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Regular Article

Late positive potentials elicited by negative self-referential processing predict increases in social anxiety, but not depressive, symptoms from age 11 to age 12

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Abstract

Social anxiety and depression exacerbate in early adolescence. Maladaptive self-referential processing confers risk for both conditions and can be assessed by the Self-Referent Encoding Task (SRET). Our cross-sectional findings indicated that the SRET-elicited anterior late positive potential (LPP) was uniquely associated with social anxiety symptoms, whereas behavioral SRET scores were uniquely associated with depressive symptoms. Expanding this work, this study investigated whether the SRET-generated behavioral and LPP indices differentially predicted changes of social anxiety or depressive symptoms over time. At baseline, 115 community-dwelling youths (66 girls; Mean age/SD = 11.00/1.16 years) completed an SRET with EEG. Youths reported social anxiety and depressive symptoms at baseline and ~six and ~ 12 months later, based on which the intercept and slope of symptoms were estimated as a function of time. A larger anterior LPP in the negative SRET condition uniquely predicted a larger slope (faster increase) of social anxiety (but not depressive) symptoms. Greater positive behavioral SRET scores marginally predicted a smaller slope (slower increase) of depressive (but not social anxiety) symptoms. We provided novel evidence concerning the differential, prospective associations between self-referential processing and changes of social anxiety and depressive symptoms in early adolescence.

Keywords: depression; late positive potential; longitudinal; self-schematic processing; social anxiety

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Introduction

Social anxiety and depression are common, co-occurring mental conditions that emerge as early as childhood. Psychopathology researchers have identified a series of risk factors for these conditions, including cognitive biases in processing socioemotionally salient information (Beck, 2008; Gotlib & Joormann, 2010). One important and potentially modifiable cognitive risk for both conditions is self-referential processing (or self-schematic processing), conceptualized as an early emerging, latent cognitive construct that organizes and guides the processing of positive and negative information about oneself (Northoff et al., 2006). Maladaptive self-referential processing has been identified as a trans-diagnostic risk marker for an array of mental health conditions, including depression, social anxiety, post-traumatic stress disorder (Frewen et al., 2011), and bipolar disorder (Zhao et al., 2016). Directly relevant to the current study, a deeper processing of negative, and a shallower processing of positive, self-referential information shows concurrent or prospective associations with depression (e.g., Allison et al., 2021; Auerbach et al., 2015; Dobson & Shaw, 1987; Kuiper & Derry, 1982; Prieto et al., 1992; Speed et al., 2016) and social anxiety (e.g., Dixon et al., 2022; Dozois & Dobson, 2001; Gotlib et al., 2004) in clinical and sub-clinical/non-clinical samples of youth and adults.

However, these extant studies have examined depression and social anxiety separately. It remains unclear to what extent the risk mechanisms of these two highly-comorbid conditions differ from, or overlap between, each other. This study aimed to address this question by examining self-referential processing and the development of social anxiety and depressive symptoms in a group of typically developing early adolescents. We investigated to what extent self-referential processing at baseline (age 11), indexed by behavioral and neurophysiological measures, was uniquely associated with the changes of social anxiety or depressive symptoms over the next year. Early adolescence is marked by rapid socioemotional development and elevated social anxiety and depression, providing a useful window to capture the individual differences in risk processes.

The pioneering work on self-referential processing and its relationship with depression in adults established the SRET (Derry & Kuiper, 1981; Kuiper & Derry, 1982), which has since been widely adopted in different populations, including children as young as six-year-old (Goldstein et al., 2015). During the SRET, participants are presented with a series of positive and negative personal trait words and decide whether each word is self-descriptive by making a "yes" or "no" response. This endorsement task is usually followed by an unexpected memory task, when

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participants are asked to recall or recognize as many of the presented words as possible. To index self-referential processing, positive and negative SRET scores are typically calculated as the proportion of positive or negative words both endorsed *and* recalled/recognized divided by the total number of words endorsed. Incorporating the incidental memory task in this calculation taps into the more latent aspect of self-referential processing.

Researchers have also combined the SRET with neural measures such as the event-related potentials (ERPs) to examine the neural substrates underlying self-referential processing (e.g., Liu & Tan, 2023b; Auerbach et al., 2015, 2016, Liu & Tan, 2023a; Speed et al., 2016), which may reflect risk processes that emerge prior to, or cannot be captured by, behavioral indices. This literature has most consistently reported the late positive potential (LPP) component. The LPP is a slow positive deflection starting around 400–600 ms post stimulus onset and lasting through the duration of stimulus. The LPP is thought to reflect elaborative, in-depth processing that may involve cognitive reappraisal and effortful memory retrieval (e.g., Foti et al., 2009; Foti & Hajcak, 2008; Macnamara et al., 2009). In healthy individuals, LPP is elicited by socioemotionally salient cues, especially those with high arousal (Cuthbert et al., 2000). Studies using non-referential emotion paradigms (e.g., passive viewing of emotional pictures) typically reported a posterior LPP (pLPP) located across the midline centro-parietal channels (e.g., Kujawa et al., 2013, 2015; Macnamara et al., 2016, 2019). Many SRET studies, however, have reported a more anterior LPP (aLPP) located across midline fronto-central channels (e.g., Liu & Tan, 2023b; Auerbach et al., 2015, 2016, Liu & Tan, 2023a; Shestyuk & Deldin, 2010). The different topography of the LPP reported in the SRET literature may reflect distinct cognitive processes that are engaged during the SRET but not other paradigms, e.g., the retrieval of instances about oneself from autobiographic memory and the comparison between these instances and the target personal trait word.

During the SRET, typically developing youths tend to show a "self-positivity" bias, e.g., they endorsed (and remembered) significantly more positive words than negative words (Goldstein et al., 2015; Hudson et al., 2021; Liu et al., 2021; Liu et al., 2020). They also showed a potentiated LPP toward positive versus negative self-referent words (Auerbach et al., 2016; Liu & Tan, 2023b). This self-positivity bias tends to decrease as children grow into adolescence (Crone & Fuligni, 2020), which may be directly linked with elevated psychopathology risks in early adolescence. Indeed, lower positive, and higher negative, behavioral SRET scores showed concurrent and prospective associations with depressive symptoms in late childhood or early adolescence even in typically developing youths (e.g., Connolly et al., 2016; Goldstein et al., 2015; Hayden et al., 2013, 2014). While healthy adolescent girls showed an enlarged LPP toward positive versus negative self-referent words (Auerbach et al., 2016), depressed girls (Auerbach et al., 2015) and depressed adults (Shestyuk & Deldin, 2010) exhibited a larger LPP toward negative versus positive words. Eight-to-14-year-old girls with a maternal lifetime history of depression showed a larger LPP elicited by negative words compared to their typical-risk peers (Speed et al., 2016). Using the same youth sample as in the current study, our recent work found that a smaller LPP evoked by positive SRET words was associated with higher depressive symptoms beyond the behavioral positive SRET scores (Liu & Tan, 2023b).

