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Computational Modeling of Self-Referential Processing Reveals Domain General Associations with Adolescent Anxiety Symptoms

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Abstract

What an adolescent thinks about themselves, commonly termed self-referential processing, has significant implications for youth long-term psychological well-being. Self-referential processing plays an important role in anticipatory and reactive processing in social contexts and contributes to symptoms of social anxiety. Previous work examining self-referential processing largely focuses on child and adolescent depression, relying on endorsement and reaction time for positive and negative self-describing adjectives in a self-referential encoding task (SRET). Here, we employ computational methods to interrogate the latent processes underlying choice reaction times to evaluate the fit of several drift–diffusion models of youth SRET performance. A sample of 106 adolescent, aged 12–17 (53% male; $M_{age} = 14.49$, $SD = 1.70$) completed the SRET and self-report measures of anxiety and depression. Our results support the utility of modeling the SRET, where the rate of evidence accumulation (i.e., drift rate) during negative self-referential processing was related to social anxiety above-and-beyond mean task performance. Our regression analyses indicated that youth efficiency in processing of self-referential views was domain general to anxiety, highlighting the importance of assessing both social and physiological anxiety symptoms when predicting SRET performance. The computational modeling results revealed that self-referential views are not uniquely related to depression-related constructs but also facets of anxiety.

Keywords Self-referential processing · Adolescence · Social anxiety · Depression · Drift diffusion

Introduction

Adolescence is a developmental period characterized by rapid physical and brain maturation changes (Sturman & Moghaddam, 2011). At this time, well-documented behavioral changes emerge including increased risk-taking (Casey et al., 2008; Crone & van Duijvenvoorde, 2021), sensation/novelty seeking (Del Giacco et al., 2021; Wills et al., 1994) and emotional lability (Bailen et al., 2019; Steinberg, 2005). Adolescence also serves as a critical period for the development and integration of self-identity (e.g., Erikson, 1956; Wilson, 1987) co-occurring with maturation changes specifically in brain regions supporting metacognition and self-reference (Arain et al., 2013; Blakemore, 2008).

The words an adolescent uses to describe themselves serves as a window into their evolving sense of self-concept. One facet of social anxiety receiving less consideration in the research literature is self-referential processing (Ingram, 1990; Spurr & Stopa, 2002). Self-referential processing is thought to be diagnostically nonspecific (Ingram, 1990) and positively associated with psychopathology severity (Woodruff-Borden et al., 2001). However, negative self-beliefs serve a primary role in maintaining social anxiety disorder (Clark & Wells, 1995; Hofmann, 2007; Rapee & Heimberg, 1997). Indeed, compared to controls, individuals with social anxiety disorder update self-evaluations to a greater degree when receiving negative feedback, (Koban et al., 2017).

The self-referential encoding task (SRET) has been extensively used to study self-referential processing of emotional stimuli. During the SRET, participants judge if negative and positive adjectives (e.g., stupid; capable) are self- or other-descriptive (Derry & Kuiper, 1981). The SRET is conceptualized as an affective decision-making self-referent task

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(Dainer-Best et al., 2018a, b) in which individuals endorse adjectives that are consistent with their self-concept or identity. Although there is a tendency for positive words to be perceived as being more self-relevant (i.e., self-positivity bias; Watson et al., 2007), patients diagnosed with social anxiety disorder typically show a *negativity* bias (Goldin et al., 2009; Miers et al., 2008; Moser et al., 2012). Not only is negative self-referential processing a critical component of the social anxiety phenotype (Dixon et al., 2022; Goldin et al., 2009; Talmon et al., 2021), it also has significant implications for treatment response (Katyal et al., 2020; Thurston et al., 2017)—improvement in self-views, as measured by the SRET, predict cognitive-behavioral and mindfulness-based treatment-related decreases in social anxiety symptoms (Thurston et al., 2017).

Previous work examining self-referential processing via the SRET mostly relies on mean number of negative/positive adjectives endorsed and/or average reaction times across groups and/or study conditions (i.e., positive versus negative adjectives) and largely within the context of depression research (Hayden et al., 2014; Kuiper & Derry, 1982; Mackrell et al., 2013; Poulsen et al., 2009). For instance, SRET performance concurrently and prospectively predicts child depressive symptoms (Goldstein et al., 2015; Hayden et al., 2013). The practice of utilizing participants' average task performance (i.e., between groups and/or study conditions) serves as a significant weakness, disregarding intraindividual variability in behavior across trials (Luu et al., 2000; Noorani, 2014). Fortunately, the expanding field of computational psychiatry (Corlett & Fletcher, 2014; Montague et al., 2012) offers methods for examining intraindividual variability in behavior across trials and critically for specifying latent processes underling observed behavior. With a focus on the latent processes that underlie behavior we can refine models of social anxiety to link these constituent processes to symptom domains (Beevers et al., 2019).

Drift Diffusion Model

Process models, such as the drift diffusion model (DDM), were developed to provide additional information about underlying cognitive mechanisms (Ratcliff, 1978; Ratcliff & McKoon, 2008). Inputs to a DDM include the distribution of responses times and performance on a binary decision-making task, whereas the DDM outputs are latent parameters thought to reflect cognitive components of decision-making.

Of particular relevance self-referential processing decision-making are the drift rate, response threshold, and starting point bias parameters (Fig 1). The drift rate reflects the degree with which an individual accumulates evidence across trials. Put simply, the drift rate can be interpreted as a measure of subjective task difficulty. In the case of the SRET, drift rate can be described as the efficiency of the cognitive processes involved in deciding

