiety), as well as puberty, age, and sex in a community sample of youth. We hypothesize that DDM parameters will be associated with youths' anxiety symptoms, where the strongest relationship will be with social anxiety. Although directional hypotheses are difficult to establish given the lack of research utilizing a DDM when examining SJP performance, we expect that adolescent anxiety will be negatively associated with drift rate (i.e., decreased processing efficiency) and positively related to the decision threshold (i.e., more information required to decide whether they will be accepted/rejected). This is supported by previous work indicating slower reaction times in those with social anxiety disorder compared to those without (Harrewijn et al., 2018). In light of previous work indicating that anticipatory psychophysiological reactivity during the SJP is associated with greater reactivity in girls (when compared to boys) (Topel et al., 2021), we also expect that there will be sex differences in mean DDM parameter estimates between girls and boys; however, we do not have specific directional hypotheses for these mean sex differences, as it is unknown how these neural differences (i.e., greater anticipatory reactivity in girls) may affect SJP performance (i.e., parameter estimates). Given past research with the SJP (e.g., van der Molen et al., 2014, 2018), we also posit that DDM parameters

TABLE 1 Drift diffusion model parameters.

Drift diffusion model parameters	
Drift rate	Speed of evidence accumulation; the efficiency with which one accumulates evidence within a trial to reach a decision. Larger values indicate more efficient processing; smaller values reflect less efficient processing
Decision threshold	The amount of evidence required to come to a decision, reflecting speed versus deliberation. Larger values indicate wide decision threshold (slower but more deliberate responses); smaller values reflect narrower thresholds typically leading to faster responses (e.g., less deliberation)
Bias	The starting point of evidence accumulation and set at .5 when no bias exists (i.e., equidistant between both decision thresholds). Larger/smaller values indicate needing much less evidence to accumulate for one decision but more evidence to accumulate to reach the alternative decision, and vice versa
Nondecision time	The portion of reaction time unrelated to the decision-making process

will predict youths' anxiety symptoms above and beyond typical metrics of SJP task performance (e.g., yes/no reaction time) while considering important covariates such as child sex (Topel et al., 2021). Specifically, we hypothesize that both the drift rate and decision threshold will be negative and positive predictors, respectively, of adolescent anxiety (Harrewijn et al., 2018). This research is particularly important as it has the potential to guide future research utilizing social evaluative tasks to better predict individual differences in psychopathology, supporting neural circuitry, and changes therein.

METHOD

Participants

The initial sample consisted of 109 healthy adolescents ($n_{male}=58$, $n_{female}=51$) between the ages of 12- and 17-years-old ($M_{age}=14.44$, SD = 1.72). Participants were recruited through a mass mailing list targeting New Haven, CT, and the surrounding towns. Youth were recruited as part of a large-scale study that included multiple paradigms, such as the SJP, which is the focus of the current study. SJP data were collected along with a concurrent EEG as reported previously (Topel et al., 2021). Two participants were removed due to a large amount of missing demographic/self-report data and four participants were removed because their performance on the SJP was associated with low convergence after model fitting (i.e., Gelman–Rubin statistic >1.1, detailed below), suggesting unreliable performance (e.g., random responding, not engaging in the task, etc.). Thus, a final sample of 103 adolescents ($n_{male}=55$, $n_{female}=48$, $M_{age}=14.49$, SD = 1.69) was used for our analyses. None of the adolescents participating in the study had a current diagnosis of a serious psychiatric disorder (e.g., schizophrenia), nor a history of traumatic brain injury with loss of consciousness that may interfere with data collection. All youth had corrected-to-normal vision, were fluent English speakers, and the majority of the participants were right handed (i.e., 95.1%). Demographic information was collected through a standard demographics form completed by the participant's caregiver. Youth predominantly identified as White/European-American ($n=79$, 76.7%; coded 1), followed by Black/African American ($n=9$, 8.7%; coded 2), Hispanic/Latin ($n=6$, 5.8%; coded 3), and Asian ($n=6$, 5.8%; coded 4). Three (2.9%) participants identified as other or unknown racial/ethnic origins. Sex was coded as boys = 1 and girls = 2. The study was approved by the Human Investigation Committee of the of the Yale University School of Medicine.