Compared to depression, less work has been done on the associations between self-referential processing and social anxiety, with most of them behavioral studies. In 12-to-13-year-old adolescents, a smaller number of self-endorsed positive words was associated with social anxiety symptoms controlling for comorbid depressive symptoms; a larger number of self-endorsed negative words was associated with greater likelihood of lifetime social phobia controlling for other lifetime diagnoses (Alloy et al., 2012). Adults with anxiety disorders (e.g., generalized social phobia) recalled more negative words and less positive words in an SRET compared to healthy controls (Dixon et al., 2022; Dozois & Dobson, 2001; Gotlib et al., 2004; Thurston et al., 2017). In another study, a similar pattern was observed when socially anxious adults were anticipating social interactions with other people (Heinrichs & Hofmann, 2001).

Our recent work is the only ERP study that examined the neural correlates of self-referential processing in association with *social anxiety* symptoms (together with depressive symptoms) in youths with an average age of 11 years (Liu & Tan, 2023a). We found that in both the positive and negative SRET conditions, behavioral SRET scores were uniquely associated with depressive (but not social anxiety) symptoms, whereas a larger aLPP showed a unique marginal association with higher social anxiety (but not depressive) symptoms. This suggested that the two indices of the SRET, behavioral SRET scores and SRET-elicited aLPP, might reflect different facets of self-referential processing. The behavioral SRET scores, which incorporated an incidental free recall component, might tap into a more latent, implicit aspect of self-referential processing. The aLPP, elicited when participants were actively deciding whether a trait was self-descriptive, might reflect a more deliberate aspect of self-referential processing. Youths with a larger aLPP might tend to overly deliberate or dwell on these traits. This over deliberation might be particularly maladaptive for social anxiety, a core feature of which is a hypersensitivity to social evaluation of oneself, whether the evaluation is positive or negative (Fredrick & Luebbe, 2020; Rapee & Heimberg, 1997; Weeks et al., 2008; Weeks & Howell, 2012).

This recent work provides novel evidence on the differential associations between the behavioral and LPP indices of SRET and symptoms of social anxiety and depression in youths. However, its cross-sectional data cannot speak to the directional associations between self-referential processing and symptoms: does self-referential processing function as an early precursor of risk, or is it a concomitant or consequence of elevated symptoms? The present study aimed to (partly) address this question by using the same SRET-elicited ERP data as reported in our recent work (Liu & Tan, 2023a) with the addition of three waves of symptoms of social anxiety and depression measured over 12 months following the ERP data collection. These data allowed us to examine the directional relationship between self-referential processing at baseline and subsequent changes in symptoms. Specifically, we estimated the initial level (intercept) and rate of change (slope) of symptoms for each individual as a function of time. We then examined to what extent the behavioral SRET scores and SRET-elicited LPP at baseline uniquely predicted the slope of social anxiety (or depressive) symptoms over time, with the intercept controlled for. We also aimed to isolate the unique variance in the slope of social anxiety (or depressive) symptoms explained by the predictors, by controlling for the slope of depressive (or social anxiety) symptoms as another covariate. Based on our recent findings (Liu & Tan, 2023a), we expected that the behavioral SRET scores might be uniquely associated with the slope of depressive symptoms over the 12-month period, whereas the SRET-elicited LPP might show unique associations with the slope of social anxiety symptoms over time.

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Method

Participants and procedure

Data are drawn from a larger project investigating the neurobehavioral correlates of cognitive processing risks for anxiety and depression in early adolescence. At baseline (T1), 115 typically developing youths (66 girls; Mean age/SD = 11.00/1.16 years) and their caregivers were recruited from the community in a Midwestern urban area and invited to a lab visit on campus. None of the youths had any reported major physical diseases, serious mental illness, or neurodevelopmental disabilities. The demographics of the sample lined up with the local demographics (87.5% White, 3.6% Asian, 8.9% multi-racial; 7.2% Hispanic or Latino; family income range: $15,000–$350,000). During the T1 visit, caregiver consent and youth assent were acquired first. Next, youths completed a battery of four EEG tasks (including the SRET) in a counter-balanced order and an eye-tracking task tapping different cognitive processing biases. Upon finishing the lab visit, youths completed a questionnaire package reporting their socioemotional functions and mental health problems, including social anxiety and depressive symptoms, via Qualtrics at home (Qualtrics, Provo, UT).

We collected follow-up data from this cohort approximately six months (T2; Mean/SD = 6.77/1.09 months) and 12 months (T3; Mean/SD = 12.20/1.72 months) after T1, respectively. The T2 follow-up consisted of online questionnaire data collection only using the same questionnaire package as T1, including the same measures of social anxiety and depressive symptoms. Of the initial 115 youths, 95 participated in T2 (56 girls; Mean age/SD = 11.77/1.18 years). The T3 follow-up consisted of both questionnaire data collection and lab task data collection, using the same questionnaire package and lab protocol as T1. Of the initial 115 youths, 92 participated in T3 (53 girls; Mean age/SD = 12.06/1.20 years). In the current study, we reported the SRET data from T1 and the symptom data from T1, T2, and T3. At each time point, participants received monetary compensation upon completing the study. The study protocol was approved by the Institutional Review Board of the university.

Measures of social anxiety and depressive symptoms

At all three time points, youths reported their anxiety symptoms via the child-report version of the Screen for Child Anxiety Related Disorders-Revised (SCARED; Birmaher et al., 1999). SCARED consists of 41 items assessing a range of DSM-defined anxiety disorder symptoms in eight-to-18-year-old youths, including social anxiety, generalized anxiety, separation anxiety, school avoidance, and panic/somatic symptoms. For each item, participants selected from a three-point scale the one that best describes themselves for the last three months (0 = not true or hardly ever true, 1 = somewhat or sometimes true, 2 = very true or often true). Given our focus on social anxiety, we calculated the total score of the seven-item subscale of social anxiety to indicate social anxiety symptoms (Cronbach's α at T1, T2, and T3 = .86, .84, .86 in the current sample).