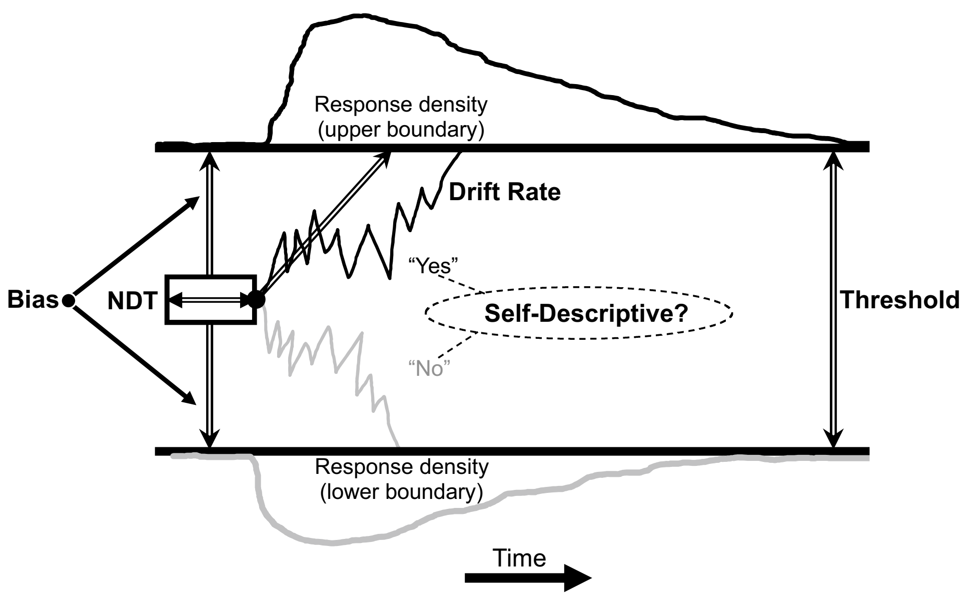

Fig. 1 Simulated trajectories of the two drift-processes during the SRET (black and grey lines). Evidence is accumulated over time (x-axis) where the drift-rate per trial continues until it reaches one of two boundaries. The degree of separation is defined by threshold that, when crossed, a response is initiated (e.g., button press); an individual's starting point along the y-axis is defined by the bias parameter. The arrow line in the beginning of the drift-processes indicates the non-decision time where no accumulation happens. Upper (black) and lower (grey) distributions indicate density plots for the two responses (yes, self-descriptive versus no, not self-descriptive). While simulation data is depicted here, HDDM uses a closed-form likelihood function

whether a negative (or positive) adjective is self-descriptive. Drift rate is sensitive to changes in perceptual-, memory-, value, and affective features of a decision, all of which might impact the efficiency of performance (Nayak et al., 2019; Vugt et al., 2019). Moreover, drift rate is influenced by affective state of the decision-maker (White et al., 2010), including anxiety in reward-based (Aylward et al., 2020) and attention bias tasks (Thompson & Steinbeis, 2021). As an example, an individual with high anxiety may be more likely to have a smaller drift rate (i.e., less efficient in self-referential processing) potentially reflecting less confident in their sense of self.

The decision threshold, on the other hand, reflects speed-accuracy tradeoff, where larger values of the parameter lead to more accurate, but slower choices. Specifically, decision threshold refers to the amount of information an individual considers before making a decision. Thus, the threshold separation influences the average amount of information needed to make a decision equally to both the upper (e.g., responding yes) and lower boundary (e.g., responding no). Larger threshold separation values reflect a more conservative decision style (Voss et al., 2004). In terms of the SRET, decision threshold can be thought of as reflecting the amount of evidence needed to accumulate to decide whether a negative (or positive) adjective is self-descriptive. For example, an individual with high anxiety may be more likely to have a larger decision threshold (i.e., more conservative decision style), as they are cautious in how they describe themselves due to fear providing the "wrong" answer. This parameter has been useful when modeling brain dynamics and emotional decision-making (Forstmann et al., 2008; Mansfield et al., 2011; Nayak et al., 2019).

The starting point bias parameter (simply referred to as the bias parameter throughout) reflects a preference for one response (e.g., "yes") over the alternative (e.g., "no"). Thus, the preferred option requires less evidence to accumulate while much more evidence is needed to reach the alterative option. Applied to the SRET, the bias parameter governs an individual's potential preference for responding yes/no irrespective of the self-descriptive adjective. For example, an individual with high anxiety may have a bias towards responding "no" (and therefore, requiring much more evidence to accumulate to respond "yes" for any given adjective) due to feeling too self-conscious to endorse any given positive/negative self-descriptor. Support for examining the bias parameter when explaining adolescent SRET performance comes from a recent study by Hitchcock et al. (2022), where the starting-point bias term further improved SRET DDM fit in a sample of depressed adults.

An assumption of the DDM is that the total choice response time includes a decision and a nondecision portion. While aspects of the decision time are reflected in the three aforementioned parameters, the nondecision time parameter is thought to capture time spent on perceptual and motor processes. While important for modeling purposes, the non-decision time was not the focus of the present study.

Current Study

Despite the promising advances in computational modeling of cognitive processes, only a handful of recent studies have applied this technique to the SRET (e.g., Beevers et al., 2019; Hsu et al., 2020), where the focus was on adult depressive symptomatology (c.f., Dainer-Best et al., 2018a, b). Our goal was to apply a hierarchical DDM to youth SRET performance to evaluate whether a computational modeling approach would uncover linkages between parameters reflecting the underlying cognitive processes of decision making on the SRET and individual differences in social anxiety symptoms. First, we compared the fit of several drift–diffusion models of youth SRET performance. We extracted the parameters of the best-fitting model to determine if this approach is useful in accounting for individual differences in social anxiety symptoms. Second, given the literature linking SRET and depression (e.g., Dainer-Best et al., 2018a, b), we examined the relation between model parameters and depressive symptomatology. Third, we compared these associations to the ratio of positive to negative adjectives endorsed, with the expectation that modeling SRET performance will prove to be a valuable method in uncovering unique information regarding anxiety and depression in youth. Fourth, we evaluated whether model parameters were specific to social anxiety, anxiety more broadly (i.e., physical anxiety and harm avoidance symptoms), or depressive symptoms. We expected that parameter estimates of SRET behavior would be specific to both social anxiety and depressive symptoms. This is particularly important as it has the potential to guide future research looking to utilize this self-referential processing tasks to better predict individual differences in psychopathology and treatments that link self-views to treatment change processes (Thurston et al., 2017).

Methods

Participants & Procedure

The initial sample consisted of 109 healthy adolescents ($n_{male} = 57$, $n_{female} = 51$, one unknown due to missing data) were between the ages of 12–17 years old ($M_{age} = 14.44$, $SD = 1.72$). Youth were recruited as part of a large-scale study that included multiple paradigms including the SRET (detailed below) and the assessment of EEG, reported elsewhere (Ke et al., 2018, 2020). Three participants were removed due to large amount of missing demographic/self-report data. Thus, the final sample of 106 adolescents ($n_{male} = 56$, $n_{female} = 50$, $M_{age} = 14.49$, $SD = 1.70$) was used for our analyses. Youth predominantly identified as White (n = 81, 76.4%), followed by Black (n = 9, 8.5%), Hispanic (n = 6, 5.7%), and Asian (n = 6, 5.7%). Four (3.8%) participants identified as other or unknown racial/ethnic origins. The majority of the participants were right-handed (i.e., 95.1%). All youth had corrected-to-normal vision and were fluent English speakers. Participants were recruited through a mass mailing list targeting New Haven, CT, and the surrounding towns. On average, our sample had minimal to mild depression symptoms ($M = 8.86$, $SD = 6.21$, Range = 0 to 26) (Kovacs & Preiss, 1992) and average level of anxiety ($M = 47.78$, $SD = 15.79$, Range = 20 to 98) (March, 1998). Adolescents were compensated $80 USD for participation and their parent or guardian received $10. Parents provided written informed consent and adolescents provided written informed assent following procedures approved by the Yale School of Medicine Human Investigation Committee.