Materials and procedure

Multidimensional Anxiety Scale for Children

The Multidimensional Anxiety Scale for Children (MASC) is a 45-item youth self-report questionnaire for symptoms of anxiety (March et al., 1997). Total scores range from 0 to 120, with high scores indicating greater childhood anxiety. The four empirically derived factor index scores are social anxiety (e.g., "I'm afraid other kids will make fun of me" and "I worry about getting called on in class"), separation anxiety (e.g., "I get scared when my parents go away" and "I try to stay near my mom or dad"), harm avoidance (e.g., "I keep my eyes open for danger" and "I usually ask permission to do things"), and physical symptoms (e.g., "I feel tense or uptight" and "I get dizzy or faint feelings"). The MASC has shown good internal consistency ratings from 0.70 to 0.83 and Cronbach's alpha ranging from .74 to .85 (March et al., 1997). The MASC has been found to be a clinically useful measure to discriminate between anxious and depressed pediatric patients (Rynn et al., 2006). Here, the MASC physical symptoms ($\alpha=.89$), harm avoidance ($\alpha=.80$), social anxiety ($\alpha=.83$), separation anxiety ($\alpha=.89$), and total scores ($\alpha=.86$) were found to have good internal consistency.

Pubertal Development Scale

Adolescents and parents completed the self-report and parent versions of the PDS respectively. The Pubertal Development Scale (PDS) is designed to assess physical development on five indices of pubertal growth (Petersen et al., 1988). All participants are asked about growth, body hair, and skin changes (e.g., pimples). Males are asked about changes to voice and growth of facial hair. Females are asked about breast development and the onset and age of menstruation. The questions are rated on a Likert-type scale: *not yet started* (1), *barely started* (2), *definitely started* (3), and *seems complete* (4). A number of studies have provided support for the scale's validity by demonstrating that PDS scores are related to physical examination and hormone levels (Hibberd et al., 2015; Schmitz et al., 2004; Shirtcliff et al., 2009). The PDS has also been found to have high internal consistency in both boys ($\alpha=.77$) and girls ($\alpha=.81$) (Petersen et al., 1988). Cronbach's alpha of PDS used in the current study also found high levels of reliability for boys ($\alpha=.81$) and girls ($\alpha=.87$).

Social judgment paradigm

An adapted version of the SJP was employed in the present study (Gunther Moor et al., 2010; Somerville et al., 2006; van der Molen et al., 2014). Using a cover story, participants were led to believe that they were participating in a study on first impressions. Portrait photographs were collected from participants 2 weeks prior to testing day. The participants were told a panel of peers would evaluate them based on their photographs by reporting whether they liked or disliked the participant. When participants came into the laboratory on the testing day approximately 2 weeks later, they received the instructions that they would be shown the photographs of the peers who evaluated them and were asked to indicate whether they thought each peer liked or

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disliked them. In reality, the participants were not evaluated by actual peers, and the like/dislike feedback was generated by computer. Following the participants' responses, the fictitious peer feedback was presented in each trial in a pseudorandom order (i.e., determined by numbers that are statistically random). Participants received acceptance feedback 50% of the time. Different combinations of participant expectancies and the feedback they were shown resulted in four experimental conditions upon receipt of feedback: expected acceptance, expected rejection, unexpected acceptance, and unexpected rejection. Given that the current study focused on the period after participants reported their expectations and right before they received feedback, there were two conditions for anticipation: anticipation of acceptance and anticipation of rejection from peers.

The stimuli used for this version of the SJP included 160 peer photographs with a neutral facial expression (50% female, 100% White, and non-Hispanic) used in the task which were obtained from previous studies (Gunther Moor et al., 2010; van der Molen et al., 2014, 2018; van der Veen et al., 2016). Stimuli were presented on a 19-inch monitor with a refresh rate of 60 Hz using E-prime 2.0 software (Psychology Software Tools, Pittsburgh, PA). Trial schematic for the experiment is shown in Figure 2.

For each trial, a photograph of a peer was presented as a cue for a maximum duration of 3000 ms during which the participants were required to provide a response showing their expectancies. If they did not provide their response within this time interval, they were presented with the feedback "too slow." For each peer stimulus, participants indicated whether they expected to receive acceptance ("YES") or rejection ("NO") feedback from that particular peer by pressing one of the two buttons with their index fingers. The order in which buttons corresponded to acceptance and rejection expectancies was counterbalanced across participants. Following the participants' response was a delay period for the fixed duration of 3000 ms which was used to study anticipation (the duration of feedback presentation was varied across conditions with the purpose of generating a condition-specific marker for heart rate recordings that are not within the scope of the current report). Specifically, feedback for the "Yes–Yes" (expected acceptance), "Yes–No" (unexpected rejection), "No–Yes" (unexpected acceptance), and "No–No" (expected rejection) conditions was presented for 300, 400, 500, and 600 ms, respectively. Feedback presentation was followed by a jittered intertrial interval between 500 and 1000 ms where the participants were shown a fixation cross in the middle of the screen. There were 10 practice trials at the beginning of the task preceding the three experimental blocks containing 50 trials each. Mean number of trials used in the analyses was 76.11 (SD = 17.9) for anticipated rejection and 71.33 (SD = 18.36) for anticipated acceptance condition. Before and after the SJP, youth used a visual analog scale (*0, exclusively rejection feedback*; *100, exclusively acceptance feedback*) to report how he/she expected to be evaluated (pre-estimate) and how he/she thought they were evaluated (postestimate). Debriefing was done through a letter provided after each session was complete.

