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Neurophysiological Markers Related to Negative Self-referential Processing Differentiate Adolescent Suicide Ideators and Attempters

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ABSTRACT

BACKGROUND: Adolescent suicide is a major public health concern, and presently, there is a limited understanding of the neurophysiological correlates of suicidal behaviors. Cognitive models of suicide indicate that negative views of the self are related to suicidal thoughts and behaviors, and this study investigated whether behavioral and neural correlates of self-referential processing differentiate suicide ideators from recent attempters.

METHODS: Adolescents with depression reporting current suicidal ideation and no lifetime suicide attempts (suicide ideators, $n = 30$) and past-year suicide attempts (recent attempters, $n = 26$) completed a self-referential encoding task while high-density electroencephalogram data were recorded. Behavioral analyses focused on negative processing bias (i.e., tendency to attribute negative information as being self-relevant) and drift rate (i.e., slope of reaction time and response type that corresponds to how quickly information is accumulated to make a decision about whether words are self-referent). Neurophysiological markers probing components reflecting early semantic monitoring (P2), engagement (early late positive potential), and effortful encoding (late late positive potential) also were tested.

RESULTS: Adolescent suicide ideators and recent suicide attempters reported comparable symptom severity, suicide ideation, and mental disorders. Although there were no behavioral differences, compared with suicide ideators, suicide attempters exhibited greater P2 amplitudes for negative versus positive words, which may reflect enhanced attention and arousal in response to negative self-referential stimuli. There were no group differences for the early or late late positive potential.

CONCLUSIONS: Enhanced sensory arousal in response to negative stimuli—that is, attentional orienting to semantic, emotional, and self-relevant features—differentiates adolescent suicide attempters from ideators and thus may signal risk for suicidal behavior.

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Suicide is a major public health concern (1). Rates of suicide death and suicide attempts have been rapidly increasing during the past 2 decades (2), with rates among adolescents showing the steepest incline (3). Although suicidal thoughts are common among adolescents with depression, the vast majority of depressed ideators do not attempt suicide (4,5). Thus, identifying characteristics that differentiate suicide ideators (SIs) with no history of attempts from suicide attempters (SAs) may inform future prevention and treatment efforts (6).

Maladaptive self-schemas, or negative mental representations of the self, are a core feature of major depressive disorder (MDD) (7). These schemas are hypothesized to underlie depressogenic self-referential processing biases whereby negative information is perceived as self-relevant (8), which increases the severity and duration of depressive symptoms (9). Depressogenic self-referential processing biases emerge and are stable across early development (10,11) and predict MDD onset, symptom severity, and recurrence for adolescents and adults (12–15). Despite a well-developed literature indicating that depressogenic self-referential processing biases are stable and state independent (16), their association with suicidal thoughts and behaviors (STBs) is less clear. To address this gap, this study used neurophysiological measures associated with self-referential processing to test differences among SIs and SAs.

Negative Self-referential Processing and Suicide Risk

According to the cognitive model of suicide (17), when the severity of life stressors exceeds a tolerable level (i.e., the threshold of tolerance), negative expectancies about the self, the world, and the future intensify (i.e., the suicidal belief system) (18). The suicidal belief system disproportionately focuses on negative self-evaluations wherein the self is viewed as unlovable, worthless, and helpless (18,19). Most studies that have probed the association of self-focus and STBs have relied on self-report and clinical observations [e.g., (20,21)].

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Natural language processing analyses provide additional support for the hypothesis that negative self-reference may signal suicide risk (22). For example, in youth and adults, a higher frequency of personal pronoun usage, particularly in the context of negative self-referential phrases (e.g., "I'm pathetic"), in text messages and social media posts is associated with more severe suicidal ideation (23–25). Compared with nonattempters, adults and youth who died by suicide or attempted suicide report greater frequency and intensity of these types of statements on social media (26–29), with the occurrence accelerating 2 weeks before the onset of suicidal behavior (30–32). Collectively, these studies provide preliminary evidence that increased negative self-reference may be associated with STBs. However, limited research has investigated biobehavioral correlates that may underlie self-referential processing biases among adolescents reporting STBs.

Only two studies have examined behavioral correlates of self-referential processing biases in the context of suicide risk. Among a community sample of adolescents, endorsement of negative self-referential statements predicted suicide ideation at a 2-year follow-up assessment, above and beyond baseline depression symptom severity (33). In contrast, in a study directly comparing depressed adults with a lifetime suicide attempt history and depressed control subjects with no lifetime STB history, there were no significant differences related to endorsement and recall of negative self-referent information (34). Despite mixed support for behavioral self-referential processes characterizing STBs, alternative approaches may yield clearer insight. For example, computational modeling has shown promise in decomposing self-referential behavioral patterns (9,35).

Specifically, drift diffusion modeling (DDM) estimates several features underlying binary choice and reaction time data to better understand task behavior. Drift rate (v) is a key DDM parameter that provides a latent estimate of the accumulation rate of evidence required to make a decision (36,37). As DDM can model trial-by-trial variability, reduce the influence of outlier trials, and separate the effects of lower-level processing (e.g., motor and visual), drift rate may be a more rigorous measurement of information processing speed than mean reaction time (38). Higher drift rate corresponds to faster and more consistent responses (i.e., evidence accumulates faster toward a decision), whereas values closer to zero reflect slower, less consistent response patterns (39). A growing body of research has employed DDM on self-referential tasks, and results indicated that drift rates to negative stimuli predicted depressive symptom severity in adolescents and adults (9,35) and also differentiated adults with depression from those without (40,41). This, however, has not been examined in adolescents reporting a history of STBs.