During the cross-sectional study, parents and adolescents completed questionnaires in different rooms on tablet computers. Information regarding gender, age, ethnicity, and socioeconomic status was obtained from the parent. During the study, adolescents were seated in a dimly lit, sound-attenuated room 24 inches away from a 19-inch LCD monitor.

Measures

The Self-Referential Encoding Task (SRET). The SRET required participants to read a single-word adjective (e.g., "gloomy", "joyful") and indicate whether the word was self-descriptive or not self-descriptive. The Oregon Self-Concept inventory (OSCI-II; Tucker et al., 2003) and previous studies with the SRET (Auerbach et al., 2015; Waters & Tucker, 2013) were used to create the 104-word list (see Supplemental A). The 52 positive and 52 negative adjectives were balanced for number of letters and reading level. Participants completed three practice trials using affectively neutral words (e.g., "tall", "boy") and confirmed that they understood the instructions prior to the task. Each trial consisted of the stimulus (i.e., single word adjective) was presented (500 ms), followed by a fixation cross (1800 ms), and then the question ("Does this word describe you?"), to which participants answered by pressing buttons corresponding to "yes" or "no" on a button response box as quickly but accurately as possible. The inter-trial interval (during which a fixation cross was displayed) was jittered between 1500 and 1700 ms. Participants completed all 104 trials, which were presented in a pseudorandom order with no more than two stimuli of the same valence presented in succession. Stimuli were presented using E-Prime 2.0 (PST, Sharpsburg, PA, USA).

Children's Depression Inventory (CDI). The CDI is a 27-item self-report questionnaire used to assess depressive symptoms in children and adolescents (Kovacs & Preiss, 1992). The CDI may be completed by children and adolescents between the ages of 7 and 17 years and administration takes approximately 15 min. Each CDI item assesses one depression symptom; youth are presented with three choices graded from 0 to 2 in the direction of increasing symptom severity (e.g., "*I am sad once in a while*" [0], "*I am sad many times*" [1], or "*I am sad all the time*" [2]). Items on the CDI address a number of factors, including negative mood, interpersonal problems, ineffectiveness, anhedonia, and negative self-esteem. The reliability and validity of the CDI has been measured extensively and found to be adequate in clinical and non-clinical samples of children and adolescents (e.g., Saylor et al., 1984). In the current study, the CDI demonstrated good internal consistency ($\alpha = 0.85$).

Multidimensional Anxiety Scale for Children. The MASC (March, 1998) is a 45-item child self-report questionnaire for symptoms of anxiety. The MASC is a 4-point Likert scale, and each item (e.g., "I worry about other people laughing at me") is rated as either, "*Never true about me*" (0), "*Rarely true about me*" (1), "*Sometimes true about me*" (2), or "*Often true about me*" (3). Total scores range from 0 to 120, with high scores indicating greater childhood anxiety. The four empirically derived factor index scores are Social Anxiety, Separation Anxiety, Harm Avoidance, and Physical Symptoms. The MASC has shown good internal consistency ratings from 0.70 to 0.83 and Cronbach's alpha ranging from 0.74 to 0.85 (March, 1998). 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 was found to have good internal consistency ($\alpha = 0.86$).

Data-analysis Approach

We examined youth SRET performance using a specific sequential sampling method known as drift diffusion modeling with stimulus coding (Ratcliff & McKoon, 2008; Wiecki et al., 2013). Models were run with the Hierarchical Drift Diffusion Modeling (HDDM 0.8.0) Python toolbox (Wiecki et al., 2013), where trial type served as a factor with two levels (i.e., positive versus negative self-descriptive adjectives). For all models, 20,000 samples were generated from posteriors with the first 5,000 serving as a burn-in, and every second sample was discarded as part of a thinning procedure. To informally test model convergence, trace, autocorrelation, and marginal posterior plots of model parameters were inspected. To formally test convergence, the Gelman-Rubin statistic (Gelman & Rubin, 1992) was calculated to confirm identical within- and between-chain variance of different runs of the same mode (i.e., a value of 1.0 if the samples of the different chains are indistinguishable). The Gelman-Rubin statistic was calculated (10,000 iterations, 1,000 burn-in each) for each participant and found to be $\geqq 1.1$. The deviance information criterion (Dickerson & Kemeny, 2004) was used for model comparison, where lower scores indicate a better fitting model.

While group models are useful, they do not typically have the power to detect the effect of condition on a within-subject effect (e.g., condition on an individuals' parameter estimate), as there would be large posterior variance in all of the drift rates, for example, that overlap. In contrast to the between-subject difference in parameters as a function of SRET conditions (i.e., positive versus negative adjective trials), the within-subjects model does not make the assumption that the two conditions are completely independent. Within-subject models were then conducted to further probe the effect of task condition on individual subjects' parameter estimates; a particular parameter's intercept is used to capture overall performance in the positive adjective condition as a baseline, which is then expressed relative to negative adjective trials. The specific within-subject model was determined from the best-fitting group model.

We examined the relation between individual parameter estimates of the best fitting model (i.e., drift rate, decision threshold, bias, nondecision time), adjective endorsement ratio on the SRET (i.e., typical metric used in past studies), anxiety domains (i.e., physical symptoms, harm avoidance, social anxiety), and depressed mood domains (i.e., negative mood, interpersonal problems, ineffectiveness, anhedonia, negative self-esteem) via Pearson correlations. Next, three separate linear regression models were run to answer three specific research questions. Our regression analyses focused on the drift rate (Dainer-Best et al., 2018a, b) and starting point bias (Hitchcock et al., 2022) during the SRET as they have been found to be relate to psychopathology. We chose the Negative Mood subscale of the CDI, as it has been found to be the most important depressive symptom when predicting adult SRET performance from a diffusion framework (Beevers et al., 2019).

First, we were interested in whether drift rate and/or starting point bias predicted youth social anxiety scores above-and-beyond typical metrics of SRET task performance (i.e., adjective endorsement ratio). Second, we were interested in whether drift rate and/or starting point bias were specific to social anxiety, or anxiety symptoms more generally; therefore, separate regression models predicting drift rate and starting point bias were run with anxiety domains (i.e., physical symptoms, harm avoidance, social anxiety) serving as predictor variables. All variables were centered prior to regression analyses. Age and sex were considered as covariates depending on whether they are found to significantly correlate with respective outcome variables. Correlational and regression analyses were conducted in R.