Youths also completed a child-report version of Child Depression Inventory (CDI; Kovacs, 1978). The CDI consists of 27 items assessing the presence and severity of depressive symptoms in seven-to-17-year-old youth. Due to limited inter-individual variability, we excluded the item "I want to kill myself." For each of the remaining 26 items, youths selected from three statements the one that best describes themselves (e.g., I have fun: 0 = in many things; 1 = in some things; 2 = in nothing). A total score was calculated to indicate depressive symptoms (Cronbach's α at T1, T2, and T3 = .84, .94, and .92 in the current sample).

The SRET

Following common practice in the literature (e.g., Gotlib et al., 2006; Hayden et al., 2013, 2014; Liu et al., 2021; Prieto et al., 1992), youths first watched an age-appropriate three-minute sad movie clip (*The Neverending Story*) to induce a sad mood, which is thought important to activate latent cognitive vulnerability (Abela & Hankin, 2008). Youths rated their mood before and after watching the clip on a five-point scale (1 = very sad, 5 = very happy). Comparing their ratings pre- (M/SD = 3.72/0.71) and post-induction (M/SD = 2.75/0.91) indicated that mood induction was effective, $t(114) = 10.31$, $p < .001$, Cohen's $d = 1.19$.

Next, youths completed an SRET with EEG signals recorded. We adopted 60 personal trait words (30 positive, 30 negative) used by a previous SRET study in eight-to-14-year-old girls (Speed et al., 2016). The positive and negative words differed in valence but were matched on arousal and length based on the Affective Norms for English (Bradley & Lang, 1999). The 60 words were presented in a pseudo-random manner, such that no more than two words of the same valence were presented successively. Each trial started with a 500 ms fixation cross, after which a positive or negative word was presented for 1000ms, followed by another 500 ms fixation cross. Next, a question ("Does this word describe you?") popped up on the screen until youths pressed one of two buttons on a response box (left = yes, right = no). Immediately following the endorsement task, youths were unexpectedly asked to recall as many of the presented words as possible for up to two minutes.

Following standard scoring of SRET (e.g., Derry & Kuiper, 1981; Gotlib et al., 2006; Hayden et al., 2013, 2014; Kuiper & Derry, 1982), we calculated the behavioral SRET scores as the proportion of positive or negative words both endorsed *and* recalled (positive SRET score = # of positive words endorsed *and* recalled/total # of words endorsed; negative SRET score = # of negative words endorsed *and* recalled/total # of words endorsed). Consistent with previous findings in youths of similar ages (Goldstein et al., 2015; Hayden et al., 2013, 2014; Mackrell et al., 2013), negative SRET scores showed a positively skewed distribution (i.e., most youths endorsed *and* recalled a small number of negative words). Thus, the negative SRET scores were log-transformed with base 10 to account for the non-normality. The log-transformed values were used in subsequent analyses.

EEG data acquisition and processing

Youths completed the SRET in an electrically shielded chamber while EEG signals were recorded via a 64-channel HydroCel GSN Electrical Geodesics Inc. (EGI) net and an EGI 200 NetAmps Amplifier, with a 250 Hz sampling rate, a reference of the vertex electrode (Cz), and electrode impedance below 50 kΩ. EEG data were processed using the EEGLab (Delorme & Makeig, 2004) and ERPLab (Lopez-Calderon & Luck, 2014) toolboxes in MATLAB 9.10.0 (Mathworks, Inc., Natick, MA). Raw data were first subjected to offline filter (0.1–40 Hz) and re-referenced to the average of the two mastoid electrodes. An independent component analysis approach was used to remove ocular artifacts caused by eye blinks and eye movement. Next, the processed continuous EEG data were time-locked to the onset of each word and segmented into epochs from 200 ms before to 1000ms post the word onset, with a 200 ms baseline correction. We further rejected segments with (1) voltage beyond±100 μV, (2) *a* > 50 μV change of voltage

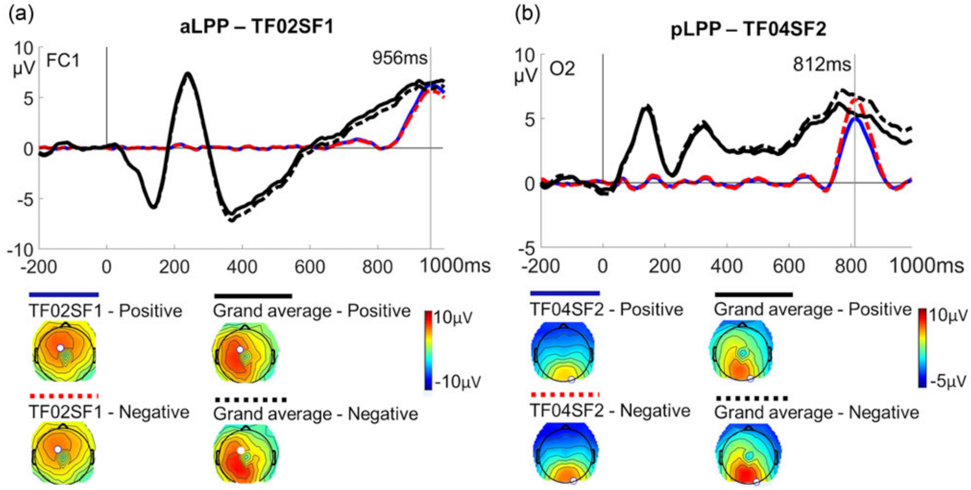

Figure 1. ERP waveforms and topographic maps at peak latencies of (*a*) aLPP - TF02SF1 and (*b*) pLPP - TF04SF1 in the positive and negative Self-Referent Encoding Task conditions superimposed on the grand average of the original data note. aLPP = anterior late positive potential; pLPP = posterior late positive potential.

between timepoints, or (3) *a* > 300 μV change of voltage between the most positive and most negative timepoints within a 200 ms moving window. Finally, average ERPs were computed for each youth, time-locked to positive or negative words, irrespective of whether the word was endorsed. Following artifact rejection, 102 youths with $\geq$ 10 trials in each condition were retained for subsequent analyses.

Principal component analysis of the ERP data

We focused on the LPP component that has been identified as a neural marker of internalizing psychopathology in the literature (Allison et al., 2021; Auerbach et al., 2015; Shestyuk & Deldin, 2010; Speed et al., 2016). The LPP was quantified via principal component analysis (PCA), a factor-analytic approach that isolates underlying ERP components by accounting for the variance across all time points and electrodes, thereby maximizing the utility of the data and generating more accurate temporo-spatial information (Dien et al., 2005; Dien, 2010; Dien & Frishkoff, 2005).