Neurophysiological Correlates of Self-referential Processing

Neurophysiological approaches, which can parse cognitive-affective processes with greater temporal resolution (e.g., early attendance to vs. encoding of emotional stimuli), may identify risk factors that are separable from behavioral indices. Event-related potentials (ERPs) provide temporal resolution in the milliseconds range, and two ERP components in particular differentiate individuals with depression and those without depression during self-referential tasks (42). The P2, peaking around 200 ms after stimulus, indexes early sensory arousal and attentional orienting in response to semantic, emotional, and self-relevant features of the stimuli (43,44). Previous work found that adolescents and adults with depression exhibited greater P2 amplitudes after negative stimuli than after positive stimuli, whereas healthy individuals exhibited the opposite pattern (45,46). For the late positive potential (LPP), which is associated with elaborative processing and emotional encoding (47,48), adolescents and adults with depression, as well as youth at risk for depression (i.e., parental history of MDD), have enhanced LPP amplitudes to negative compared with positive self-referential stimuli (46,49–52). The LPP can be further separated into a posterior early LPP and an anterior late LPP (53). The early LPP, typically maximal around 300–600 ms after stimulus, corresponds to task engagement and motivation, whereas the late LPP, maximal after approximately 600 ms after stimulus, corresponds to encoding of emotional content and arousal (53). When examining these subcomponents, adolescents and adults with depression exhibited greater early and late LPP amplitudes to negative self-referential information, whereas healthy individuals showed the opposite pattern (45,54).

Although no research has investigated ERPs associated with self-referential processing in the context of STBs, there is evidence that early and late ERPs evoked after viewing emotional images associate with suicidal thinking. Specifically, among adults with depression, P2 amplitudes following punishment cues were correlated to suicidal ideation severity (55). Similarly, compared with nonideators, past-month ideators showed blunted LPP amplitudes when viewing positive pictures (56), but this effect was not observed in a subsequent study (57). Previous research directly comparing ideators and attempters shows mixed results. There is some limited support for differentiating SIs from SAs when probing early sensory components [e.g., (58,59)], but the majority of studies found no differences [e.g., (60,61)]. Similarly, some research has shown evidence of blunted LPP amplitudes after viewing pleasant and threatening images among SAs versus SIs (62), but again, other research did not demonstrate these differences (63,64). Taken together, there is inconsistent support demonstrating neurophysiological differences among SIs and SAs. However, given previous behavioral research linking self-referential processing to youth STBs (33), our study aimed to clarify whether early (P2) and late (LPP) ERPs related to self-referential processing differentiated adolescent SIs from SAs.

Goals of This Study

Identifying behavioral and neurophysiological markers that differentiate SIs from SAs may highlight promising mechanisms specifically related to suicidal behaviors. To test whether there are differences related to self-referential processing, we compared adolescent SIs and SAs with comparable depression severity, suicidal ideation, and mental disorder comorbidity. First, we hypothesized that, relative to SIs, SAs would exhibit a more negative processing bias (i.e., tendency to attribute negative information as being self-relevant) and faster drift rates to negative stimuli (i.e., how quickly information is accumulated to determine whether words are self-referent). Second, we tested whether, relative to SIs, SAs exhibited enhanced P2 and LPP amplitudes for negative versus positive information.

METHODS AND MATERIALS

Participants

Adolescents reporting current suicidal ideation with no lifetime suicide attempts (*n* = 30 SIs) and current ideation with a past-year suicide attempt (*n* = 26 SAs) were recruited from an intensive residential treatment program in the greater Boston area. Inclusion criteria were being 12 to 19 years old, English fluency, current depressive disorder diagnosis, current suicide ideation (i.e., Scale for Suicide Ideation [SSI] score of ≥4), normal or corrected to normal vision, and right-handedness. An additional inclusion criterion among SAs was the occurrence of a past-year suicide attempt. Participants were excluded if they had a history of mania, psychosis, substance use disorder, pervasive developmental disorder, neurological illness, and/or a head injury resulting in loss of consciousness for >5 minutes. Among SIs, a lifetime history of suicide attempts was an exclusion criterion. Demographic information, stratified by group, is summarized in Table 1.

Table 1. Demographic and Clinical Information for Suicide Ideators and Suicide Attempters

Characteristics	SI, *n* = 30	SA, *n* = 26	χ^2/*t*/*U* (*df*)	*p* Value	Φ/*d*/*r*/IRR
Age, Years	16.27 (1.62)	15.42 (1.36)	−2.09 (54)	.041	−0.561
Gender					
Female	19 (63.33%)	17 (65.38%)	7.21 (3)	.065	0.359
Male	7 (23.33%)	2 (7.69%)	–	–	–
Transgender, female-to-male	3 (10.00%)	1 (3.85%)	–	–	–
Prefer not to report	1 (3.33%)	6 (23.08%)	–	–	–
Race					
White	23 (76.67%)	20 (76.92%)	2.77 (4)	.597	0.222
More than one race	3 (10.00%)	5 (19.23%)	–	–	–
Asian	2 (6.67%)	1 (3.85%)	–	–	–
Black	1 (3.33%)	0 (0.00%)	–	–	–
Native Hawaiian/Pacific Islander	1 (3.33%)	0 (0.00%)	–	–	–
Mental Disorders[a]					
Anxiety disorders	16 (53.33%)	19 (73.08%)	2.32 (1)	.128	0.203
Behavioral disorders	6 (20.00%)	3 (11.54%)	0.74 (1)	.390	−0.115
Substance use disorders	1 (3.33%)	1 (3.85%)	0.01 (1)	.918	0.014
Eating disorders	0 (0.00%)	1 (3.85%)	1.18 (1)	.278	0.145
Number of comorbid disorders	1.93 (0.94)	2.35 (0.98)	292.00	.091	−0.226
Symptom Severity					
Depression	36.03 (11.16)	40.08 (11.05)	1.36 (54)	.180	0.364
Suicide ideation	12.70 (6.02)	14.92 (7.65)	1.22 (54)	.229	0.326
Child Abuse History					
Physical abuse	2 (6.67%)	4 (15.38%)	1.11 (1)	.293	0.141
Sexual abuse	5 (16.67%)	4 (15.38%)	0.02 (1)	.896	−0.017
Suicidal Thoughts and Behaviors[b]					
Past-week suicide ideation	3.03 (2.62)	2.19 (2.43)	0.67 (1)	.412	0.796
Past-month suicide ideation	13.60 (10.72)	12.42 (9.58)	0.10 (1)	.748	1.074
Past-week suicide plans	0.03 (0.18)	0.58 (1.30)	6.54 (1)	.011	16.611
Past-month suicide plans	0.97 (2.68)	4.77 (7.16)	11.34 (1)	.001	5.669
Lifetime suicide attempts	0.00 (0.00)	1.42 (0.90)	–	–	–