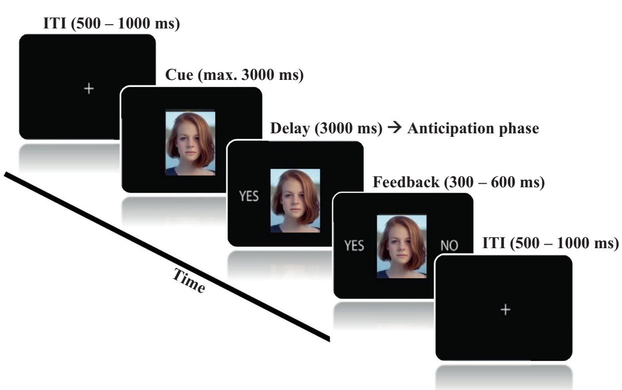

FIGURE 2 Schematic outline of the experimental trial.

Modeling

We used hierarchical drift diffusion modeling (HDDM 0.9.8; Wiecki et al., 2013) to estimate drift diffusion parameters via the Bayesian modeling of youth reaction time during the SJP, in which trial type served as a two-level factor reflecting the feedback received in the previous trial (i.e., acceptance and rejection; see Figure 1). HDDM is an open-source software package written in Python that allows for the flexible construction of hierarchical Bayesian DDMs as well as the estimation of its posterior parameter distributions (Patil et al., 2010). A basic graphical hierarchical model implemented by HDDM is shown in Figure S1. It provides many commonly used statistics (e.g., deviance information criterion, posterior mean deviance, etc.) and plotting functionality used to assess model fit (e.g., histograms, autocorrelation, etc.). Posterior plots of parameter estimates are presented in Figure S2.

The data feedback was shifted down a trial for each participant, with each initial decision and last feedback received removed. Doing so allowed feedback to be paired with the participant's subsequent trial decision. Without this change, the diffusion model would be examining how decision-making was affected by feedback they received *after* their decision. Moreover, the first choice was deleted as it did not have prior feedback to relate to and therefore represented a "cold" decision, not made as a function of peer acceptance/rejection. Similarly, the last feedback was removed as it was not followed by a decision by the participant (i.e., accepted/rejected feedback without a subsequent decision).

We tested different models in which the parameter (or parameters) was allowed to vary as a function of the feedback received previously (i.e., "yes" or "no"). The first model was the null model, where no parameters were allowed to vary as a function of feedback (i.e., "yes" or "no"), thereby providing four parameter estimates (see Table 1).

The second model allowed the threshold parameter to vary as a function of feedback, providing five parameter estimates (i.e., decision threshold—yes, decision threshold—no, drift rate, bias, and nondecision time). The third model allowed drift rate to vary as a function of feedback, providing five parameter estimates (i.e., drift rate—yes, drift rate—no, decision threshold, bias, and nondecision time). In the fourth model, the bias parameter was allowed to vary as a function of feedback, providing five parameter estimates (i.e., bias—yes, bias—no, decision threshold, drift rate, and nondecision time). Finally, the fifth model allowed threshold, drift rate, and bias parameters to vary and included eight parameter estimates (i.e., decision threshold—yes, decision threshold—no, drift rate—yes, drift rate—no, bias—yes, bias—no, and nondecision time). We determined model fit through the interpretation of the HDDM-generated output of the respective models' deviance information criterion, posterior mean deviance, and the effective number of parameters, with preference for more parsimonious models. Model fits are provided in Table S1.

Parameter estimates for each participant were then extracted from the best-fitting group model, as well as the null model for the purpose of comparison. All models were run with 10,000 posterior samples with a burn-in of 1000 (Wiecki et al., 2013). After running the first null model, the Gelman–Rubin statistic (Gelman & Rubin, 1992) was calculated via HDDM. This statistic is used as a formal test of model convergence by comparing within- and between-chain variance of different runs of the same model. The Gelman–Rubin statistic was calculated from the comparison of all models (10,000 iterations and 1000 burn-in each). This statistic should be close to 1.0 if the samples of the different chains generated are indistinguishable (Gelman & Rubin, 1992). As previously mentioned, four participants were excluded due to a Gelman–Rubin statistic >1.1. All models were run as outlined on the final sample ($N = 103$).