We used a two-step temporo-spatial PCA approach via the ERP PCA Toolkit in MATLAB (Dien et al., 2005; Dien, 2010; Dien & Frishkoff, 2005). A temporal PCA was first performed using Promax rotation to reduce the temporal dimensions of the data (Dien & Frishkoff, 2005), treating time points as variables and participants, experimental conditions (positive & negative), and electrodes as observations. In our data, 21 temporal factors were retained (Cattell, 1966). Next, a spatial PCA was performed on each of the 21 temporal factors using Infomax rotation to reduce the spatial dimensions of the data, treating electrodes as variables and participants, conditions, and temporal factors as observations. Five spatial factors were extracted for each temporal factor, resulting in 105 temporo-spatial factors in total (21 temporal $\times$ five spatial).

Nineteen out of the 105 factors, each accounting for $\geq$ 0.5% of the variance, were retained for further inspection. Among the 19 factors, the TF02SF1 factor (peak channel FC1, peaking latency 956 ms, 8.20% variance, Figure 1a) and the TF04SF2 factor (peak channel O2, peak latency 812 ms, 1.64% variance, Figure 1b) appeared temporally and spatially analogous to the aLPP (e.g., Allison et al., 2021; Auerbach et al., 2015, 2016; Shestyuk & Deldin, 2010) and the pLPP (e.g., Speed et al., 2016) reported in the literature, respectively. The factor scores of each factor were extracted for each participant in each condition and treated as indicators of LPP amplitudes in subsequent analysis (SPSS 29.0, IBM, Armonk, NY). Paired-sample *t*-test was run on both factor scores to test the differences between the positive and negative conditions. For TF02SF1 (aLPP), there was no significant difference between the positive (Mean/SD = 6.49/6.98) and negative (Mean/SD = 6.56/6.97) conditions, $t(101) = .13$, $p = .45$, Cohen's $d = 0.01$. For TF04SF1 (pLPP), however, the negative condition elicited a larger amplitude (Mean/SD = 7.44/6.06) than the positive condition (Mean/SD = 6.06/5.05), $t(101) = 3.58$, $p < .001$, Cohen's $d = 0.37$.

Missing data imputation

Of the 115 youths at T1, 16 had missing data for at least one study variable (four missing symptom data, two not completing the SRET, 11 with unusable ERP data). Of the 95 participating youths at T2, four missed symptom data. Of the 92 youths who returned for T3, seven missed symptom data. Little's Missing Completely at Random Test (Little, 1988) showed that data were missing completely at random ($\chi^2 = 110.39$, $df = 112$, $p = .52$). To account for the missing data, we implemented multiple imputation using the R mice package (van Buuren & Groothuis-Oudshoorn, 2011). Fifty imputations with ten iterations per imputation were conducted for each variable; averaged data were then calculated across the 50 imputed datasets. The imputed data ($N = 115$) were used for the subsequent analyses to increase power. For data missing completely at random, multiple imputation can provide relatively unbiased estimates with improved efficiency regardless of the proportion of missingness (Madley-Dowd et al., 2019).

Estimation of intercepts and slopes of the symptoms

First, to inspect the patterns of symptoms over time (Figure 2), we conducted two unconditional linear mixed-effects models on the SCARED scores and CDI scores, respectively, with group-level intercept as the fixed-effects factor and subject as the random-effects factor (including random intercepts and random slopes). Time was centered such that the intercept reflected symptoms assessed at T1. Results demonstrated significant group-level intercepts (SCARED: $\beta = 5.97$, $SE = 0.23$, $t = 26.15$, $p < .001$, 95% CI = [5.52, 6.42]; CDI: $\beta = 8.41$, $SE = 0.53$, $t = 15.79$, $p < .001$, 95% CI = [14.12, 27.15]) and random effects (SCARED: $\beta = 3.10$, $SE = 0.56$, Wald $Z = 5.50$, $p < .001$, 95% CI = [2.17, 4.43]; CDI: $\beta = 19.58$, $SE = 3.27$, Wald $Z = 5.99$, $p < .001$, 95% CI = [7.36, 9.46]) for both scores. These patterns indicated that for both symptom scores, the group means at baseline were

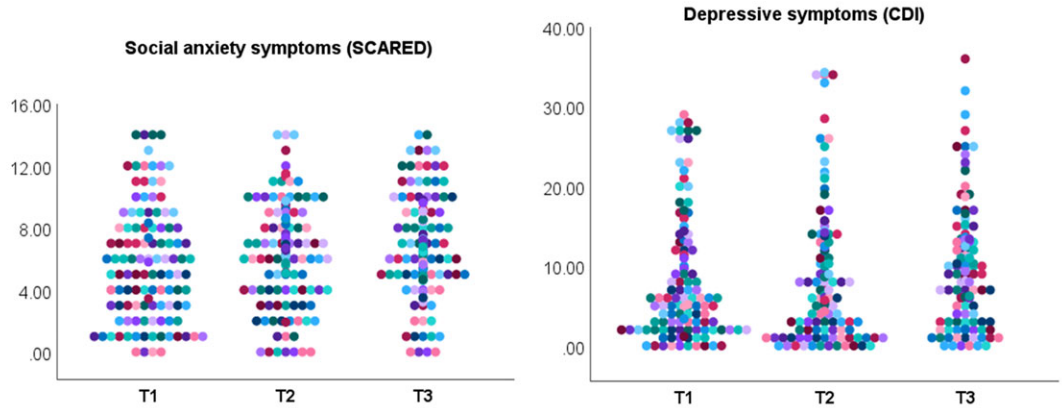

Figure 2. Scatter plot of youths' social anxiety and depressive symptoms at T1, T2, and T3. CDI = child depression inventory; SCARED = screen for child anxiety related disorders (social anxiety subscale).