Values are presented as mean (SD) or *n* (%).

Mini-International Neuropsychiatric Interview for Children and Adolescents was used for anxiety disorders (adjustment disorder, agoraphobia, generalized anxiety disorder, obsessive-compulsive disorder, panic disorder, posttraumatic stress disorder, separation anxiety, social phobia, specific phobia), behavioral disorders (attention-deficit/hyperactivity disorder, conduct disorder, oppositional defiant disorder), substance use disorders (alcohol abuse, alcohol dependence, other substance abuse, other substance dependence), and eating disorders (anorexia nervosa, binge-eating disorder, bulimia). For depression symptoms, the Center for Epidemiologic Studies Depression Scale was used; for suicide ideation, the Scale for Suicide Ideation was used; for child abuse history, the Childhood Trauma Questionnaire was used.

IRR, incidence rate ratio; SA, suicide attempter; SI, suicide ideator.

[a]100% reported depressive disorders.

[b]Self-Injurious Thoughts and Behaviors Interview: Past week and month for suicide ideation and plans reflect number of days; Results from negative binomial models with group as a categorical predictor, controlling for age with a robust estimator.

Procedure

The Partners Human Research Committee Institutional Review Board approved all study procedures. After an initial screening to determine eligibility, parent consent and adolescent assent were obtained for participants aged 12–17 years, and informed consent was completed for participants aged 18 and 19 years. On the first testing day, participants were administered diagnostic interviews and completed self-report measures. During day 2, which on average occurred within 10.3 days (SD = 3.5) of the initial assessment, participants completed a self-referential encoding task while electroencephalography (EEG) data were recorded. The duration between testing days was shorter for the SI group (mean = 9.3, SD = 2.9) than for the SA group (mean = 11.5, SD = 3.8; t_{54} = 2.46, p = .017, d = 0.66). Participants were remunerated $50.

Clinical Interviews

Before administering interviews, diagnosticians received approximately 25 hours of training, which included didactics, role-play, mock interviews, and direct observation. In addition, regular calibration meetings were held to confirm diagnoses and STBs.

Mini-International Neuropsychiatric Interview for Children and Adolescents. The Mini-International Neuropsychiatric Interview for Children and Adolescents (65) is a brief structured diagnostic interview that assesses current and past mental disorders in adolescents. The interview was used to determine eligibility for the study. The Mini-International Neuropsychiatric Interview for Children and Adolescents has moderate to strong psychometric properties and agreement with other gold-standard clinical assessments for adolescents (65,66).

Self-Injurious Thoughts and Behaviors Interview. The Self-Injurious Thoughts and Behaviors Interview (67) is a structured interview that assesses the frequency of STBs as well as nonsuicidal self-injury. For this study, the number of days in the past week and month in which participants experienced suicidal thoughts and plans were assessed. In addition, the number of lifetime suicide attempts, including whether the attempt had occurred in the past year, was assessed. Previous research using the Self-Injurious Thoughts and Behaviors Interview has shown strong psychometric properties, including excellent interrater reliability, strong test-retest reliability over a 6-month period, and strong parent-adolescent agreement on the occurrence of STBs (67). Importantly, the Self-Injurious Thoughts and Behaviors Interview has demonstrated acceptable reliability and validity among inpatient adolescents (68,69).

Self-report Questionnaires

Center for Epidemiologic Studies Depression Scale. The Center for Epidemiologic Studies Depression Scale is a 20-item self-report measure (70) assessing the frequency of depressive symptoms experienced in the past week on a scale ranging from 0 (rarely) to 3 (most of the time). Previous work has shown strong psychometric properties (71,72). Internal consistency in the present sample was excellent (α = .90).

The Scale for Suicide Ideation. The SSI (73) is a 21-item self-report scale in which subjects rate the severity of aspects of suicide ideation and previous suicide attempts. To compare groups, we used the 19-item version, which excludes items related to suicide attempts. Scores range from 0 to 38, with greater scores indicating greater suicidal ideation. The SSI is a reliable and valid measure of suicidal ideation in adolescents, with a clinically significant level of suicide ideation $\geq$ 4 (74). Internal consistency among participants completing all 19 items (n = 52) was excellent (α = .86); the SSI includes skip items, which precludes the ability to measure the internal consistency across all participants.

Childhood Trauma Questionnaire. The Childhood Trauma Questionnaire (75) includes 25 items rated on a scale ranging from 1 (never true) to 5 (very often true). Analyses focused on two 5-item subscales reflecting exposure to physical abuse (α = .70) and sexual abuse (α = .81). In accordance with Childhood Trauma Questionnaire guidelines, scores were dichotomized into the presence or absence of physical (scores $\geq$ 8) and sexual (scores $\geq$ 6) abuse.