Statistical analyses

With individual participant model parameter estimates calculated, we examined their relations to self-reported anxiety domains (i.e., physical symptoms, harm avoidance, social anxiety, separation anxiety, and total anxiety), mean reaction times for "yes" and "no" feedback, self- and parent-reported puberty, age, and sex via Pearson correlations (performed with a 2000 bootstrap). Given previous SJP research (Topel et al., 2021), we conducted post hoc *t*-tests to examine whether girls and boys significantly differed in their DDM parameters. A linear regression was used to test the assumption that DDM parameters provide additional information regarding sensitivity to social feedback above and beyond simple reaction time. HDDM 0.9.8 was run in Python 3.8.3 and correlational and regression analyses were computed in SPSS 28.0.

RESULTS

Model fit

The comparison of the model fit metrics (i.e., deviance information criterion, posterior mean deviance, and the effective number of parameter values) across all tested models suggested that the null model provided the best fit for the data (Spiegelhalter et al., 2002). In sum, feedback participants received (i.e., either "yes" or "no) across trials did not reliably alter their speed–accuracy trade-off (decision threshold), response efficiency (drift rate), or their preference for responding either "yes" or "no" (bias). See Table S1.

Correlational analyses

To examine the potential utility of using diffusion modeling to better understand the underlying cognitive processes on the SJP, as opposed to simple reaction time after receiving acceptance (i.e., "yes") or rejection (i.e., "no") feedback, we conducted Pearson correlations among parameters of the best fitting model (i.e., null model), reaction time to feedback, baseline/post-task expectation measures, anxiety symptoms, puberty, adolescent age, and sex. To control for the false discovery rate (FDR), Benjamini–Hochberg FDR-corrected *p* values are reported (Benjamini & Hochberg, 1995). As shown in Table 2, the threshold parameter of the diffusion model was negatively correlated with self-reported separation anxiety and total anxiety. Interestingly, the posttask measure, which recalls adolescent beliefs about how they were reviewed (positive values indicating a more positive perception), was negatively correlated with the threshold parameter, whereas it was positively associated with the drift rate and the bias parameter. In addition, the threshold parameter was negatively correlated with puberty and child sex. These results suggest that individual differences in the amount of evidence needed to make a decision ("yes" or "no") are related to aspects of anxiety, puberty, and child sex. More specifically, a reduced threshold (i.e., less evidence needed to accumulate to make a decision) was associated with greater levels of anxiety and advanced puberty status and was more common among girls. Importantly, reaction time to feedback (i.e., either "yes" or "no") was neither related to anxiety symptoms or puberty. A correlation matrix also including mean 'yes', mean 'no', and yes/no ratio during the SJP is provided in Table S2. Scatter plots of the relationships between the drift rate (see Figure S3) and bias (see Figure S4) parameters and all self-reported anxiety subscales are provided in our Appendix S1.

Independent sample *t*-tests

Post hoc independent sample *t*-tests were calculated to examine whether girls and boys significantly differed in

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TABLE 2 Pearson correlations matrix of measured variables (2000 sample bootstrap).

Variables	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	*M*	SD	Range
1. Decision threshold	–																1.72	.21	1.08–2.15
2. Drift rate	.03	–															–.03	.32	–1.32 – .64
3. Nondecision time	.07	.10	–														.58	.22	.12–1.41
4. Bias	–.19	**.30**	–.19	–													.50	.19	.41–.61
5. Yes RT	**.63**	–.16	**.75**	**–.51**	–												1.31	.29	.66–2.0
6. No RT	**.64**	.11	**.71**	–.03	**.85**	–											1.29	.25	.74–1.98
7. BL Expectancy	.08	.15	.04	.05	.00	.08	–										57.2	19.50	10–100
8. Postrecall	–.21	**.36**	.04	**.30**	–.18	–.01	.18	–									50.9	15.32	10–86.2
9. Physical	–.13	–.15	.10	–.09	.00	–.03	–.23	–.12	–								10.57	6.16	1–30
10. Harm Avoidance	–.22	.12	.08	–.04	.01	–.00	–.06	.14	.22	–							18.42	3.78	7–25
11. Social Anxiety	–.11	–.02	.01	–.13	–.08	.11	–.11	–.08	**.60**	.08	–						11.90	6.14	0–27
12. Separation	**–.31**	.11	.10	.04	–.11	–.10	.06	.12	**.53**	**.44**	**.51**	–					6.97	4.60	0–18
13. Total Anxiety	**–.24**	–.05	.09	–.08	–.06	–.08	–.13	–.01	**.84**	**.49**	**.80**	**.81**	–				47.85	15.64	20–98
14. PDS-SR	**–.32**	.11	.07	.12	–.08	–.03	–.08	–.00	.04	–.06	.10	–.07	.02	–			3.04	.70	1.25–4
15. PDS-PR	**–.35**	.08	.07	.07	–.07	–.06	–.09	–.03	.02	.04	.10	–.05	.04	**.86**	–		3.02	.69	1–4
16. Age	–.10	.07	.05	.01	.02	.03	–.01	–.12	–.03	.01	.04	**–.23**	–.06	**.61**	**.65**	–	14.44	1.72	12–17
17. Sex	**–.35**	–.04	–.04	–.01	–.19	–.24	–.13	.02	.13	–.02	.23	.26	.22	**.47**	**.51**	.01	1.47	.50	–

