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Self-Referential Processing in Adolescents: Stability of Behavioral and Event-Related Potential Markers

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Abstract

The self-referential encoding task (SRET)—an implicit measure of self-schema—has been used widely to probe cognitive biases associated with depression, including among adolescents. However, research testing the stability of behavioral and electrocortical effects is sparse. Therefore, the current study sought to evaluate the stability of behavioral markers and event-related potentials (ERP) elicited from the SRET over time in healthy, female adolescents ($n = 31$). At baseline, participants were administered a diagnostic interview and a self-report measure of depression severity. In addition, they completed the SRET while 128-channel event-related potential (ERP) data were recorded to examine early (P1) and late (late positive potential [LPP]) ERPs. Three months later, participants were re-administered the depression self-report measure and the SRET in conjunction with ERPs. Results revealed that healthy adolescents endorsed, recalled, and recognized more positive and fewer negative words at each assessment, and these effects were stable over time (rs = 0.44–0.83). Similarly, they reported a faster reaction time when endorsing self-relevant positive words, as opposed to negative words, at both the initial and follow-up assessment ($r = 0.82$). Second, ERP responses, specifically potentiated P1 and late LPP positivity to positive versus negative words, were consistent over time (rs = 0.56–0.83), and the internal reliability of ERPs were robust at each time point (rs = 0.52–0.80). As a whole, these medium-to-large effects suggest that the SRET is a reliable behavioral and neural probe of self-referential processing.

Keywords

Self-referential processing; Depression; P1; LPP; Reliability

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Introduction

Depression is a leading cause of disability worldwide (Bromet et al., 2011; Kessler, 2012), and deeply entrenched cognitive biases—particularly depressogenic self-referential processing biases (i.e., the tendency to attribute negative information as being self-relevant)—play a prominent role in the onset and maintenance of major depressive disorder (MDD) in children and adolescents (Auerbach, Stanton, Proudfit, & Pizzagalli, 2015; Goldstein, Hayden, & Klein, 2015; Jaenicke et al., 1987). Over the past three decades, the self-referential encoding task (SRET; Kuiper & Derry, 1982) has been used to probe cognitive biases implicated in MDD. During the SRET, individuals indicate whether a series of positive and negative adjectives, typically matched across relevant conditions (i.e., arousal, word length), describe themselves. The SRET is conceptualized as an implicit test of self-schema (Goldstein et al., 2015; Kuiper & Derry, 1982), and the resulting negative biases, operationalized as greater endorsement and recall of negative versus positive self-relevant adjectives, are moderately-to-strongly associated with core cognitive vulnerabilities linked to depression, including self-criticism, rumination, and dysfunctional attribution styles (Alloy, Abramson, Murray, Whitehouse, & Hogan, 1997; Auerbach et al., 2015; Hayden et al., 2013; Joormann, Dkane, & Gotlib, 2006).

Among adults tested with the SRET, depressed individuals endorse and recall a greater number of negative as compared to positive adjectives relative to non-depressed individuals (Derry & Kuiper, 1981; Dobson & Shaw, 1987; Matt, Vázquez, & Campbell, 1992; Moulds, Kandris, & Williams, 2007). Findings in youth are largely consistent. Namely, depressed children and adolescents endorse and recall a greater number of negative words relative to positive words (Auerbach et al., 2015; Connolly, Abramson, & Alloy, 2015; Timbremont & Braet, 2004; Zupan, Hammen, & Jaenicke, 1987), and additionally, they respond faster when endorsing negative words but exhibit a slower RT when endorsing positive words (Auerbach et al., 2015). These depressotypic self-referential processing biases also emerged in remitted depressed children and adolescents (Timbremont & Braet, 2004) as well as at-risk children (i.e., owing to parental history of depression) (Jaenicke et al., 1987). Further, in children aged 6–9 years, SRET effects demonstrated modest stability over time (Goldstein, Hayden, & Klein, 2015). Taken together, these findings suggest that the SRET provides a useful measurement of depressogenic self-referential processing biases.