Behavioral Task

Self-referent Encoding Task. The self-referential encoding task (45) used in this study includes 40 positive and 40 negative words matched in arousal, word length, and frequency of use in the English language (see the Supplement for stimuli set). In each trial, a word was presented for 200 ms, followed by a fixation cross for 1800 ms, and then the prompt, “Does this word describe you?” Participants responded by pressing “Yes” or “No” on a button box. The prompt was self-paced. Intertrial intervals were jittered between 1500 and 1700 ms. Stimuli were presented pseudorandomly, with no more than two words of the same valence presented successively. After the task ended there was a brief distractor, and participants were then instructed to recall words presented during the task.

Analyses focused on processing bias and drift rate. Positive and negative processing bias scores were computed by dividing the number of positive or negative words that were endorsed and then later recalled by the total number of words that were endorsed. Hierarchical DDM for Python was used to compute drift rate (v), threshold (a), and nondecision time (t) parameters based on trialwise data, where drift rate was the key parameter of interest. Drift rate reflects the average slope of reaction time to make a decision over the course of the task (38,40) and can be understood as how quickly information accumulates to make a binary decision (38,76,77). For this study, more positive v values (i.e., $v > 0$) for negative words reflect more rapid evidence accumulation, leading to endorsement of a stimulus as self-referential. Conversely, more negative v values for positive words (i.e., $v < 0$) reflect more rapid evidence accumulation that leads to rejecting the stimulus as self-referential.

EEG Recording, Data Reduction, and Analysis

EEG data were recorded using a 128-channel net from HydroCel GSN (Electrical Geodesics, Inc., Eugene, OR). During recording, impedances were kept below 75 kΩ, data were referenced to electrode Cz, and continuous EEG data were sampled at 250 Hz. Data were analyzed offline using BrainVision Analyzer 2.1.1 (Brain Products, Munich, Germany). Offline, EEG data were filtered from 0.1 to 30 Hz and then re-referenced to an average of all electrodes. Vertical and horizontal ocular artifacts were corrected using independent component analysis with the following parameters: whole data, classic principal component analysis sphering, infomax independent component analysis, energy ordering, and 512 convergence steps. A semiautomated procedure to reject intervals for individual channels was used with the following criteria: 1) a voltage step > 50 μV between sample rates, 2) a voltage difference > 200 μV every 200 ms within a trial, and 3) a maximum voltage difference of <0.50 μV within a 100-ms interval. Finally, all segments were inspected visually for manual artifact removal.

ERPs were time locked to stimulus onset for all words viewed, with a 200-ms baseline and extending to a 1200-ms time window after stimulus onset. ERP amplitudes were examined at sensor locations equivalent to selected electrodes in the 10/10 system. Observation of topographical maps indicated that the P2 was maximal from 164 to 236 ms in electrodes FCz and Fz, which is similar to the findings reported in previous work (78,79). Based on previous work using self-referential tasks (45) and on topographical maps, mean amplitudes were extracted for the early LPP from 400 to 600 ms at electrode Pz and for the late LPP from 600 to 1200 ms at electrode FPz. Residualized scores were calculated by regressing mean amplitudes from positive stimuli onto those from negative stimuli and computing standardized residuals for each component. Residualized difference scores are preferable to subtraction for detecting individual differences because they are more effective at isolating variance unique to a specific condition (80). For ERP analyses, data from 6 subjects were omitted because of excessive noise or equipment failure. Thus, ERP analyses focused on group comparisons (SIs n = 25, SAs n = 25) for the residualized P2, early LPP, and late LPP.

Data Analysis

Pearson correlations were conducted to test associations among the clinical and self-referential processing variables. Because age differed between groups and may affect behavioral responses as well as neurophysiological activity (Table 1), age was included as a covariate. Results, however, remained the same whether including or excluding age as a covariate. Group differences in STBs were analyzed using a negative binomial regression controlling for age. A group (SA, SI) × valence (positive, negative) analysis of covariance controlling for age was conducted to test differences in processing bias. For both negative and positive words, Bayesian inference (part of the hierarchical DDM package) was used to directly compare group differences in posterior distribution for drift rate (v), defining significance as $<$2.5% overlap (Bayesian q value $< .025$) to account for the two tests conducted (.05/two tests). Group differences in residualized P2, early LPP, and late LPP were analyzed using independent samples t tests. Significant t tests were followed up with logistic regression analyses, controlling for age, depressive symptoms, and suicidal ideation to test the robustness of these effects. Sensitivity analyses explored whether recency of the attempt among SAs, measured in days, related to ERPs.

RESULTS

Descriptive Analyses

The groups did not significantly differ on depression severity, suicide ideation, and mental disorder comorbidity, but SIs were slightly older than SAs. Compared with SIs, SAs had a significantly higher rate of past-week and past-month suicide plans (Table 1). Correlations among clinical, behavioral, and ERP variables are summarized in Table 2. Positive and negative drift rate were inversely correlated to negative and positive processing bias, respectively. In addition, a more positive negative drift rate (i.e., a more rapid endorsement of negative words as being self-relevant) was related to greater depression severity, and there was a modest association between negative processing bias and suicide ideation. The Spearman-Brown–corrected split-half reliability coefficients correlating odd and even trials were acceptable: P2 (negative ρ = .64; positive ρ = .77), the early LPP (negative ρ = .79; positive ρ = .73), and the late LPP (negative ρ = .83; positive ρ = .83).

Behavioral Results

Means and standard deviations for processing bias, drift rate, and ERP amplitudes are summarized in Table 3.

Processing Bias. The main effect of group ($F_{1,53}$ = 0.135, p = .715, η_p^2 = .003) was not significant. However, the main effect of valence was significant ($F_{1,53}$ = 5.816, p = .019, η_p^2 = .099), whereby bias scores for negative stimuli (mean = 0.131, SE = 0.010) were greater than for positive stimuli (mean = 0.092, SE = 0.007). The group × valence interaction was not significant ($F_{1,53}$ = 1.691, p = .199, η_p^2 = .031).