Note: Bold correlations = $p \leq .05$ (Benjamini–Hochberg false discovery rate corrected). Sex = child reported sex, boy = 1, girl = 0; Age = child age in years.

Abbreviations: BL Expectancy, baseline measure of how youth perceived they will be reviewed; PDS-PR, Pubertal Development Scale, Parent-Report; PDS-SR, Pubertal Development Scale, Self-Report; Postrecall, posttask rating of how youth think they were reviewed.

their DDM parameters. To control for the false discovery rate (FDR), a Benjamini–Hochberg FDR correction for independent tests was applied to the following statistical tests (Benjamini & Hochberg, 1995). Girls and boys did not significantly differ in parameter estimates of drift rate, $t(102) = 0.64$, $p = .52$, CI [−0.08, 0.16], Cohen's $d = 0.13$, bias, $t(102) = -0.03$, $p = .97$, CI [−0.02, 0.02], Cohen's $d = -0.01$, or nondecisional time, $t(102) = 0.44$, $p = .66$, CI [−0.07, 0.10], Cohen's $d = 0.09$, but girls tended to have a smaller decision threshold (i.e., less evidence needed to reach a decision), $t(102) = -3.23$, $p = .002$, CI [−0.20, −0.05], Cohen's $d = -0.67$.

Linear regressions

A hierarchical multiple linear regression was conducted with youth self-reported anxiety as the response variable in order to examine the assumption that DDM parameter estimates of SJP data improve predictive utility above and beyond typical metrics of performance (i.e., simple reaction time during yes/no SJP trials). We utilized our correlational analyses to inform our decision on potential DDM parameter(s) and covariates. The final model included child sex as a covariate (step 1), the yes/no trial reaction times, and the decision threshold parameter (step 2) as predictors. All dimensional predictor variables were centered prior to analysis. As shown in Table 3, the first step including only child sex was not a significant predictor. The second step significantly improved overall model fit, in which only the decision threshold was a significant predictor of youths' anxiety. Overall, youths' self-reported anxiety was predicted by a reduced decision threshold, suggesting that higher levels of anxiety were related to requiring less information to make a decision that the participant expected to be "accepted" or "rejected" during the SJP. See Figure 3. Scatter plots of the relationship between the decision threshold parameter and all self-reported anxiety subscales are provided in Figure S5. Linear regressions with the addition of the decisions made during the task (see Table S3) and an index of participant DDM model fit (see Table S4) did not alter the direction or strength of the results and are provided in our Appendix S1.

DISCUSSION

The goal of the current study was to apply a drift diffusion model (DDM) to youths' social judgment paradigm (SJP) performance to evaluate whether this more nuanced approach uncovers linkages between DDM parameters and individual differences in anxiety symptoms. This research is of importance given the promising advances in computational modeling of cognitive processes. Notably, no studies to date apply computational modeling to social evaluative tasks. It is our hope that our research will aid future studies using social evaluative feedback tasks by providing evidence that this novel approach may be useful for understanding social decision-making and uncovering individual differences in psychopathology related to task performance.

The best-fitting model did not allow any of the model parameters to vary as a function of feedback (i.e., being accepted or rejected, null model). These findings suggest that the feedback participants receive (i.e., either "yes" or "no) over the course of trials did not reliably alter the amount of evidence needed to make decisions in a uniform manner (decision threshold), response efficiency (drift rate), or their preference for responding either yes or no (bias). For instance, the threshold ($a_{yes} - a_{no} = 0.02$, SD = 0.20), the drift rate ($v_{yes} - v_{no} = -0.07$, SD = 0.29), or the bias parameter ($z_{yes} - z_{no} = 0.02$, SD = 0.20) demonstrated a large difference, approximately a tenth of a standard deviation, as a function of the feedback the participant just received. A potential explanation for these negligible differences across conditions may be that the simple feedback being received ("yes" or "no") to indicate peer acceptance or peer rejection may

TABLE 3 Linear multiple regression: Youth sex (first step), yes/no trial reaction times, and the decision threshold parameter (step 2) predicting youth anxiety.