Results

Group Models

We first set out to compare two null models to determine if the bias parameter improved overall model fit. The best-fitting null model (i.e., with or without bias) would inform our subsequent model comparisons. Specifically, whether the seven models, differing in which parameters were allowed to vary as a function of SRET task condition, would focus on the three- (i.e., drift rate, decision threshold, and non-decision time) or four-parameter (i.e., inclusion of a bias parameter) DDM. As shown in the first two rows of Table 1, the four-parameter DDM that included the bias parameter was a better fit to participants' SRET task performance (null model without bias, DIC = 2852; null model with bias, DIC = 2841).

Next, a series of models were examined to explore which latent parameters, when allowed to vary by task condition (i.e., positive versus negative adjective trials), provided the best fit to participants' performance. Allowing parameters to vary by task condition creates different parameter estimates for each condition (for each participant), thus indicating parameter behavior was affected by SRET conditions.

Table 1 Convergence statistics of models examined

Model	DIC
1. Null Model without Bias	2852
2. Null Model with Bias	**2841**
3. Drift Rate Split Model	702
Δ Null Model	(–2139)
4. Threshold Split Model	2863
Δ Null Model	(+22)
5. Bias Split Model	2827
Δ Null Model	(–14)
6. Drift Rate & Threshold Split Model	692
Δ Null Model	(–2149)
7. Threshold & Bias Split Model	2850
Δ Null Model	(+9)
8. Drift Rate & Bias Split Model	**654**
Δ Null Model	**(–2187)**
9. Drift Rate, Threshold, & Bias Split Model	661
Δ Null Model	(–2180)

Hierarchical drift diffusion modeling utilized stimulus coding

DIC deviance information criterion, *Split* parameters allowed to vary as a function of SRET condition, *bold* best fit, *Δ Model* change in model convergence statistics from null model

Table 1 provides the fit statistics of the seven models examined. When compared to the null model with bias, the model that allowed both the drift rate and bias parameters to vary by condition provided the best fit to youths' behavioral data (ΔDIC = –4056), where lower values indicate better model fit. Figure 2a, b provides a visualization of the posterior probability of the drift rate (positive adjectives: $M = 1.00$, $SD = 0.90$; negative adjectives: $M = -1.39$, $SD = 0.90$) and bias (positive adjectives: $M = 0.52$, $SD = 0.02$; negative adjectives: $M = 0.50$, $SD = 0.02$) parameters vary by SRET conditions. Thus, the parameters were extracted from this best-fitting model to examine their relation to social anxiety and depressive symptomatology.

Visual inspection of the trace, autocorrelation, and the marginal posterior of the parameters provided support for model convergence (see Supplemental B). Additional evidence for model convergence comes from the Gelman-Rubin statistic, where all participants had an $\check{R} \leq 1.1$, indicating that the Markov-chains were indistinguishable.

Within-subject Models

Within-subject models provides additional information on the effects of task condition on individual subjects' parameter estimates. As shown in Fig. 2c, d, the drift rate and bias intercepts (referring to the positive adjective condition) were

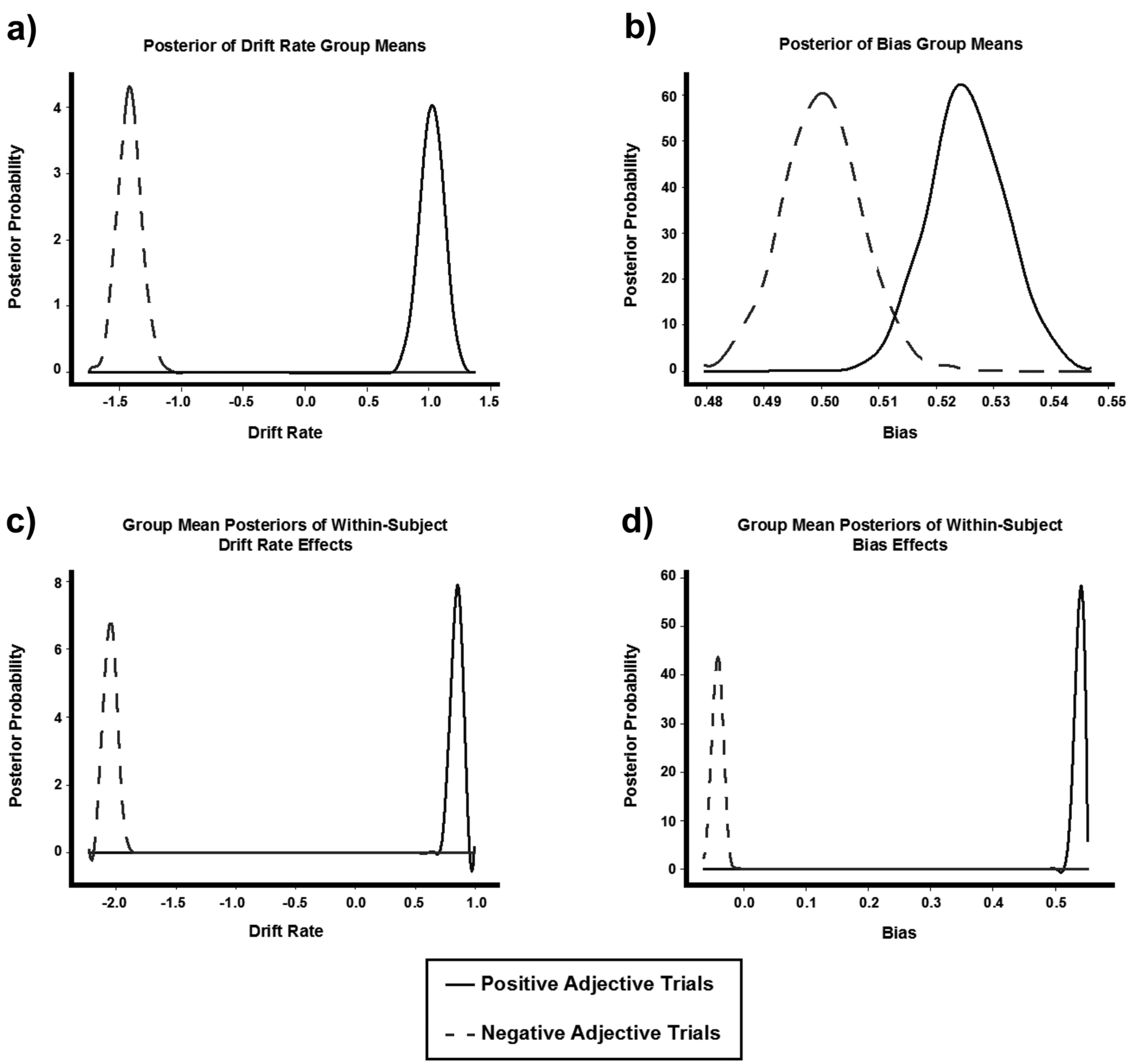

Fig. 2 Posterior probability of drift rate group means for positive (blue) and negative (red) adjective trials during the SRET (**a**); posterior probability of bias group means during the SRET (**b**); within-subject model group mean posterior probability of drift rate during the SRET (**c**); within-subject model group mean posterior probability of bias during the SRET (**d**)