More recently, research has leveraged scalp-recorded event-related potentials (ERPs), which provide excellent temporal resolution in the milliseconds (ms) range, to better understand putative processes associated with depressotypic self-referential processing elicited during the SRET (Auerbach et al., 2015; Shestyuk & Deldin, 2010). ERP studies with the SRET have focused on early and late ERP components. Early ERP components, including the P1 and P2, are maximal over parietal-occipital areas, stable, reflect semantic monitoring of emotional information, and are modulated by word valence (Flor, Knost, & Birbaumer, 1997; West & Holcomb, 2000). Conversely, the late positive potential (LPP) spans several hundred ms to seconds and indexes sustained engagement to both emotional words (Fischler & Bradley, 2006) and images (Foti, Hajcak, & Dien, 2009). Prior work probing the LPP using an emotion-based paradigm has demonstrated strong test-retest reliability over a 2-year period (Kujawa, Klein, & Proudfit, 2013); however, to date, the stability of the LPP

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within an SRET context has not been tested. During the SRET, the LPP is initially maximal over parietal sites (i.e., early LPP), and later in the temporal course, it propagates to frontocentral regions (i.e., late LPP). This frontal propagation is particularly important in light of prior neuroimaging evidence implicating prefrontal cortex abnormalities in negative self-referential processing (Auerbach et al., 2015; Lemogne et al., 2010).

ERP studies using the SRET have revealed promising findings. Shestyuk and Deldin (2010) found that depressed adults exhibited enhanced P2 and late LPP positivity to negative versus positive words, whereas healthy individuals showed the opposite effect. Our group recently published similar findings in depressed youth (Auerbach et al., 2015). This study reported that depressed youth displayed a potentiated P1, but not P2, in response to negative as compared to positive words, whereas healthy adolescents showed the opposite pattern. Interestingly, greater P1 positivity to negative words was associated with depressotypic cognitive vulnerability factors, including greater self-criticism and a more negative self-view. Results among depressed adolescents also indicated enhanced early (parietal-occipital sites) and late (frontocentral sites) LPP positivity to negative versus positive words, and again, healthy adolescents showed the opposite effect. Building on these findings in a sample of healthy low- and high-risk youth (owing to a maternal history of depression) aged 8–14 years, Speed and colleagues (in press) demonstrated that high-risk youth exhibited a potentiated LPP response to negative words; no between-group differences emerged following positive words. Collectively, these findings suggest that ERPs elicited through the SRET may differentiate healthy and depressed individuals, and further LPP positivity to negative words may be a trait marker that precedes depression onset.

Through its Strategic Plan for Research, the National Institute of Mental Health (NIMH) has outlined the importance of identifying “clinically useful biomarkers and behavioral indicators that predict change across the trajectory of illness” (*Strategic Objective 2.2*). Toward this goal, the current study evaluated the stability of behavioral and neural (ERP) indices of the SRET over time in healthy, female adolescents. This is a critical initial step, as any proposed biomarker or behavioral indicator must demonstrate stability over time in healthy populations, prior to being used as a predictor or indicator of mental illness. To this end, we retested healthy female participants evaluated in our recent ERP study in adolescent depression (Auerbach et al., 2015) three months after the initial session (and recruited 7 additional participants to increase sample size). We tested the following a priori hypotheses. First, we expected to confirm the behavioral and ERP task effects reported in Auerbach et al. (2015) in this extended sample; specifically, we expected that healthy adolescents will (1) endorse, recall, and recognize more positive as opposed to negative words; (2) exhibit a faster reaction to endorse self-relevant positive as opposed to negative words; and (3) show greater P1 and LPP amplitudes in response to positive versus negative words. Second, we hypothesized that these behavioral and ERP effects will remain stable and consistent at the 3-month follow-up assessment.