Youth anxiety (MASC)	β	SE	t	p	95% CI Lower	95% CI Upper
1st Step						
Sex	.18	3.3	1.78	.08	−0.69	12.39
2nd Step						
"Yes" Trials RT	.13	6.4	0.33	.74	−10.65	14.92
"No" Trials RT	.03	6.5	0.07	.95	−12.42	13.31
Decision threshold	−.32	2.2	−2.21	.02	−8.97	−0.27
Model						
R^2	.05					
Adj. R^2	.02					
$F(3, 99)$	4.52					

Note: Predictors were converted to *z*-scores.

Abbreviations: SE, standard error; β, standardized beta.

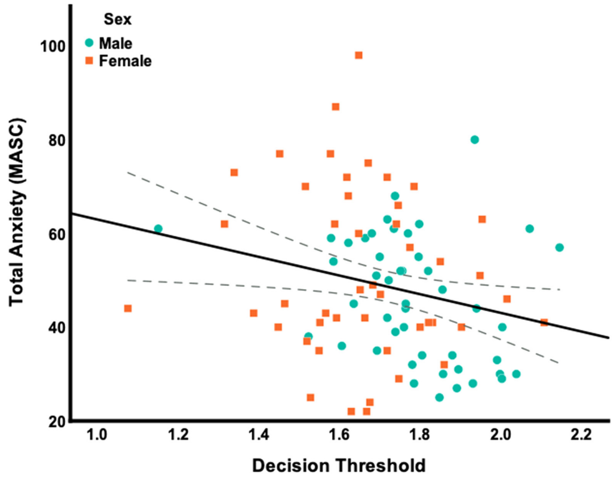

FIGURE 3 Scatterplot of the relationship between total self-reported anxiety (MASC) and the decision threshold parameter during the social judgment paradigm.

not be a strong enough cue to alter participants' decision-making trial-to-trial as evidenced by these quantitative (i.e., deviance information criterion, posterior mean deviance, and effective number of parameters) and qualitative statistics supporting the use of the null DDM. This is bolstered by the nature of the task, where participants do not make predictions (learning) about the same individuals but, rather, view a different individual each time.

We found partial support for our hypothesis that modeling SJP performance would provide a valuable alternative when compared to examining task reaction time group differences alone. Our regression analysis provided support for our hypothesis demonstrating that the decision threshold predicted youth self-reported anxiety above and beyond their SJP reaction time and rejection/acceptance decisions. In fact, the relationship between youths' SJP behavior and anxiety would not have been found when relying on typical metrics of youths' performance alone. These results highlight the potential advantage of parsing task performance according to the underlying cognitive processes indexed using a DDM framework. Interestingly, many of the relevant factors examined in correlation analyses were uniquely linked to the separation threshold parameter, namely separation anxiety, total self-reported anxiety, self-/parent-reported puberty, as well as youth sex. The direction of the aforementioned associations was negative, contrary to our hypothesis, indicating that a smaller separation threshold tended to be related to increased anxiety-related symptoms and puberty. Notably, participants' posttask recall of how accepted they felt was significantly associated with the drift rate parameter (processing efficiency), where the positive relationship indicates higher levels of postevent recall of being accepted was related to greater processing efficiency during the social evaluative task.

The DDM parameters were extracted from the null model; it is important to note that they were not allowed to vary as a function of feedback, but rather reflect participants' general approach to the social evaluative task. More specifically, these results suggest that youth with elevated anxiety-related symptoms, as well as girls in the later stage of puberty, tend to approach the social evaluative task in such a way that they need less evidence to accumulate in order to make a decision, regardless of whether that response is preceded by peer acceptance or rejection. As noted, our regression analysis was informed by the correlational findings which led to focusing on predicting youths' anxiety total score; counter to predictions, social anxiety symptoms (as well as physical anxiety) were unrelated to the decision threshold parameter. Furthermore, in contrast to our hypotheses, none of the DDM parameters were specifically related to social anxiety symptoms. It is possible that despite youth making decisions about whether he/she will be accepted/rejected by peers during social evaluation, the parameters reflecting underlying cognitive processes are related to anxiety symptoms more generally rather than processes that are specific to social anxiety. This would also be consistent with one study finding that youth with (compared to those without) social anxiety disorder demonstrate slower reaction times during the SJP (Harrewijn et al., 2018). This potential discrepancy could be clarified by future work applying a drift diffusion model to SJP performance in clinical versus nonclinical samples.