Drift Rate. Probability distributions of posterior drift rates are presented in Figure 1. For negative stimuli, 78% of the distribution for SAs (mean = 0.47, SD = 0.17; 95% confidence interval [CI] = 0.14 to 0.82) was greater than that for SIs (mean = 0.28, SD = 0.17; 95% CI = −0.05 to 0.60). Thus, the SAs accumulated evidence faster to endorse a negative stimulus but not at a rate that would be considered significant (q = .22). For the positive stimuli, 40% of distribution for the SAs (mean = −0.46, SD = 0.17; 95% CI = −0.78 to 0.11) was greater than that for SIs (mean = 0.40, SD = 0.16; 95% CI = −0.70 to −0.07), suggesting that SAs and SIs accumulated evidence to reject a positive stimulus at a similar rate (q = .60).

Neurophysiological Components

For the P2, SAs exhibited a significantly larger P2 difference wave (i.e., positive stimuli regressed onto negative stimuli) than SIs (t_{48} = 2.343, p = .023, d = 0.663) (Figure 2). To test the robustness of this group difference, we estimated a model controlling for age, depression symptoms, and suicidal ideation; greater P2 residual scores (i.e., greater negative vs. positive stimuli amplitudes) predicted SA group membership (B = 0.743, SE = 0.365; χ^2_1 = 4.157, p = .041; odds ratio [OR] =

Table 2. Correlations Among Self-referential Processing and Clinical Variables

	1	2	3	4	5	6	7	8	9
1. Negative Bias	–								
2. Positive Bias	−.075	–							
3. Negative, *v*	.251	−.389[a]	–						
4. Positive, *v*	−.526[b]	.377	−.501[b]	–					
5. P2 Residualized[c]	−.036	.212	.211	.048	–				
6. Early LPP Residualized[c]	.220	.011	.051	.063	.026	–			
7. Late LPP Residualized[c]	.090	.074	.134	−.144	.378[a]	−.208	–		
8. Depression Symptoms	.015	−.108	.301[d]	−.131	.322[d]	−.062	.152	–	
9. Suicidal Ideation	−.274[d]	−.213	.204	−.035	.227	−.232	.058	.462[b]	–

For depression symptoms, the Center for Epidemiologic Studies Depression Scale was used; for suicide ideation, the Scale for Suicide Ideation was used. *v* indicates drift rate.

ERP, event-related potential; LPP, late positive potential; SA, suicide attempter; SI, suicide ideator.

[a]$p < .01$.

[b]$p < .001$.

[c]ERPs: SIs $n = 25$, SAs $n = 25$.

[d]$p < .05$.

2.103, 95% CI = 1.029 to 4.297). Within this model, older age associated with being in the SI group ($B = -0.490$, SE = 0.231; $\chi^2_1 = 4.507$, $p = .034$; OR = 0.613, 95% CI = 0.390 to 0.963). Suicide ideation ($B = 0.009$, SE = 0.052; $\chi^2_1 = 0.028$, $p = .867$; OR = 1.009, 95% CI = 0.910 to 1.118) and depression symptoms ($B = 0.026$, SE = 0.035; $\chi^2_1 = 0.544$, $p = .461$; OR = 1.026, 95% CI = 0.958 to 1.100) did not predict group membership. In light of this finding, we explored whether suicide attempt recency was related to P2 amplitudes among the SAs. Results indicated that days since the most recent suicide attempt was not associated with the residualized P2 amplitude ($B = -0.002$, SE = 0.002; $\beta = -.18$, $p = .383$, $R^2_{adj} = -.009$). As a test of specificity for our effect, we also examined a model in which negative stimuli were regressed onto positive stimuli. No group difference emerged for the P2 ($t_{48} = -1.43$, $p = .159$, $d = -0.405$).

When testing group differences for the slow wave components, effects were nonsignificant for the early LPP ($t_{48} = -0.406$, $p = .687$, $d = -0.115$) (Figure 3) and the late LPP ($t_{48} = 1.047$, $p = .300$, $d = 0.296$) (Figure 4). Among SAs, attempt recency was not associated with the early or late LPP ($ps > .45$).

DISCUSSION

Adolescent suicide rates continue to rise (3), and identifying novel risk factors that facilitate the transition from suicidal ideation to action may inform future prevention and treatment

Table 3. Behavioral and Neurophysiological Markers Related to Self-referential Processing

Markers	Suicide Ideators	Suicide Attempters
Behavior[a]		
Total negative words endorsed	22.73 (6.61)	23.35 (7.19)
Total positive words endorsed	16.00 (6.08)	15.35 (7.64)
Negative processing bias	0.14 (0.07)	0.12 (0.08)
Positive processing bias	0.09 (0.06)	0.09 (0.05)
Negative drift rate, *v*	0.25 (0.71)	0.46 (0.64)
Positive drift rate, *v*	−0.38 (0.63)	−0.46 (0.79)
ERPs, µV[b]		
P2 negative	2.56 (2.30)	3.61 (1.77)
P2 positive	2.80 (2.57)	3.01 (2.06)
Early LPP negative	2.19 (3.38)	2.39 (3.84)
Early LPP positive	1.95 (3.69)	2.44 (3.74)
Late LPP negative	2.99 (4.05)	3.53 (8.19)
Late LPP positive	3.79 (5.31)	3.05 (6.26)

Values are presented as mean (SD).

ERP, event-related potential; LPP, late positive potential; SA, suicide attempter; SI, suicide ideator.

[a]Behavior: SIs $n = 30$, SAs $n = 26$.

[b]ERPs: SIs $n = 25$, SAs $n = 25$.