Table 2 Correlations among DDM parameters, SRET task performance, anxiety, and depression

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.
1. Drift Rate (Pos)	——															
2. Drift Rate (Neg)	**–0.64**	——														
3. Bias (Pos)	0.24	**–0.38**	——													
4. Bias (Neg)	0.15	–0.03	–0.08	——												
5. Decision Threshold	–0.17	0.16	–0.11	0.05	——											
6. NDT	0.03	0.06	0.06	0.02	**–0.26**	——										
7. Endorsement Ratio	**–0.60**	**0.72**	**–0.28**	0.02	–0.00	0.17	——									
8. Sex	0.07	0.18	–0.08	–0.14	0.02	**0.37**	0.15	——								
9. Age	0.06	0.03	–0.02	0.11	–0.21	0.19	0.04	0.04	——							
10. Physical Symptoms	–0.22	**0.36**	–0.12	–0.07	–0.04	0.15	0.18	0.10	–0.05	——						
11. Avoidance	0.20	–0.13	0.03	0.14	0.03	0.06	–0.06	0.03	0.01	0.23	——					
12. Social Anxiety	**–0.27**	**0.41**	**–0.31**	–0.07	0.01	0.12	0.21	0.20	0.03	**0.60**	0.11	——				
13. Negative Mood	**–0.30**	**0.51**	–0.16	**–0.32**	–0.17	0.21	0.26	0.22	0.07	**0.51**	–0.06	**0.50**	——			
14. Interpersonal Problems	**–0.37**	**0.27**	–0.11	–0.14	–0.05	–0.02	0.12	–0.15	–0.16	0.20	**–0.34**	0.04	**0.34**	——		
15. Ineffectiveness	–0.18	**0.34**	–0.20	–0.21	–0.05	–0.05	0.11	–0.02	–0.06	**0.37**	–0.17	**0.42**	**0.36**	**0.47**	——	
16. Anhedonia	**–0.41**	**0.43**	–0.23	–0.19	–0.12	0.07	0.20	0.06	0.05	**0.52**	0.01	**0.49**	**0.56**	**0.36**	**0.50**	——
17. Negative Self-Esteem	**–0.40**	**0.51**	**–0.29**	**–0.27**	–0.04	0.16	**0.36**	0.11	0.06	**0.40**	–0.06	**0.43**	**0.57**	**0.43**	**0.41**	**0.51**

Bold $p < 0.01$, *Pos* positive adjective trials of the SRET, *Neg* negative adjective trials of the SRET, *NDT* non-decision time

positive, whereas the within-subject effects of the negative adjective condition were negative. None of the four effects (i.e., drift rate and bias for both SRET conditions, respectively) overlapped with zero. These results indicated that processing negative adjectives as potentially being self-referential decreased processing efficiency (i.e., drift rate) but facilitate a negative bias – requiring more information to endorse the negative adjective as being self-descriptive.

Correlation Analyses

We next examined the Pearson correlations between DDM parameter estimates, SRET endorsement ratio, anxiety (i.e., physical, harm avoidance, and social anxiety symptoms), and depression (i.e., negative mood, interpersonal problems, ineffectiveness, anhedonia, and negative self-esteem). We also included demographic variables (i.e., age and sex) to inform the potential inclusion of covariates in our regression analyses. As shown in Table 2, drift rate (processing efficiency) during negative adjective trials was significantly, positively related to physical anxiety ($r=0.36$, $p<0.01$), social anxiety ($r=0.41$, $p<0.01$), negative mood ($r=0.51$, $p<0.01$), interpersonal problems ($r=0.27$, $p<0.001$), ineffectiveness ($r=0.34$, $p<0.01$), anhedonia ($r=.43$, $p<0.01$), and negative self-esteem ($r=0.51$, $p<0.001$). Drift rate during positive adjective trials, on the other hand, was significantly, negatively associated with many of the same variables with the exception of physical anxiety symptoms and ineffectiveness. Bias parameter estimates during negative adjective trials was significantly (negatively) related to negative mood ($r=–0.32$, $p<0.01$) and negative self-esteem ($r=–0.27$, $p<0.01$). Bias during positive adjective trials was negatively associated with social anxiety ($r=–0.31$, $p<0.001$) and negative self-esteem ($r=0.29$, $p<0.01$). Notably, only negative self-esteem was associated with the endorsement ratio during the SRET ($r=0.36$, $p<0.01$).

Regression Analyses

Next, linear regression models were run to explore whether modeling provides utility beyond typical metrics used to quantify participants SRET performance and whether parameter estimates psychopathology specificity (within anxiety and between social anxiety and depression symptoms, respectively). Our correlational analyses indicated that including demographic covariates was unwarranted. As shown in Table 3, the overall model predicting social anxiety was significant, $F(5, 105)=5.59$, $p<0.001$, $R^2=0.22$, Adjusted $R^2=0.18$. Endorsement ratio, $t(105)=–1.44$, $p=0.15$, starting point bias (negative), $t(105)=–0.71$, $p>0.05$, and drift rate (positive), $t(105)=–0.26$, $p>0.05$, were not significant predictors. In contrast, both drift rate (negative) ($\beta=0.45$, $t(105)=3.19$, $p<0.01$, 95% CI: [0.17, 0.73]) and starting point bias (positive) ($\beta=–0.20$, $t(105)=–2.00$, $p<0.05$, 95% CI: [–0.37, –0.03]) were significant predictors of youth social anxiety symptoms.