One potential explanation for the current findings is that when approaching a social evaluative task, youth with elevated levels of anxiety-related symptoms (more generally) may tend to default to a fast-paced (avoidance) approach when processing social evaluative feedback (again, regardless of the social feedback they received, which was not found to alter parameter estimates). It is possible that high levels of anxiety could lead to narrower decision boundaries because these individuals may experience greater state anxiety during the task, which is supported by our previous work indicating an association between psychophysiological anticipatory reactivity (i.e., stimulus preceding negativity event-related potential) during the SJP and adolescent social anxiety (Topel et al., 2021). Past work also shows that highly anxious adolescents exhibit atypical emotional reactivity in social contexts perceived as threatening, as indexed by elevated self-reported state anxiety (e.g., Chen et al., 2017; Howell et al., 2016), heart rate (e.g., Rösler et al., 2021), and anticipatory processing (e.g., Topel et al., 2021; van der Molen et al., 2014). Moreover, adolescent social anxiety is also associated with fear of both negative and *positive* evaluation (e.g., Lipton et al., 2014), which may also explain, at least partially, why the reduced decision thresholds were found in following both rejection and acceptance feedback. As such, in the context of the SJP, tuning decision-making to be as fast paced as possible may represent an emotion regulation strategy that minimizes the need to engage with the distressing thoughts that come with evaluating others' social judgment. Support for this potential explanation could be provided by future research finding an association between differences in participants' reaction time during social evaluative and nonsocially evaluative tasks.

While the SJP does not involve an accuracy component per se, it is important to note that an underlying assumption in sequential sampling models, such as DDM, is that people seek to make good decisions quickly (Ratcliff & McKoon, 2008). Specifically in the context of SJP, when asked to make simple decision, such as "will they like you?", a number of cognitive systems (e.g., schema, self-regulation, etc.) sample evidence until some termination criterion is met (e.g., evidence for a "yes" response exceeds that for the alternative "no" response by some amount) (Ratcliff, 1978). While speculative, recruitment of this overgeneralized default strategy is consistent with the fact that individuals' decision parameters were not sensitive to peer feedback, although this finding was not unique to individuals with high levels of anxiety. This may contribute to the tendency to enter a self-focused style of cognition, typically associated with anxious thinking, where attention is shifted toward internal states and others' actual judgments are perceived as less salient than preexisting negative self-schemas (Wells et al., 1995). Over time, the use of strategies that evade negative affect, such as that proposed here, may reduce opportunities to engage with positive cues in the social environment, thereby exacerbating psychosocial impairments in adolescence (e.g., Miers et al., 2014).

Additionally, from a cognitive theoretical standpoint (Rapee & Heimberg, 1997; Wells et al., 1995; Wong & Rapee, 2016), and taken in conjunction with the belief bias framework, it is conceivable that this may explain, at least partially, why models that are allowed to vary as a function of feedback received did not provide any improvements in model fit. For instance, the reception of rejection in anxious individuals may not alter their decision-making (i.e., accepting or rejecting the counterpart) as it serves to confirm their initial belief which does not prompt a counteraction to be rejected (Clark & McManus, 2002). At the same time, the reception of positive feedback in anxious adolescents, from a reward devaluation framework (Winer & Salem, 2016; Young et al., 2019), could also not alter decision-making through the active avoidance of experiencing positivity (Buck et al., 2013).

As mentioned, smaller threshold separation parameter values in this context are interpreted as needing less information to make a decision to accept or reject. Therefore, we posit that youth with greater anxiety symptom severity may exhibit a lower threshold separation as their decision is not tied to the acceptance/rejection feedback they just received, thus, requiring less processing/evidence to make such decision. Stated differently, it is plausible that youth with higher levels of anxiety require less evidence in order to make a decision to accept or reject as they are not processing whether they were previously rejected when making a decision as it confirms their initial biased belief that they will be socially rejected. This interpretation is consistent with the significant, negative correlation between the separation threshold and posttask recall of how rejected they felt. Our findings in youth appear to diverge from those in adults, where individuals with elevated fear of negative evaluation need *more* time to make their prediction of whether they will be accepted or rejected (van der Molen et al., 2014). It is possible that greater reaction time in adults reflects reduced avoidance toward processing potential rejection/acceptance that produces negative affect, which would be consistent with evidence that adolescents have poorer fear discrimination (increased fear generalization) and greater fear avoidance when compared to adults (Klein et al., 2021). Together, these differences in fear generalization/avoidance may explain the divergence in findings between adults and youth. Given the differences in analytical assessment of SJP performance, as well as focus (i.e., fear of negative evaluation vs. anxiety), this potential developmental dissociation warrants future research.