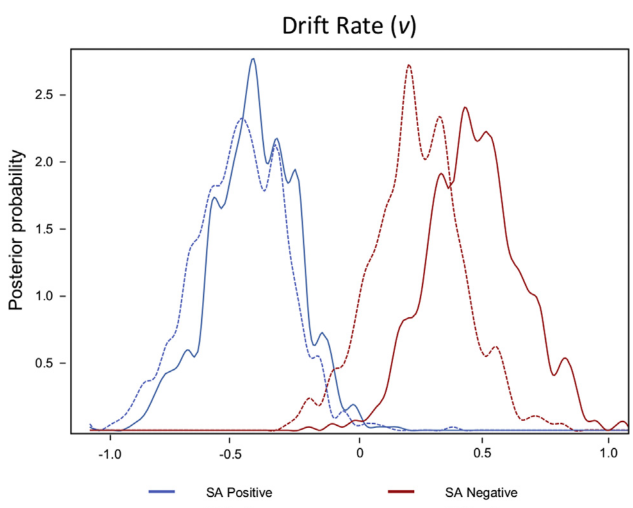

Figure 1. Distribution of drift rate (*v*) for suicide attempters (SA) (solid lines) and suicide ideators (SI) (dashed lines) for positive (blue lines) and negative (red lines) stimuli. These results indicated that the two groups did not differ in their drift rate for positive or negative stimuli.

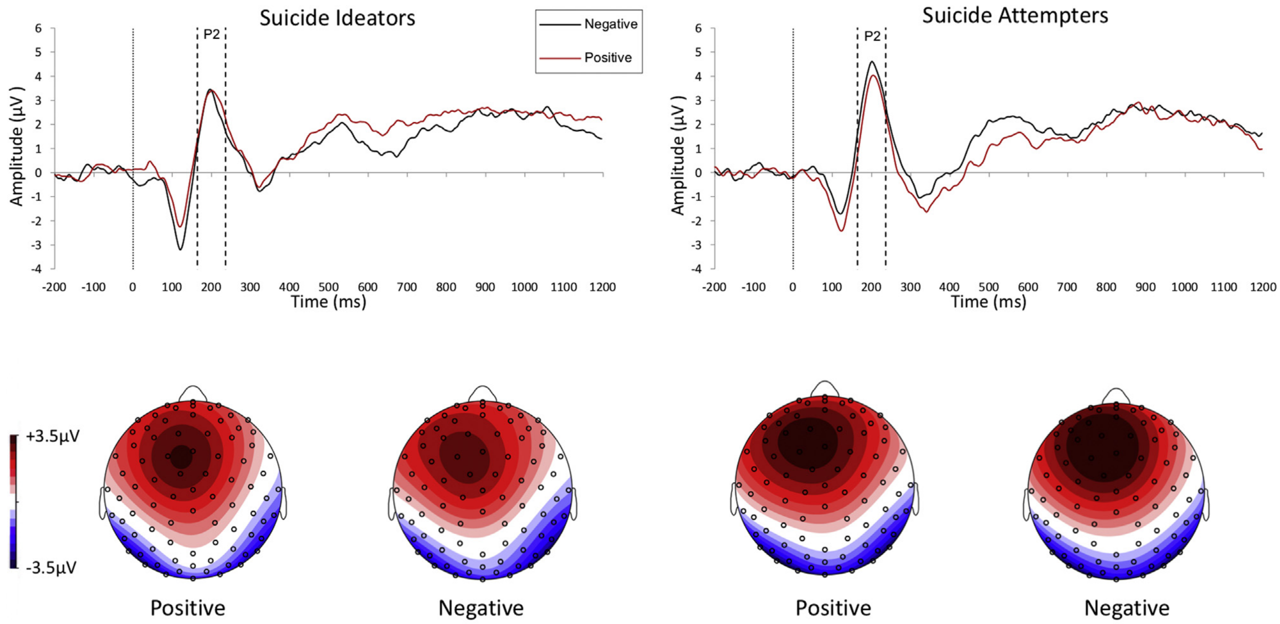

Figure 2. (Top panel) Waveforms depicting the P2 component (164–236 ms) elicited by negative stimuli (black lines) and positive stimuli (red lines) for suicide ideators (left) and suicide attempters (right). Waveforms are pooled from FCz and Fz based on inspection of all participants across conditions. (Bottom panel) Topographic maps depicting the mean amplitudes during the P2 time window.

efforts. Consistent with recent recommendations for identifying neural markers associated with STBs (81), the study compared depressed adolescent SIs and SAs with comparable suicide ideation, depression severity, and mental disorder comorbidity (Table 1). There were no behavioral differences in processing bias or drift rate. However, compared with SIs, SAs were characterized by enhanced P2 amplitudes to negative information, which may reflect early semantic monitoring of