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Method

Procedure

A full description of the procedure was provided in a recent paper, in which female adolescents with MDD and healthy females were compared at a baseline session (Auerbach et al., 2015). Briefly, the Partners Institutional Review Board approved the study. Youth aged 13 to 17 years provided assent, while 18-year-old participants and legal guardians provided written consent. The research project included three study visits. On the first visit, adolescents completed a semi-structured diagnostic interview of current and past mental illness and were administered a self-report instrument assessing depressive symptoms. During the second study visit, which occurred within 1–2 weeks of the first study visit, participants completed the self-referential encoding task (SRET) while ERP data were recorded. The average length between the first and second visits was 7.87 ± 6.04 days. At the third study visit (i.e., the follow-up assessment), which occurred 3 months later, participants were administered the same depression self-report measure and SRET task in conjunction with ERP. Participants were remunerated $70 for their participation.

Participants

The sample included 37 healthy female adolescents (30 healthy females included in Auerbach et al., 2015 plus seven additional participants). Participants were aged 13–18 years and recruited from the greater Boston area through online advertisements, posted flyers, and direct mailing. To meet inclusion criteria, participants were required to be fluent in English, right-handed, and female. Exclusion criteria included lifetime diagnosis of any psychopathology, mental retardation, organic brain syndrome, head injury resulting in loss of consciousness for 5 minutes or seizures, and use of psychiatric medication. One participant was excluded for poor data quality during the initial EEG assessment, and five of the original participants did not complete the 3-month follow-up EEG assessment. Compared to participants lost due to poor data quality and attrition ($n = 6$), the final adolescent sample ($n = 31$) did not differ in age, $t(35) = -0.22$, $p = 0.83$, or race, $\chi^2(2) = 1.54$, $p = 0.46$; they did differ in socioeconomic status (SES), $\chi^2(3) = 16.75$, $p = 0.001$, with the adolescents lost to attrition reporting a higher SES. The final sample of 31 female adolescents ($M = 15.16$, $SD = 1.5$) included: 87.1% White, 6.5% Asian, and 6.5% multiple races. The income distribution included the following: 74.2% = more than $100,000, 6.5% = $50,000 to $75,000, and 19.4% = not reported.

Instruments

Schedule for Affective Disorders and Schizophrenia for School-Age Children Present (K-SADS-PL; Kaufman et al., 1997)—The K-SADS-PL is a semi-structured clinical interview used to assess current and past psychiatric disorders according to the DSM-IV-TR (American Psychiatric Association, 2000), and past research has demonstrated excellent reliability and validity (Kaufman et al., 1997). Graduate students and bachelor's-level research assistants administered the clinical interview after receiving 40 hours of training, which included didactics, mock interviews, and direct supervision. The principal investigator (RPA) reviewed digital audio files of 20% of the interviews selected at random to assess interrater reliability, and the Cohen's kappa coefficients were excellent ($\kappa = 1.00$).

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Beck Depression Inventory II (BDI-II; Beck et al., 1996)—The BDI-II is a 21-item self-report questionnaire that assesses depressive symptom severity over the past two weeks. Items range from 0 to 3, and higher scores indicate higher levels of depressive symptoms. Cutoffs for the BDI-II include: (a) 0 to 13 = no or minimal depression, (b) 14 to 19 = mild depression, (c) 20 to 28 = moderate depression, and (d) 29 to 63 = severe depression. In the current study, the Cronbach's alpha for the BDI-II ranged from 0.87 to 0.91, suggesting strong internal consistency.