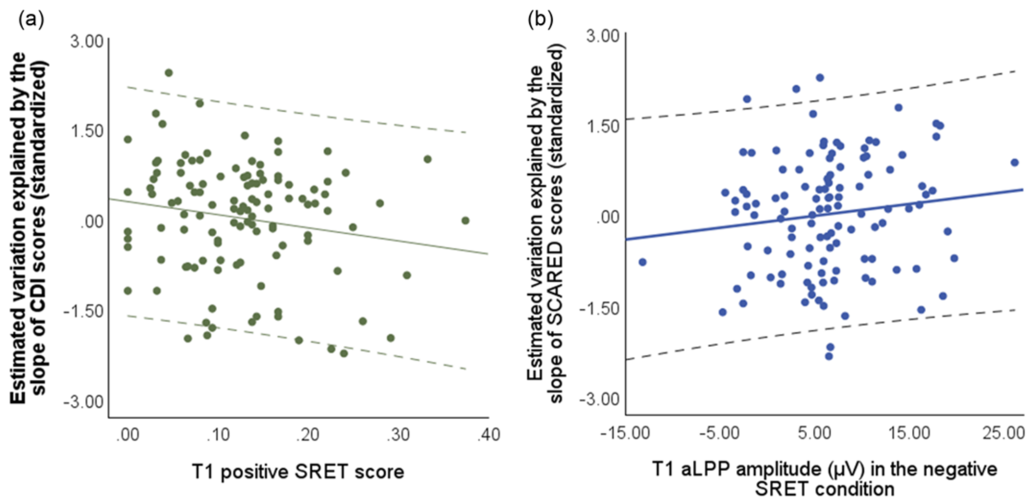

Figure 3. Illustration of the associations between (*a*) T1 positive SRET score and the slope of CDI scores and (*b*) T1 aLPP in the negative SRET condition and the slope of SCARED scores. SRET = self-referent encoding task; aLPP = anterior late positive potential; CDI = child depression inventory; SCARED = screen for child anxiety related disorders (social anxiety subscale); dashed lines: 95% confidence interval.

significantly larger than zero and that there was significant inter- and intra-individual variability over time.

According to one-way ANOVAs, the main effect of time was significant on both the SCARED ($F(2, 113) = 11.44$, $p < .001$) and CDI scores ($F(2, 113) = 3.49$, $p = .03$). Pairwise comparisons showed that youths' SCARED scores significantly increased from T1 (Mean/SD = 5.76/3.69) to T2 (Mean/SD = 6.21/3.34, $t(114) = 1.71$, $p = .04$, Cohen's $d = 0.16$), from T2 to T3 ($t(114) = 2.96$, $p < .01$ Cohen's $d = 0.28$), and from T1 to T3 (Mean/SD = 6.96/3.32, $t(114) = 4.80$, $p < .001$ Cohen's $d = 0.45$). Their CDI scores did not change from T1 (Mean/SD = 8.24/7.97) to T2 (Mean/SD = 8.73/8.53, $t(114) = -0.86$, $p = .20$, Cohen's $d = -0.08$), but significantly increased from T2 to T3 ($t(114) = 2.34$, $p = .01$ Cohen's $d = 0.22$) and from T1 to T3 (Mean/SD = 9.98/7.53, $t(114) = 2.83$, $p < .01$, Cohen's $d = 0.26$). These patterns indicated significant increases in both symptom scores over the 12-month period. Next, for both the SCARED and CDI scores, we extracted the coefficients of intercept (initial level) and standardized slope (rate of change) for each youth based on individual linear regression models as a function of time.

Statistical analysis

We conducted two multiple regression models to examine to what extent the behavioral SRET scores and SRET-elicited LPPs at T1 predicted the slope of social anxiety symptoms or depressive symptoms from T1 to T3. Both models treated the behavioral SRET scores and the amplitudes of aLPP and pLPP in the two conditions as the predictors and youth sex and age at baseline as covariates. Model 1 treated the standardized slope of CDI scores as the dependent variable (DV) and the intercept of CDI scores as an additional covariate; Model 2 treated the standardized slope of SCARED scores as the DV and the intercept of SCARED scores as another covariate. Controlling for the intercept of symptoms allowed us to isolate the unique contribution of the predictors to the DV without being confounded by the individual differences in the symptoms at baseline (Biesanz et al., 2004; Singer & Willett, 2003). In each model, we also included the standard error (SE) of the slope to account for the uncertainty in estimating the coefficient.[1] Finally, considering the high co-occurrence between the elevation of social anxiety and depression at the target ages, we further included the slope of SCARED scores in Model 1, and the slope of CDI scores in Model 2, as another covariate to partial out the shared variance between depression and social anxiety.[2]

[1]Due to high collinearity between the SE of the slope and the SE of the intercept, we included the SE of the slope only in the model. None of the other predictors or covariates showed high collinearity with each other (all values of variance inflation factor [VIF] < 2.8).

[2]An alternative approach is to conduct multi-level modeling with symptoms as the DV and time as one of the predictors, with the simple effect of time as an indicator of the slope of symptoms (which may vary depending on different levels of the SRET indices). However, in multi-level modeling, it is complicated to account for the slope of the other symptom variable (e.g., control for the slope of SCARED scores in the model with CDI scores as the DV or vice versa). Therefore, we opted for the current approach to first explicitly estimate the slope and intercept of symptoms, which were then subjected to multiple regression as the DV or a covariate. This gave us more flexibility in deciding which variables to include in the model.

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Further, to test the robustness of the regression results and examine whether the large number of predictors biased the results, we conducted sensitivity analysis by running two partial correlations: one tested the correlations between the slope of CDI scores and the T1 SRET variables while controlling for the intercept of CDI, and the other tested the correlations between the slope of SCARED scores and the T1 SRET variables while controlling for the intercept of SCARED.

Results

Descriptive statistics and bivariate correlations of study variables

Table 1 shows the means, standard deviations, and bivariate correlations of study variables. Compared to boys, girls were older, showed a smaller SRET-elicited pLPP in the negative condition, and reported greater depressive symptoms (CDI) at all three time points and greater social anxiety symptoms (SCARED) at T1. Girls also showed larger intercepts of both CDI and SCARED and a smaller slope of SCARED than boys. Age was correlated with greater positive SRET scores and a smaller pLPP in the positive SRET condition. The positive SRET score at T1 was associated with lower CDI and SCARED scores at all time points as well as smaller intercepts of CDI and SCARED. The negative SRET score at T1 was correlated with greater CDI and SCARED scores at T1, larger intercepts of CDI and SCARED, and smaller slopes of both CDI and SCARED. The aLPP amplitude in both the positive and negative conditions at T1 was associated with greater SCARED scores at T3. The amplitude of aLPP and pLPP at T1 was positively correlated with each other and between the two conditions. The CDI scores and SCARED scores were positively correlated with each other and across time points. The intercepts and slopes of CDI and SCARED were positively correlated with each other; intercepts were negatively associated with slopes.