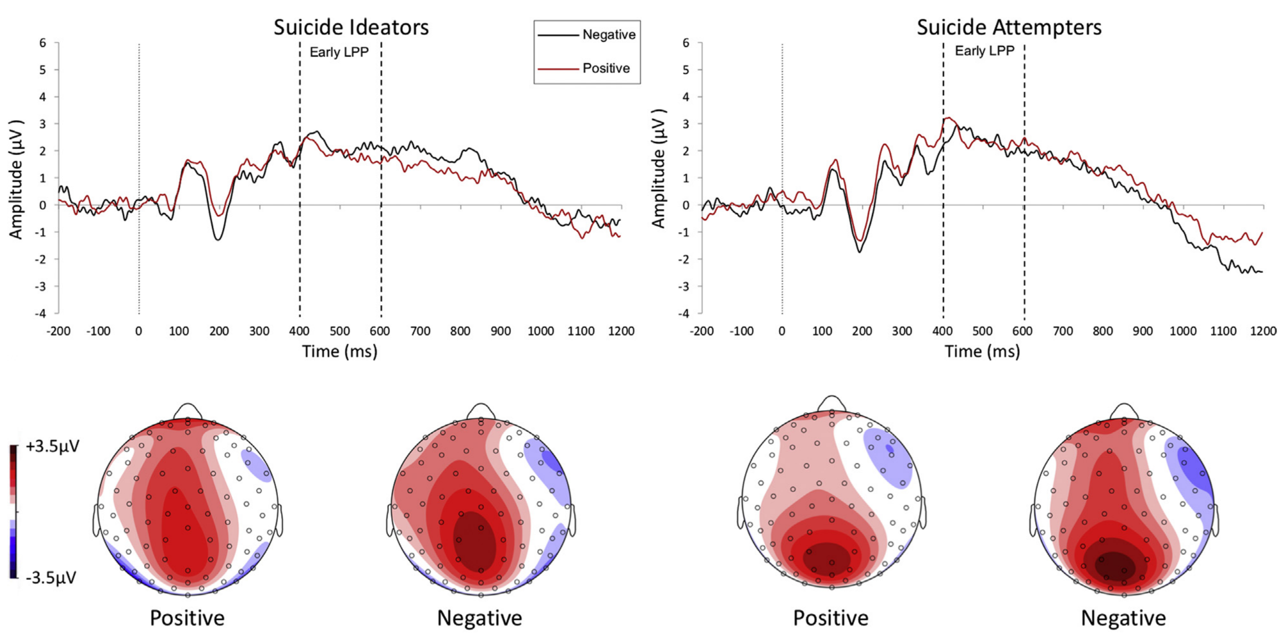

Figure 3. (Top panel) Waveforms depicting the early late positive potential (LPP) component (400–600 ms) elicited by negative stimuli (black lines) and positive stimuli (red lines) for suicide ideators (left) and attempters (right). Waveforms are pooled from Pz based on inspection of all participants across conditions. (Bottom panel) Topographic maps depicting the mean amplitudes during the early LPP time window.

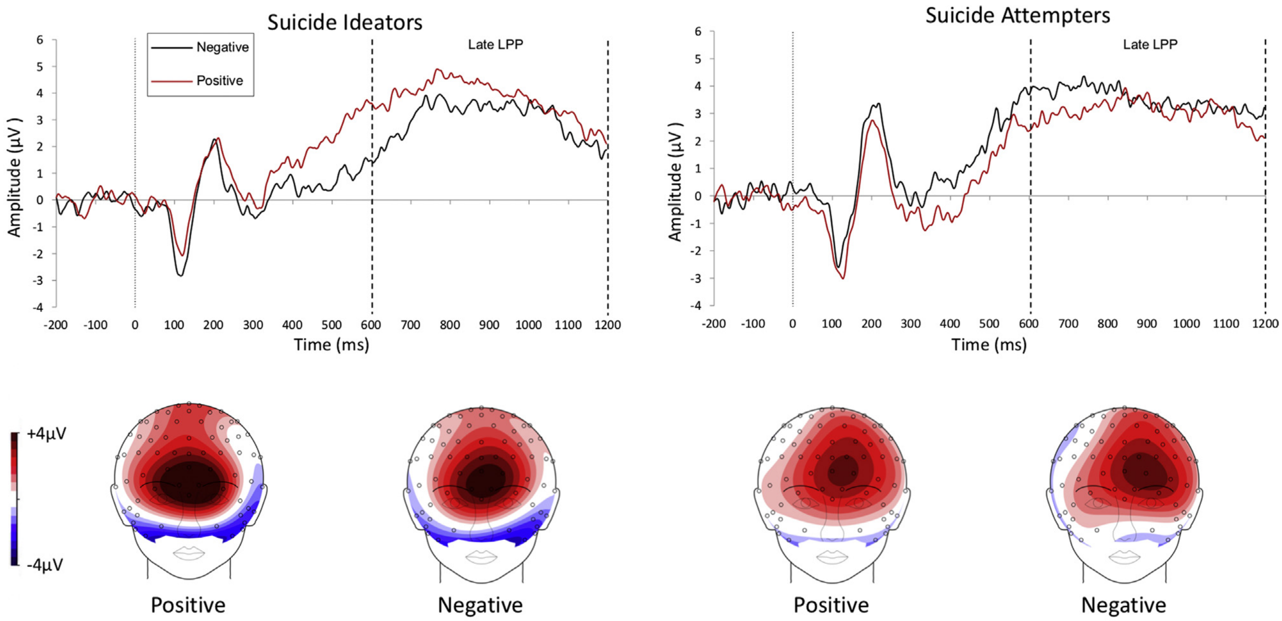

Figure 4. (Top panel) Waveforms depicting the late late positive potential (LPP) component (600–1200 ms) elicited by negative stimuli (black lines) and positive stimuli (red lines) for ideators (left) and attempters (right). Waveforms are pooled from FPz based on inspection of all participants across conditions. (Bottom panel) Topographic maps depicting the mean amplitudes during the late LPP time window.

depressogenic information. No group differences emerged for the LPP.