Four regression models predicting drift rate (positive), drift rate (negative), starting point bias (positive), and

Table 3 Linear regression: endorsement ratio of the SRET, drift rate (positive and negative), and starting point bias (positive and negative) predicting youth self-reported social anxiety

Social Anxiety	*β*	*SE*	*t*	*p*	*95% CI* Lower	Upper
SRET Endorsement	–0.19	0.13	–1.44	0.15	–0.45	0.07
Positive Drift Rate	–0.03	0.12	–0.26	0.80	–0.27	0.21
Negative Drift Rate	**0.45**	**0.14**	**3.19**	**0.00**	**0.17**	**0.73**
Positive Bias	**–0.20**	**0.10**	**–2.00**	**0.04**	**–0.37**	**–0.03**
Negative Bias	–0.06	0.09	–0.71	0.48	–0.24	0.11
Model						
R^2	**0.22**					
Adj. R^2	**0.18**					
F(5, 105)	**5.59**					

Bold $p < 0.05$l; predictors and outcome were converted to z-scores, *SRET* self-referential evaluation task, *Bias* starting point bias parameter, *β* standardized beta, *SE* standard error

starting point bias (negative) were conducted with anxiety domains (i.e., physical symptoms, harm avoidance, social anxiety) serving as predictor variables. As seen in Table 4, the model predicting drift rate during positive SRET trials was significant, F(3, 105) = 5.61, $p < 0.01$, $R^2 = 0.14$, Adjusted $R^2 = 0.12$, where harm avoidance was the only significant predictor (β = 0.26, *t*(105) = 2.79, $p < 0.01$, 95% CI: [0.08, 0.45]). The model predicting drift rate during negative trials was also significant, F(3, 105) = 10.14, $p < 0.001$, $R^2 = 0.23$, Adjusted $R^2 = 0.21$; physical anxiety (β = 0.23, *t*(105) = 2.04, $p < 0.05$, 95% CI: [0.01, 0.45]), harm avoidance (β = –0.21, *t*(105) = –2.36, $p < 0.05$, 95% CI: [–0.39, –0.03]), and social anxiety (β = 0.30, *t*(105) = 2.74, $p < 0.01$, 95% CI: [0.08, 0.52]). In an exploratory nature, two models predicting positive and negative starting point bias were also conducted. Only the positive starting point bias model was significant, F(3, 105) = 3.97, $p < 0.01$, $R^2 = 0.11$, Adjusted $R^2 = 0.08$, where social anxiety was the only significant predictor (β = –0.37, *t*(105) = –3.17, $p < 0.01$, 95% CI: [–0.61, -0.14]). See Table 5.

Two regression models (see Table 6) were run, as we were interested in whether negative mood[1] and/or social anxiety significantly predict youths drift rate (positive and negative) during the SRET. The model predicting positive drift rate was significant, F(2, 105) = 6.36, $p < 0.001$, $R^2 = 0.11$, Adjusted $R^2 = 0.09$, and only negative mood was a significant, negative predictor (β = –0.23, *t*(105) = –2.12, $p < 0.05$, 95% CI: [–0.44, –0.02]). The negative drift rate model was also significant, F(2, 105) = 20.92, $p < 0.001$, $R^2 = 0.29$, Adjusted $R^2 = 0.28$, where both negative mood (β = 0.40, *t*(105) = 4.17, $p < 0.001$, 95% CI: [0.21, 0.60])

Table 4 Linear regression: physical anxiety symptoms, harm avoidance symptoms, and social anxiety symptoms predicting youth drift rate (positive and negative) during the SRET

Positive Drift Rate (Negative Drift Rate)	*β*	*SE*	*t*	*p*	*95% CI* Lower	Upper
Physical Anxiety	–0.16	0.12	–1.36	0.18	–0.39	0.07
	(0.23)	**(0.11)**	**(2.04)**	**(0.04)**	**(0.01)**	**(0.45)**
Harm Avoidance	**0.26**	**0.10**	**2.79**	**0.01**	**0.08**	**0.45**
	(–0.21)	**(0.09)**	**(–2.36)**	**(0.02)**	**(–0.39)**	**(–0.03)**
Social Anxiety	–0.20	0.12	–1.74	0.09	–0.43	0.03
	(0.30)	**(0.11)**	**(2.74)**	**(0.01)**	**(0.08)**	**(0.52)**

Positive Drift Rate Model		**Negative Drift Rate Model**	
R^2	**0.23**	R^2	**0.14**
Adj. R^2	**0.21**	Adj. R^2	**0.12**
F(3, 105)	**10.14**	F(3, 105)	**5.61**

Bold $p < 0.05$; predictors and outcome were converted to z-scores, *SRET* self-referential evaluation task, *β* standardized beta, *SE* standard error

[1] Both models were also run replacing negative mood with the CDI total score, where both positive and negative drift rate was only significantly predicted by the CDI total score (See Supplemental C).

Table 5 Linear regression: physical anxiety symptoms, harm avoidance symptoms, and social anxiety symptoms predicting youth starting point bias (positive and negative) during the SRET

Positive Bias (Negative Bias)		*β*	*SE*	*t*	*p*	*95% CI* Lower	Upper
	Physical Anxiety	0.10	0.12	0.81	0.42	–0.14	0.34
		(–0.09)	(0.13)	(–0.70)	(0.49)	(–0.34)	(0.16)
	Harm Avoidance	0.04	0.10	0.45	0.65	–0.15	0.24
		(0.16)	(0.10)	(1.63)	(0.11)	(–0.04)	(0.37)
	Social Anxiety	**–0.37**	**0.12**	**–3.17**	**0.00**	**–0.61**	**–0.14**
		(–0.04)	(0.12)	(–0.29)	(0.77)	(–0.28)	(0.21)
Positive Bias Model				**Negative Bias Rate Model**			
	R^2	0.03		R^2	**0.11**		
	Adj. R^2	0.00		Adj. R^2	**0.08**		
	F(3, 105)	1.10		F(3, 105)	**3.97**		

Bold $p<0.05$; predictors and outcome were converted to z-scores, *SRET* self-referential evaluation task, *Bias* starting point bias parameter, *β* standardized beta, *SE* standard error

and social anxiety ($\beta=0.22$, $t(105)=2.21$, $p<0.05$, 95% CI: [0.02, 0.41]) were significant predictors.

Finally, two regression models predicting starting point bias (positive and negative) by way of negative mood[2] and social anxiety (see Table 7) were conducted in an exploratory nature. The model predicting positive starting point bias was significant, $F(2, 105)=5.43$, $p<0.001$, $R^2=0.10$, Adjusted $R^2=0.08$, and only social anxiety was a significant, negative predictor ($\beta=-0.31$, $t(105)=-2.81$, $p<0.01$, 95% CI: [–0.53, –0.09]). In contrast, in the significant negative starting point model, $F(2, 105)=3.11$, $p<0.01$, $R^2=0.06$, Adjusted $R^2=0.04$, only negative mood was a significant predictor ($\beta=-0.26$, $t(105)=-2.39$, $p<0.05$, 95% CI: [–0.49, –0.05]).