Results of multiple regression

Table 2 shows the results of the two multiple regression models. Both models showed good model fit (Model 1: $R^2 = .38$, $F(11, 103) = 5.83$, $p < .001$; Model 2: $R^2 = .50$, $F(11, 103) = 9.20$, $p < .001$). In Model 1 with the slope of CDI scores as the outcome, the T1 positive SRET score marginally predicted the slope of CDI scores ($\beta = -0.17$, $SE = 0.89$, $p = .06$, *95% CI* = [−3.43, 0.09]; Figure 3a), with higher positive SRET scores associated with a lower value of the slope (e.g., slower increase of CDI scores over time). Neither LPP component in either condition at T1 predicted the slope of CDI scores. Among the covariates, both sex ($\beta = 0.15$, $SE = 0.13$, $p = .09$, *95% CI* = [−0.04, 0.48]) and the slope of SCARED scores ($\beta = 0.16$, $SE = 0.09$, $p = .08$, *95% CI* = [−0.02, 0.35]) marginally predicted the slope of CDI. Girls showed a faster increase of CDI scores over time; a faster increase of the SCARED scores was associated with a faster increase of CDI scores. Finally, larger intercept of CDI predicted a smaller value of the slope of CDI scores (slower increase; $\beta = -0.62$, $SE = 0.01$, $p < .001$, *95% CI* = [−0.06, −0.03]).

In Model 2 with the slope of SCARED scores as the outcome, a larger aLPP in the negative SRET condition at T1 predicted a larger value of the slope of SCARED scores (i.e., faster increase; $\beta = 0.24$, $SE = 0.01$, $p = .03$, *95% CI* = [0.00, 0.05]; Figure 3b). However, a larger pLPP in the negative condition predicted a smaller value of the slope of SCARED scores (i.e., slower increase; $\beta = -0.24$, $SE = 0.02$, $p = .03$, *95% CI* = [−0.07, −0.01]). Among the covariates, larger slopes of CDI scores ($\beta = 0.16$, $SE = 0.07$, $p = .03$, *95% CI* = [0.01, 0.29]) predicted larger slopes of SCARED scores. Larger intercepts of SCARED predicted smaller slopes of SCARED scores (slower increase; $\beta = -0.67$, $SE = 0.01$, $p < .001$, *95% CI* = [−0.13, −0.08]).

Results of partial correlations

Table 3 presents the results of partial correlations. With the intercept controlled for, the slope of CDI scores showed a marginal, negative correlation with the positive SRET score; the slope of SCARED scores showed a positive correlation with the aLPP in the negative condition. These patterns were consistent with the results of the multiple regression, supporting the robustness of these results. However, deviant from the multiple regression results, the slope of SCARED scores was not correlated with the pLPP in the negative condition.

Discussion

Expanding on our recent work (Liu & Tan, 2023a), the current study investigated the extent to which the behavioral and LPP indices of self-referential processing at baseline differentially predicted the slope of social anxiety or depressive symptoms over a 12-month period in early adolescence. We isolated an anterior and a posterior LPP component via a PCA approach, accounting for 8.20% and 1.64% of the variance, respectively. Regression analyses showed that a larger aLPP elicited in the negative SRET condition at baseline uniquely predicted a larger slope (or faster increase) of social anxiety symptoms; neither LPP was associated with the slope of depressive symptoms. Further, higher positive behavioral SRET scores at baseline marginally predicted a smaller slope (or slower increase) of depressive symptoms over time. The behavioral SRET scores were not associated with the slope of social anxiety symptoms. Consistent with our hypothesis, this study provides novel evidence concerning the differential, *prospective* associations between behavioral SRET scores and SRET-elicited LPP around age 11 and the changes of social anxiety and depressive symptoms from age 11 to age 12, a critical period for elevated risks of depression and social anxiety and rapid maturation in self-related processes.

SRET-elicited aLPP uniquely predicted increases of social anxiety symptoms

The SRET-elicited aLPP in the negative condition at baseline showed a positive association with the slope of social anxiety, but not depressive, symptoms from T1 to T3. Specifically, a larger aLPP at baseline predicted faster increases of social anxiety symptoms over time. This association remained significant in partial correlation analyses where only the intercept of symptoms was controlled for, supporting the robustness of the result. The pattern of this association appeared consistent with our recent cross-sectional data, where a larger aLPP in both SRET conditions was (marginally) associated with heightened social anxiety symptoms at T1 (Liu & Tan, 2023a). These findings suggested that an enlarged aLPP elicited during negative self-referential processing not only served a risk marker for concurrent social anxiety symptoms, but might also portend risks for prospective increases of social anxiety symptoms; on the other hand, a smaller aLPP at baseline might "slow down" the increases of symptoms over time.

As discussed earlier, the aLPP elicited during the SRET may reflect distinct cognitive processes that are involved during the

Table 1. Mean, standard deviation, and bivariate correlations of main study variables

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	Sex (1 = boys, 2 = girls)																		
2	T1 Age	.18*																	
3	T1 positive SRET score	.07	.20*																
4	T1 negative SRET score†	.15	.15	– .13															
5	T1 aLPP-positive	– .06	– .10	– .11	– .09														
6	T1 aLPP-negative	– .15	– .03	– .10	– .12	.74**													
7	T1 pLPP-positive	– .14	– .24**	– .07	– .13	.25**	.29**												
8	T1 pLPP-negative	– .26**	– .08	– .11	– .13	.31**	.43**	.69**											
9	T1 CDI	.31**	.13	– .45**	.40**	.06	.03	.00	– .07										
10	T2 CDI	.19*	– .03	– .36**	.16	.06	.06	.00	– .05	.72**									
11	T3 CDI	.19*	.00	– .33**	.14	– .01	.04	– .06	– .10	.64**	.75**								
12	Intercept of CDI	.29**	.15	– .40**	.40**	.08	.03	.02	– .05	.95**	.67**	.38**							
13	Slope of CDI	– .05	– .12	.12	– .25**	– .11	– .06	– .11	– .11	– .39**	.01	.32**	– .57**						
14	T1 SCARED	.28**	.13	– .26**	.28**	.18	.13	– .03	– .10	.55**	.41**	.40**	.51**	– .17					
15	T2 SCARED	.18	.03	– .27**	.18	.10	.09	.03	– .03	.43**	.50**	.40**	.41**	– .08	.68**				
16	T3 SCARED	.14	– .01	– .20*	.12	.20*	.20*	– .03	– .08	.37**	.45**	.46**	.28**	.08	.71**	.67**			
17	Intercept of SCARED	.29**	.16	– .24**	.29**	.12	.05	.01	– .09	.55**	.36**	.31**	.54**	– .25**	.94**	.68**	.45**		
18	Slope of SCARED	– .25**	– .15	.17	– .25**	– .05	.07	.02	– .01	– .34**	– .06	– .03	– .37**	.33**	– .48**	– .15	.21*	– .67**	
	Mean		11.00	0.13	0.01	6.56	6.51	6.53	7.43	8.24	8.73	9.98	7.41	0.23	5.76	6.21	6.96	5.19	0.23
	SD		1.16	0.08	0.02	6.33	6.35	4.76	4.59	7.97	8.54	7.53	10.1	0.72	3.69	3.34	3.32	4.36	0.68

Note. SD = standard deviation; SRET = self–referent encoding task; aLPP = anterior late positive potential; pLPP = posterior late positive potential; CDI = Child Depression Inventory; SCARED = Screen for Child Anxiety Related Disorders (social anxiety subscale); † = log-transformed with base 10; **: $p < .01$, *: $p < .05$.