Experimental Task—The self-referential encoding task (SRET) included 80 trials consisting of 40 positive and 40 negative adjectives (see Auerbach et al., 2015). Adjectives were selected from the Affective Norms for English Words based on criteria including valence, arousal, frequency, and length (Bradley & Yang, 2010). Positive and negative adjectives were significantly different in valence ($t(79) = -55.88$, $p < 0.001$), but not arousal ($t(79) = 0.68$, $p = 0.50$), frequency ($t(79) = -1.64$, $p = 0.11$), or word length ($t(79) = -0.06$, $p = 0.95$). Stimuli were presented in a pseudo-random order, with no more than two words of the same valence presented in a row. Consistent with past research (Auerbach et al., 2015; Shestyuk & Deldin, 2010), in each trial, the stimulus was presented for 200 ms, followed by a fixation cross (1800 ms) and a question prompt, "Does this word describe you?" Participants responded by pressing "yes" or "no" on a button box. Intertrial intervals were jittered between 1500 ms and 1700 ms. Participants completed three practice trials using affectively neutral words prior to the start of data collection. After completing the 80 trials, participants were given a distractor task, consisting of counting backwards from 50. Upon completing this distractor task, participants were asked to recall as many words as they could that were presented during the task. Following the recall component, participants were given a recognition task that included 160 words – 80 words that appeared in the task and 80 matched distractors (i.e., an additional 40 positive and 40 negative words). In line with prior research (e.g., Prieto, Cole, & Tageson, 1992; Golstein, Hayden, & Klein, 2014), we also created a processing bias score for positive and negative words. The positive processing bias score was calculated by dividing the number of positive words endorsed that also were recalled by the total number positive and negative words endorsed. Similarly, the negative processing bias represented the number of negative words endorsed that were recalled divided by the sum of the total number of words endorsed.

EEG Recording, Data Reduction, and Analysis

The EEG data were recorded using a 128-channel net from Hydro-Cel GSN Electrical Geodesics, Inc. (EGI). Continuous EEG data were sampled at 250 Hz and referenced to Cz. Electrode impedances were kept below 50–75 kΩ, and offline analyses were performed using BrainVision Analyzer 2.04 software (Brain Products, Germany). EEG data were re-referenced to the average reference, and offline filters (0.1 to 30 Hz) were applied. Vertical and horizontal eye movement artifacts were identified and removed using an independent component analysis transform. For each trial, EEG data were segmented 200 ms before and 1200 ms after stimulus onset. A semi-automated procedure to reject intervals for individual channels used the following criteria: (a) a voltage step > 50 μV between sample rates, (b) a voltage difference > 300 μV within a trial, and (c) a maximum voltage difference of < 0.50

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μV within a 100-ms interval. All trials were visually inspected for manual artifact identification and removal.

ERPs were computed time-locked to all available positive and negative words, and the average amplitude 200 ms pre-stimulus (i.e., word presentation) served as the baseline. ERP amplitudes were examined at sensor locations equivalent to selected electrodes in the 10/10 system. Scalp location and time windows were consistent with previously published findings using a subset of participants from the current study (Auerbach et al., 2015). The P1 and early LPP components were calculated as the mean area across electrode sites Pz, P1, PO3, POz, PO4, and P2 for the following time windows where the component was maximal: (a) P1 = 108–172 ms and (b) early LPP = 400–600 ms post-stimulus. The late LPP was examined across the average of frontocentral midline electrode sites Fz, FCz, and Cz 600–1200 ms post-stimulus[1].

All analyses were conducted with SPSS (version 20.0). A repeated measure analysis of variance (RMANOVA) tested main effects for *Time* (Time 1, Time 2) and *Condition* (Positive Words, Negative Words) as well as the *Time* × *Condition* interaction. To demonstrate the stability of a given effect over time, we anticipated a significant main effect for *Condition*; neither the main effect for *Time* nor the *Time* × *Condition* interaction was expected to be significant. All analyses included effect sizes (η^2) where: (a) .02 – .12 = small, (b) .13 – .25 = medium, and (c) ≥.26 = large. Test-retest reliability for behavioral and ERP indices was evaluated by performing Pearson correlations. The internal consistency of our ERP indices was computed by examining the correlation of the odd and even trials at each time point.