Previous research has shown that MDD is characterized by behavioral and neurophysiological alterations related to negative self-referential processing. However, among asymptomatic high-risk individuals (i.e., offspring of parents with depression), only neural differences emerged. Namely, compared with low-risk youth, high-risk youth showed enhanced LPP amplitudes to negative words (50) and blunted ventrolateral prefrontal cortex activation to positive words (82). Neither of these studies revealed behavioral performance differences, suggesting that effects related to processing bias, endorsement, and recall reported in earlier depression research may be driven by current symptoms rather than latent vulnerability to MDD [e.g., (46,83)]. Accordingly, a recent study among remitted depressed and healthy adults did not find differences in rates of endorsement or processing bias but, interestingly, showed that remitted adults with depression exhibited blunted LPP amplitudes to positive self-referential words (84). Taken together, these studies provide preliminary evidence that cognitive-affective processes probed with enhanced temporal (EEG/ERP) and spatial (functional magnetic resonance imaging) resolution may capture markers that are separable from depressogenic self-referential processing behavioral outcomes and perhaps less susceptible to the influence of current depressive symptoms. This may explain, in part, why we observe neurophysiological but not behavioral differences, as the groups did not differ in their depressive symptoms, suicidal ideation, or mental disorder comorbidity.

Consistent with the cognitive model of suicide (17,85), our ERP findings show that there is enhanced attention to negative information among SAs, perhaps reflecting a mechanism that may reinforce their suicide schema. Previous research has shown that emotional words elicit ERP modulations early in the time course (i.e., approximately 100–300 ms after stimulus), supporting the belief that automated lexical processing occurs rapidly [e.g., (86)]. For example, among patients with chronic pain, there are clear P1 modulations to pain-specific words relative to nonpain words (87,88), and similarly, in youth diagnosed with MDD (45) and borderline personality disorder (89), there are P2 modulations after exposure to negative information. Among SAs, this enhanced attendance to and arousal from negative information may explain, in part, why certain suicidal youth transition from ideation to action. Namely, attendance to negative emotional information may elicit more impulsive behaviors that lead to suicide attempts, which is consistent with previous research focusing on the role of negative urgency—or feelings triggering action—in relation to adolescent suicidal behaviors (90). Our cross-sectional design is ill suited to directly address this important empirical issue; however, future longitudinal research may clarify whether P2 amplitudes to negative information directly facilitate the transition to suicide attempts and death among high-risk youth. More broadly, SAs' greater attendance to negative versus positive information may afford some insight regarding why SAs present significant treatment challenges. Early sensory arousal in response to negative stimuli is believed to be entrenched and stable over time (83) and necessarily shapes SAs' perception of the self. Psychotherapeutic approaches, including cognitive behavioral therapy, offer a variety of skills to challenge beliefs about the self, but these skills require conscious awareness of one's biases and patterns of thinking. Insomuch as the early attendance to negative self-relevant information occurs rapidly, it may be that complementary and adjunctive approaches to standard therapeutic interventions—e.g., real-time neurofeedback aimed at modulating the default mode network (DMN), which is implicated in self-referential processing (91)—will be necessary to improve clinical outcomes among suicidal youth.

Although not directly analogous to EEG approaches, functional magnetic resonance imaging research in suicidal youth provides some converging evidence, particularly regarding findings implicating the DMN. Broadly, the DMN is involved in perspective taking, especially as this may relate to beliefs about the self (92), and it includes interconnected nodes from the dorsal medial (e.g., dorsomedial prefrontal cortex) and medial temporal (e.g., hippocampus) subsystem, of which activity therein has recently been linked to P2 amplitudes [e.g., (93)]. Several resting-state functional magnetic resonance imaging studies show DMN alterations—in particular, diminished connectivity between the DMN and the salience network as well as the frontoparietal network (94). In addition, decreased DMN coherence, which may reflect difficulties integrating emotional and cognitive inputs as well as challenges in keeping these processes in balance, prospectively predicted suicide ideation severity (but not behaviors) (95). Overall, these data suggest that neural alterations related to self-referential processing may be a promising correlate of STBs, but further research is needed to clarify whether the DMN may be a specific marker of behaviors. One approach to directly addressing this question is to probe the DMN in the context of specific environmental exposures. Neural diatheses—including DMN alterations and P2 amplitudes—are likely a necessary but not sufficient predisposition to engage in self-injurious behaviors. Consistent with the neurodevelopmental model of STBs, exposure to interpersonal stress (e.g., peer victimization) may, for some, activate underlying neural diatheses and consequently increase risk for suicidal behaviors (81). Testing neural correlates in the context of interpersonal stress exposure may, ultimately, elucidate neural risk factors that facilitate the transition from ideation to action.

Research differentiating neural processes related to adolescent SIs and SAs is limited, and therefore, this study provides an expansion of existing work. That said, there are several limitations. First, although we identify promising neurophysiological differences, the project is cross-sectional. Accordingly, it is not clear whether these markers contributed to the suicide attempt, or conversely, are a consequence of the attempt. Thus, longitudinal studies are needed to clarify whether P2 amplitudes, particularly in the context of negative emotional information, predict suicide attempts. Second, recruitment of current adolescent ideators is challenging, particularly given competing clinical priorities to stabilize well-being. Our sample size for each group is modest, which affects the generalizability of our findings. Furthermore, consistent with previous research (45,89), our ERP analyses were computed based on all words viewed and not restricted to words specifically endorsed. As reliably estimating ERPs requires a sufficient number of trials, restricting analyses to only those words endorsed would have resulted in removing additional participants from our analyses. Future research with larger samples will be better positioned to address this issue. Third, the majority of our sample is female. Although there are no known sex-specific neural differences related to adolescent STBs, there is complementary demographic and clinical evidence showing that the pathway toward suicide differs between males and females (81). Finally, clinical interviews were not recorded, and thus, interrater reliability was not obtained for either diagnoses or lifetime history of STBs.

In summary, our findings suggest that among SAs, early sensory arousal from negative information may reinforce their suicide schema. Given our methodological design, these differences cannot be attributed to current depression symptoms, suicide ideation severity, or underlying mental disorders. A critical next step in this research will be to test whether these ERP effects predict suicidal behaviors, especially in the context of interpersonal stress. Ultimately, identifying risk factors that contribute to the transition from ideation to action will further the development of innovative treatment approaches that save adolescent lives.

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