Discussion

With the burgeoning development of the self as social object during adolescence, self-referential processing plays a central role in anticipatory and reactive processing in social contexts (Spurr & Stopa, 2002). Used extensively to study self-referential processing of emotional stimuli, the self-referential encoding task (SRET) asks to participants judge if negative and positive adjectives (e.g., stupid; capable) are self- (or other-) descriptive. The majority of past research on the SRET in youth focuses on depression (e.g., Auerbach et al., 2015; Hayden et al., 2014; Kuiper & Derry, 1982) utilizing typical metrics of task performance such as mean positive and negative SRET scores (e.g., Liu et al., 2020).

Table 6 Linear regression: negative mood and social anxiety symptoms predicting youth positive and negative drift rates during the SRET

Positive Drift Rate (Negative Drift Rate)		*β*	*SE*	*t*	*p*	*95% CI* Lower	Upper
	Negative Mood	**–0.23**	**0.11**	**–2.12**	**0.04**	**–0.44**	**–0.02**
		(0.40)	**(0.10)**	**(4.17)**	**(< 0.001)**	**(0.21)**	**(0.60)**
	Social Anxiety	–0.15	0.11	–1.43	0.16	–0.37	0.06
		(0.21)	**(0.10)**	**(2.21)**	**(0.03)**	**(0.02)**	**(0.41)**
Positive Drift Rate Model				**Negative Drift Rate Model**			
	R^2	**0.11**		R^2	**0.29**		
	Adj. R^2	**0.09**		Adj. R^2	**0.28**		
	F(2, 105)	**6.36**		F(2, 105)	**20.92**		

Bold $p<0.05$; predictors and outcome were converted to z-scores, *SRET* self-referential evaluation task, *β* standardized beta, *SE* standard error

[2] Both models were also run replacing negative mood with the CDI total score; both positive and negative starting point bias models were significantly predicted by social anxiety and CDI total score, respectively (See Supplemental D).

Table 7 Linear regression: negative mood and social anxiety symptoms predicting youth positive and negative starting point biases during the SRET

Positive Bias (Negative Bias)		*β*	*SE*	*t*	*p*	*95% CI* Lower	Upper
	Negative Mood	–0.01	0.11	–0.10	0.92	–0.23	0.21
		(**–0.26**)	(**0.11**)	(**–2.39**)	(**0.02**)	(**–0.49**)	(**–0.05**)
	Social Anxiety	**–0.30**	**0.11**	**–2.81**	**0.01**	**–0.53**	**–0.09**
		(0.06)	(0.11)	(0.55)	(0.58)	(–0.16)	(0.28)
Positive Bias Model					**Negative Bias Rate Model**		
R^2	**0.10**				R^2	**0.06**	
Adj. R^2	**0.08**				Adj. R^2	**0.04**	
F(2, 105)	**5.43**				F(2, 105)	**3.11**	

Bold $p < 0.05$; predictors and outcome were converted to z-scores, *SRET* self-referential evaluation task, *Bias* starting point bias parameter, *β* standardized beta, *SE* standard error

Notwithstanding the promising advances in computational modeling of cognitive processes, only a few recent studies apply this technique to the SRET in adults (e.g., Allison et al., 2021; Hsu et al., 2020). Thus, we applied a hierarchical drift diffusion framework (DDM; Ratcliff, 1978) to youth performance to examine associations between parameters reflecting the underlying cognitive processes of decision making on the SRET, with a focus on individual differences in social anxiety symptoms. We hypothesized that parameter estimates of SRET behavior would be related to both youth self-reported social anxiety as well as depressive symptoms (Dainer-Best et al., 2018a, b).

Our results provide support for our hypothesis—drift rate and starting point bias parameters of the DDM fit to youth SRET performance and were strongly associated to social anxiety and depressive symptoms. Moreover, our regression analyses indicated that unique variance associated with both youth self-reported social anxiety and depression symptom scales predicted drift rate during negative adjective trials of the SRET. Specifically, youth processing efficiency while deciding on whether a negative adjective (e.g., stupid) was self-descriptive, predicted youth level of social anxiety while taking depressive symptom severity into consideration, and vice versa. These findings are consistent with a robust literature linking SRET performance with youth depression. Past research finds that child performance on the SRET concurrently and prospectively predicts depressive symptoms (Hayden et al., 2013); lower positive endorsement during the SRET at age six predicts an increase in depressive symptoms at age nine (Goldstein et al., 2015). Similar to the past work emphasizing the importance of positive adjective endorsement on the SRET and depression (Goldstein et al., 2015; Liu et al., 2020; Tracy et al., 2021), we observed a strong negative relation between drift rate during positive adjective trials and negative mood, but not social anxiety.

Our results build upon past work by providing evidence that performance during the SRET, when modeled from a drift diffusion framework, is not uniquely related to depression-related constructs but also facets of anxiety. Our correlational analyses indicate that parameters reflecting the underlying cognitive processes governing SRET behavior are strongly related social anxiety and physical anxiety, as well as interpersonal problems, feelings of ineffectiveness, loss of pleasure, and negative self-esteem. In regard to youth drift rate during negative adjective trials, we found a positive association with these six aforementioned variables. In contrast, drift rate during positive trials was negatively associated with four of the same symptom domains, with the exception of physical anxiety symptoms and feelings of ineffectiveness. While all three anxiety facets (i.e., physical anxiety, harm avoidance, and social anxiety) were related to drift rate during negative SRET trials, positive trial drift rate was only predicted by harm avoidance. Given the literature speculating that youth SRET performance during positive adjective trials may serve as a protective factor for future depressive symptoms (e.g., Tracy et al., 2021), future research may benefit from exploring the role of harm avoidance in the association between positive self-referential views and prospective depressive symptoms.

The bias latent parameter reflects favoring one decision boundary to the detriment to the alternative boundary. Larger bias values indicate needing less evidence to endorse a given adjective as self-descriptive, but more evidence to deny said adjective—smaller values indicate requiring more information to endorse a given adjective and less information to deny the adjective. Applied to the SRET, in positive trials (compared to negative trials), less evidence was required to endorse an adjective as being self-descriptive, while more evidence was needed to reject a positive adjective as being self-descriptive. This finding is consistent with the well-known self-positivity bias (Watson et al., 2007), and may reflect youth tendency to view information about self as being associated with a positive valence (Mezulis et al., 2004; Pahl & Eiser, 2005), where positive traits are assumed to be stable and internal personality characteristics. In contrast, during negative trials of the SRET, youth needed approximately the same amount of information to endorse (i.e., respond 'yes') or reject (i.e., respond 'no') any given negative adjective. We observed the tendency to require less evidence to endorse a negative adjective as self-descriptive (but more evidence to deny a negative adjective) was related to less self-reported negative mood and negative self-esteem. It is conceivable that more well-adjusted youth (i.e., youth with lower negative mood and low negative self-esteem) needed less evidence to endorse a negative adjective as admitting to such is not perceived as being a threat to their healthy sense of self. Conversely, during positive SRET trials, less evidence to endorse a positive adjective as self-descriptive was associated with less self-reported negative self-esteem, as well as less social anxiety. Notably, our regression analyses predicting the starting point bias during positive and negative adjective trials (respectively) uncovered a dissociation between social anxiety and negative mood (as well as total depressive symptoms, see supplemental materials). Specifically, while negative mood (but not social anxiety) negatively predicted bias during negative adjective trials, social anxiety (but not negative mood, nor total depressive symptoms) negatively predicted bias during positive adjective trials.