Table 2. Results of multiple regression analyses

Outcome		*B*	*SE*	*β*	*t*	*p*	95% *CI*
Model 1: Slope of CDI	Sex (1 = boys, 2 = girls)	0.22	0.13	0.15	1.71	.09^{+}	[– 0.04, 0.48]
	T1 Age	–0.01	0.05	–0.02	–0.19	.85	[– 0.12, 0.10]
	CDI intercept	–0.04	0.01	–0.62	–6.02	<.001**	[– 0.06, –0.03]
	SE of CDI slope	–0.02	0.03	–0.04	–0.45	.66	[– 0.08, 0.05]
	SCARED slope	0.16	0.09	0.16	1.76	.08^{+}	[– 0.02, 0.35]
	T1 positive SRET score	– 1.67	0.89	– 0.17	– 1.88	.06^{+}	[– 3.43, 0.09]
	T1 negative SRET score†	– 0.63	3.18	– 0.02	– 0.20	.84	[– 6.94, 5.68]
	T1 aLPP-positive	– 0.01	0.01	– 0.06	– 0.48	.64	[– 0.03, 0.02]
	T1 aLPP-negative	0.00	0.01	0.04	0.31	.76	[– 0.02, 0.03]
	T1 pLPP-positive	0.00	0.02	– 0.03	– 0.24	.81	[– 0.04, 0.03]
	T1 pLPP-negative	– 0.02	0.02	– 0.09	– 0.76	.45	[– 0.05, 0.02]
Model 2: Slope of SCARED	Sex (1=boys, 2=girls)	–0.06	0.11	–0.04	–0.57	.57	[– 0.27, 0.15]
	T1 Age	0.01	0.04	0.02	0.23	.82	[– 0.08, 0.10]
	SCARED intercept	–0.11	0.01	–0.67	–8.21	<.001**	[– 0.13, –0.08]
	SE of SCARED slope	–0.00	0.05	–0.01	–0.07	.94	[– 0.11, 0.10]
	CDI slope	0.15	0.07	0.16	2.16	.03*	[0.01, 0.29]
	T1 positive SRET score	– 0.01	0.68	0.00	– 0.02	.99	[– 1.36, 1.34]
	T1 negative SRET score†	0.41	2.56	0.01	0.16	.87	[– 4.66, 5.48]
	T1 aLPP-positive	– 0.01	0.01	– 0.10	– 0.94	.35	[– 0.03, 0.01]
	T1 aLPP-negative	0.03	0.01	0.24	2.15	.03*	[0.00, 0.05]
	T1 pLPP-positive	0.02	0.02	0.16	1.57	.12	[– 0.01, 0.05]
	T1 pLPP-negative	– 0.04	0.02	– 0.24	– 2.28	.03*	[– 0.07, –0.01]

Note. SE = standard error; *CI* = confidence interval; SRET = self–referent encoding task; aLPP = anterior late positive potential; pLPP = posterior late positive potential; CDI = Child Depression Inventory; SCARED = Screen for Child Anxiety Related Disorders (social anxiety subscale); † = log-transformed with base 10; ** $p < .01$, * $p < .05$, $^{+}$ $p < .10$; gray shade: covariates.

Table 3. Partial correlations between the slope of CDI scores (a) or SCARED scores (b) and the T1 SRET variables controlling for the intercept of symptoms

(a)		1	2	3	4	5	6	(b)		1	2	3	4	5	6
1	Slope of CDI							1	Slope of SCARED						
2	T1 positive SRET score	– .16^{+}						2	T1 positive SRET score	–.02					
3	T1 negative SRET score†	– .02	.04					3	T1 negative SRET score†	–.07	–.06				
4	T1 aLPP-positive	– .07	– .09	– .14				4	T1 aLPP-positive	.05	–.08	–.14			
5	T1 aLPP-negative	– .05	– .09	– .15	.74**			5	T1 aLPP-negative	.18*	–.08	–.15	.74**		
6	T1 pLPP-positive	– .10	– .06	– .16^{+}	.25**	.29**		6	T1 pLPP-positive	.01	–.08	–.14	.25**	.29**	
7	T1 pLPP-negative	– .14	– .13	– .13	.32**	.43**	.69**	7	T1 pLPP-negative	–.08	–.14	–.11	.33**	.44**	.69**

Note. SRET = self-referent encoding task; aLPP = anterior late positive potential; pLPP = posterior late positive potential; CDI = Child Depression Inventory; SCARED = Screen for Child Anxiety Related Disorders (social anxiety subscale); † = log-transformed with base 10; ** = $p < .01$, *: $p < .05$, $^{+}$: $p < .10$.

self-referential processing, e.g., the retrieval of instances about oneself from autobiographic memory and the evaluation of the target word in relation to these instances. Further, unlike the behavioral SRET scores, the aLPP is elicited as youths were actively deciding whether a trait was self-descriptive and may reflect a more deliberate or "explicit" aspect of self-referential processing (Liu & Tan, 2023a). An enlarged aLPP in the negative condition, therefore, might suggest that these youths were engaging greater cognitive resources in retrieving negative instances of themselves and overly deliberating on the self-relevance of the target negative word in comparison with these instances. Unsurprisingly, this over deliberation on negative traits may be particularly relevant to social anxiety, a key characteristic of which is the fear of negative evaluation about oneself (Fredrick & Luebbe, 2020; Rapee & Heimberg, 1997; Weeks et al., 2008; Weeks & Howell, 2012).