Given the social evaluative nature of the task, it was somewhat surprising that social anxiety was the only domain not associated with a parameter of the null model. However, the strongest association found among anxiety domains was with separation anxiety, which has some potentially interesting implications for the nonsignificant findings in regard to social anxiety symptomatology. For example, using latent class analyses, Ferdinand et al. (2006) found that separation anxiety did not represent a different construct than social anxiety in adolescence (but was distinct in children). Given the age of our sample ($M_{age} = 14.44$, SD = 1.72, $Age_{range} = 12–17$), it is possible that the significant association found is due to an aspect of social evaluation being captured by the separation anxiety subscale.

We found a similar negative relation between the threshold separation parameter and puberty status via both self- and parent report, which is consistent with our hypothesis and consistent with some past work with the SJP in adolescents (Topel et al., 2021). These findings suggest that youth in later stages of puberty may be associated with a tendency to need less evidence to accumulate in order to decide whether they will be accepted or rejected. Although this seems to contradict research that adolescence is a time of heightened sensitivity to peer rejection sensitivity (Gunther Moor et al., 2014), it is plausible that the aforementioned mechanism may be at play here. For instance, given that this is a time of sensitivity to peer rejection, and the fact that the threshold parameter of the null model is reflecting an overall approach to the task (and not in direct response to trial-to-trial social rejection), it again may reflect that less accumulated evidence is needed in an attempt to cope with the distress of the social evaluative task.

Finally, we found support for our hypothesis of an association between youth sex and the separation threshold parameter (Topel et al., 2021). The direction of these results suggests that a smaller separation threshold is more common in girls. Given the significant pattern of correlations across nearly all anxiety domains, it is possible that this finding may reflect sex-related anxiety differences, such that girls are more likely to develop anxiety symptoms when compared to boys (e.g., Lewinsohn et al., 1998). Some indirect support for this notion is reflected by the finding that the strongest anxiety–parameter relation, separation anxiety, is also associated with the largest discrepancy between girls and boys.

Limitations and future directions

There are a few limitations to this study that should be discussed. The present study employed a widely used self-report measure of pubertal development. Our measurement, therefore, reflects the imprecision of this self-report. Future studies could also consider assessing changes in specific pubertal hormones. Although we relied on a sample spanning a range of pubertal development, the cross-sectional nature of the present study does not allow for causal inferences. Moreover, our sample was fairly homogenous in terms of race and ethnicity, warranting future research in more diverse samples. Relatedly, the visual stimuli included only images of White non-Hispanic youth, and although this matches the majority of our sample, it is possible that this may have had an effect on the results. Serving as markers for heart rate recording in another project, the duration of the peer feedback presentation varied slightly across conditions which could have had an effect on information processing. In addition, although we examined anxiety symptoms, the adolescents recruited for this study were community referred. While individuals with subclinical social anxiety display interpretation biases and social impairments (Loscalzo et al., 2018), inferences about how diffusion model parameters for social judgment operate for clinical levels of anxiety remain speculative. Finally, we found the null model as the best fit for participants' data; however, it is possible that this could partially reflect the delay difference between receiving acceptance versus rejection feedback (i.e., 300 ms). That is, we cannot fully discount the possibility that the systematic difference in the presentation of the two feedback conditions is partially influencing participants' subsequent reaction time and decisions.

Despite these limitations, findings from the current study may open new avenues for future research investigating individual differences in social cognition in relation to psychopathology and development. We found that the decision threshold parameter, reflecting the amount of evidence needed to make a social evaluative decision, predicted youth self-reported anxiety above and beyond typical metrics of SJP performance. While speculative, it is possible that youth with elevated levels of anxiety-related symptoms may tend to default to a fast-paced (avoidance) approach when processing social evaluative feedback (regardless of the social feedback they received, which was not found to alter parameter estimates). It may be useful for future longitudinal studies to examine whether there are fluctuations in these parameters within an individual during the course of adolescence that map to known increases in social evaluative fears (e.g., Clark & McManus, 2002). In addition, future research may extend this approach to adolescent clinical samples. In summary, we have shown support for the notion that diffusion models may provide a refined description of social decision-making in adolescence, potentially offering a new standard for this and related lines of inquiry.

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CONFLICT OF INTEREST STATEMENT

The authors report there are no competing interests to declare.

DATA AVAILABILITY STATEMENT

Data are available upon request.

INFORMED CONSENT

Informed consent/assent was obtained from all individual participants included in the study.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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