While the correlations between the bias parameter and anxiety- and depression-related symptoms were surprising, a growing SRET literature indicates that positive self-referential processing may be a more robust predictor of future depressive symptoms (Goldstein et al., 2015; Liu et al., 2020). Goldstein et al. (2015), for example, found that negative processing at age six did not predict depressive symptoms at age nine nor did depressive symptoms at age six predict SRET processing scores at age nine. This led Goldstein et al. (2015) to posit that less positive processing of stimuli may reflect a vulnerability for future depressive symptoms. This is consistent with functional imaging of youth while completing the SRET. Children at high-risk for depression (compared to those at low-risk) were found to have greater activation in the ventrolateral prefrontal cortex and ventromedial prefrontal cortex during the positive-word trials (Liu et al., 2020). Interestingly, ventrolateral prefrontal cortex activation mediated the association between maternal depression and child depressive symptoms, but only when children had lower positive self-schemas (Liu et al., 2020).

Our findings also align with and extend recent work linking SRET performance to anxiety. For example, adults with social anxiety disorder tend to endorse more negative and less positive self-descriptors compared to healthy controls (Dixon et al., 2022; Thurston et al., 2017). Tracy et al. (2021) found that greater negative self-referential views were related to more generalized anxiety symptoms at the start of university and predicted reactivity to a naturalistic laboratory stressor. Similar to work on depression and self-referential processing (Goldstein et al., 2015; Liu et al., 2020), Tracy et al. also found that greater positive self-referential views may serve as a protective factor, as it was associated with a larger decline in generalized anxiety symptoms over students' time in university (Tracy et al., 2021). In another study by Katyal et al. (2020), meditators (compared to non-meditators) endorsed significantly more pleasant and fewer unpleasant words. They also found differences in the late-positive-potential event-related potential during the SRET. Our findings are consistent with this literature, while also extending it to a sample of adolescents. Specifically, we found that youth SRET performance was not only related to social anxiety, but also physiological anxiety symptoms and, to some extent, harm avoidance—all three anxiety facets examined (i.e., physical anxiety, harm avoidance, and social anxiety) were associated with youth drift rate during the SRET. Starting point bias during positive trials, on the other hand, appeared to be uniquely predicted by social anxiety symptoms.

We found evidence supporting the value in modeling SRET performance when compared to examining typical metrics of task behavior (i.e., positive–negative endorsement ratio). Our regression analysis indicated that the drift rate during the SRET predicted youth social anxiety symptoms, above-and-beyond that of mean performance used to quantify SRET performance. Results presented also indicated that a standard hierarchical DDM was sufficient to capture group-level differences in youth self-referential processing during positive- and negative-adjective conditions through the drift rate and bias threshold latent parameters. The inclusion of both drift rate and bias parameters (allowed to vary by task condition) provided the best-fit for participants' self-referential processing. This indicates that differences in youth behavior when deciding on whether positive and negative adjectives are self-descriptive is best captured through individual differences in processing efficiency (i.e., drift rate) and relative starting point (i.e., bias), where the latter governs the decision threshold in favor of one response (e.g., less information to respond 'yes' self-descriptive) at the cost of the alterative option (e.g., needing more information to respond 'no' not self-descriptive). Our modeling results converge with the one study to-date that applied a drift diffusion framework to analyze youth SRET performance (Dainer-Best et al., 2018a, b). While the same model was found to be the best fit (i.e., both drift rate and bias allowed to vary by condition), our results slightly diverge in that Dainer-Best et al. (2018a, b) who found that the decision threshold, along with other parameters, significantly predicted depression. In our correlational analyses, we did not find any meaningful associations between the decision threshold during the SRET and depression or anxiety. It is possible that this reflects differences in packages used to estimate parameters, as they utilized fast-dm (Voss et al., 2004) whereas we relied on HDDM (Wiecki et al., 2013). More likely though, is that the latter package (HDDM) allowed for our data to be analyzed through stimulus coding, as opposed to the DDM standard accuracy coding. Sample differences could also account for differences in our findings.

While our HDDM approach serves to highlight the unique associations between latent parameters of decision-making on the SRET, study limitations also warrant consideration. First, we relied on a community sample. Thus, findings can only be generalized to healthy youth. Future work should include clinically anxious participants to further probe the association between SRET performance and anxiety. Such a study would also allow for group-level modelling (i.e., anxious versus non-anxious youth) to further understand how anxiety influences positive and negative self-referential processing. Second, our study relies on a relatively small, homogenous sample. Though many of our primary results suggest a medium to large effect size, replication in a larger, more diverse sample is warranted. Third, we chose the endorsement ratio as the comparison to explore the utility of modelling the SRET; however, some of the methods have been applied in the literature to quantify self-referential views, such as the positive and negative SRET score (i.e., number of positive/negative words endorsed and recalled/all words endorsed) (e.g., Liu et al., 2020). Notably these other measures have the same drawbacks as other summary behavioral measures (i.e., mean response, collapsing of cognitive processes within a response). We also largely focused on negative self-referential views and the drift rate parameter. While these decisions were informed by past research modeling the SRET (Beevers et al., 2019; Dainer-Best et al., 2017, 2018a, b; Hsu et al., 2020), some past work (Goldstein et al., 2015; Liu et al., 2020; Tracy et al., 2021), taken together with the findings presented here, indicate that future research with the SRET may benefit from focusing on positive self-referential views as a protective factor against developing clinically significant anxiety and depression symptoms. Finally, we utilized a drift diffusion framework to model youth SRET performance, a general two-choice decision-making model. While this is an important first step, and consistent with the limited research modeling the SRET (Dainer-Best et al., 2018a, b), future work on self-referential views would likely benefit from applying a novel computational model comprised of parameters specific to the self-referential encoding task.

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Compliance with Ethical Standards

Conflict of Interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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

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