In addition to the aLPP, we also isolated a pLPP via the data-driven PCA approach. Multiple regression results showed that unlike the aLPP, the pLPP showed a negative association with the slope of social anxiety symptoms, i.e., a smaller, but not larger, pLPP in the negative condition at T1 predicted faster increases of

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social anxiety symptoms. However, this association was not significant in partial correlation analyses where only the intercept of symptoms was controlled for. We suspected that the significant relationship between the pLPP and slope of symptoms yielded by multiple regression might reflect unstable or chance effects related to the large number of predictors and covariates in the regression model (Babyak, 2004).

The ensuing question is why the aLPP, but not the pLPP, showed a significant and stable association with the slope of anxiety symptoms. The LPP in general is thought to indicate more in-depth and elaborative processing of socioemotional meanings (Hajcak et al., 2012). Interestingly, studies using non-referential emotion processing paradigms have typically reported a *p*LPP (Hajcak & Foti, 2020), whereas many, if not all, SRET studies (including ours) have reported an *a*LPP (e.g., Liu & Tan, 2023b; Auerbach et al., 2015, 2016, Liu & Tan, 2023a; Shestyuk & Deldin, 2010). We therefore speculated that compared to the pLPP, the aLPP might reflect the processing of the more *self*-specific aspect of information. Accordingly, a larger aLPP in the negative SRET condition might reflect overly elaborative processing of negative *self*-relevant cues and as discussed earlier, might confer risks for social anxiety. However, no work has directly examined the functional differences between the aLPP and pLPP. Without a "control" condition, we also could not directly compare the aLPP (or pLPP) elicited by self-referential versus non-referential stimuli in the current study. Future SRET research including a control condition can look to see if the aLPP elicited by self-referential condition is more pronounced than that elicited by non-referential condition, and if the pLPP elicited by non-referential condition is more pronounced than that elicited by self-referential condition. Studies like this will provide direct evidence for the functional specificity (or lack thereof) of the aLPP in comparison with the pLPP.

It is also noteworthy that in our data, the pLPP was significantly larger in response to the negative versus the positive SRET condition, whereas no between-condition difference was observed for aLPP (Figure 1). We speculated that these patterns might be related to the negative mood induction implemented before the SRET. It appeared that the evoked negative mood, which was about a character in the film (rather than oneself), enhanced the pLPP, but not the aLPP, again suggesting that the two components might reflect different facets of self-referential information processing. However, the bivariate correlation between youths' post-induction mood rating and the pLPP amplitude was non-significant.

Neither LPP in the positive SRET condition predicted the slope of social anxiety (or depressive) symptoms. This diverged from our cross-sectional findings, which indicated a marginal positive association between the aLPP in both conditions and social anxiety symptoms (Liu & Tan, 2023a). Although the marginally significant findings prevented conclusive interpretations, this different pattern suggested that the aLPP in the positive SRET condition might be a risk marker of concurrent social anxiety symptoms, whereas the aLPP in the negative condition might serve as a risk marker for both concurrent and prospective increases of social anxiety symptoms.

Positive behavioral SRET scores uniquely predicted increases of depressive symptoms

The positive behavioral SRET scores at baseline showed a marginal negative association with the slope of depressive, but not social anxiety, symptoms. This suggested that while our sample showed an overall increase in depressive symptoms from T1 to T3, higher positive SRET scores at baseline might have "slowed down" the increase, while lower positive SRET scores at baseline might have exacerbated the increase. As speculated in Liu & Tan (2023a), the behavioral SRET scores, as computed in its current form, might reflect a more latent, implicit aspect of positive self-referential processing. Consistent with this speculation, existing cognitive accounts of depression contend that negatively biased cognition confers risks for depression likely by influencing automatic or implicit processes rather than explicit, conscious processes (Ingram et al., 1998; Phillips et al., 2010; Scher et al., 2005). However, this association was only marginal. While the number of endorsement of the 30 positive words showed substantial inter-individual variation (range 1-30, mean/SD = 22.97/5.45), the number of recalled positive words showed a much narrower range of 0–13 (mean/SD = 4.51/2.31). This suggested that the unexpected free recall task with 30 target words might be a bit difficult for our participants, resulting in limited inter-individual variability in the positive SRET score and possibly, the marginal result. Future research using an easier memory task (e.g., recognition) may surpass this problem and provide further evidence on the association of interest.

The negative SRET scores did not predict the slope of depressive (or social anxiety) symptoms. This might be related to the distribution of the negative SRET scores, i.e., positively skewed with even more limited inter-individual variability (many youths had a score of zero), although we log-transformed the original values for analysis. Compared to the positive SRET score, this distribution of negative score appeared to be driven by the low endorsement of negative words (range 1–25, mean/SD = 6.08/5.34) rather than the low recall of negative words (range 0–11, mean/SD = 4.64/2.61). Indeed, paired-sample *t*-tests showed that youths endorsed significantly more positive words than negative words ($t(114) = 19.63$, $p < .001$), but recalled equal numbers of positive and negative words ($t(114) = -0.51$, $p = .61$). However, regardless of the limited individual variability, our recent cross-sectional study observed unique associations between the SRET scores in both conditions and depressive symptoms (Liu & Tan, 2023a). Similar to the case of the aLPP discussed above, this suggested that the negative SRET scores might be a risk marker of concurrent depressive symptoms, whereas the positive SRET scores might serve as a risk marker for both concurrent and prospective increases of symptoms. The dissociative pattern between the behavioral scores and the aLPP in our data – the former significant in the positive condition as a predictor of depressive symptom change and the latter significant in the negative condition as a predictor of social anxiety symptom change – further supported our argument that the two indices might reflect different aspects of self-referential processing.

One limitation of this study was that in analyzing the ERP data, we could not isolate the words endorsed from those not endorsed in each condition, due to an insufficient number of the word stimuli. Isolating the neural underpinnings of word endorsed versus not endorsed will provide novel information of self-referential processing and its associations with psychopathology. To do that, a greater number of words is needed in the SRET in future studies. We conducted a negative mood induction before the SRET. Although some studies argued that such a procedure was important to activate the latent construct of self-referential processing (Abela & Hankin, 2008), the mood induction might have influenced youths' responses during the SRET. A comparison between the SRET with and without preceding mood induction will help clarify the impact of induced mood on self-referential processing in relation to psychopathology. Finally, our sample was predominantly White and from middle-class families; examining more ethnically/racially and socioeconomically diverse youth samples is warranted in future research. Regardless of these limitations, this study provided new evidence on the differential, prospective associations between self-referential processing at baseline and the increases of social anxiety or depressive symptoms from age 11 to age 12, a critical period for the development of psychopathology and self-related constructs. Our findings can also inform the early identification of, and the selection of prevention strategies for, youths at risks for different trajectories of symptom development.

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