Results

Descriptive Statistics

Depressive symptoms were assessed at the initial and follow-up assessments (test-retest $r = 0.75$, $p < .001$). As expected, depressive symptom scores were low and in the non-depressed range at baseline ($M = 1.84$, $SD = 3.72$) and follow-up ($M = 4.09$, $SD = 5.71$). While there was a significant difference in symptom scores across assessments, $t(30) = -3.26$, $p = 0.003$, symptom levels are indicative of healthy adolescents and no adolescent reported clinically significant depressive symptoms at either of the assessments.

Behavioral Data

Behavioral data from the SRET are summarized in Table 1, and previously reported behavioral effects from the initial assessment (Auerbach et al. 2015) were replicated in this larger sample.

[1]Whereas some research has shown that the late LPP is maximal over frontocentral regions (Auerbach et al., 2015), other studies have shown that the LPP is maximal over parietal-occipital midline electrodes (e.g., Kujawa, Klein, & Proudfit, 2013). In the current study, the late LPP was maximal over frontocentral regions 600–1200 ms poststimulus (see Figure 4A/B). Nonetheless, to better integrate with prior LPP research, we also probed the late LPP effect averaged across electrode sites Pz, P1, PO3, POz, PO4, and P2. The main effect for *Condition* was not significant, $F(1, 30) = 0.41$, $p = 0.53$, $\eta^2 = 0.53$.

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Word Endorsement—As hypothesized, a main effect of *Condition* emerged for words endorsed, $F(1, 30) = 429.35$, $p < 0.001$, $\eta^2 = 0.94$, whereby participants endorsed more positive than negative words as self-relevant. Neither the main effect of *Time,* $F(1, 30) = 0.44$, $p = 0.51$, $\eta^2 = 0.02$, nor the *Time* × *Condition* interaction, $F(1, 30) = 0.55$, $p = 0.47$, $\eta^2 = 0.02$, were significant. Additionally, test-retest correlational analyses revealed associations over time for positive ($r = 0.82$, $p < 0.001$) and negative ($r = 0.83$, $p < 0.001$) words endorsed (see Figure 1 A/B).

Reaction Time—All participants endorsed positive words. However, 12 adolescents did not endorse any negative words as being self-relevant, and thus, these individuals were excluded from the RMANOVA. A main effect of *Condition* emerged for reaction time, $F(1, 18) = 6.06$, $p = 0.02$, $\eta^2 = 0.25$, indicating that participants were overall faster to endorse positive words compared to negative words. There was no significant main effect for *Time,* $F(1, 18) = 0.15$, $p = 0.70$, $\eta^2 = 0.01$, or *Time* × *Condition* interaction, $F(1, 18) = 0.06$, $p = 0.80$, $\eta^2 = 0.003$. There was a significant test-retest correlation for RT to positive words ($r = 0.82$, $p < 0.001$), which included all participants. The test-retest correlation for negative words was not significant ($r = 0.18$, $p = 0.45$) and included only individuals who endorsed negative words as self-relevant ($n = 19$).

Free Recall—There was a main effect of *Condition* for words recalled, $F(1, 30) = 23.48$, $p < 0.001$, $\eta^2 = 0.44$, whereby participants recalled more positive than negative words across assessments. Perhaps not surprisingly, there was a significant main effect of *Time,* $F(1, 30) = 24.42$, $p < 0.001$, $\eta^2 = 0.45$. During the first administration, the recall task was unanticipated. However, it was likely expected during the follow-up assessment. Thus, participants recalled more positive and negative words at the follow-up assessment compared to the initial assessment. Nevertheless, the *Time* × *Condition* interaction was not significant, $F(1, 30) = 0.98$, $p = 0.33$, $\eta^2 = 0.03$. Analyses indicated significant test-retest correlations for positive ($r = 0.63$, $p < 0.001$) and negative ($r = 0.73$, $p < 0.001$) words recalled over time (see Figure 1 B/C).

Recognition—In the recognition portion of the task, there was a main effect of *Condition,* $F(1, 30) = 30.22$, $p < 0.001$, $\eta^2 = 0.50$, as more positive words than negative words were recognized. No main effect of *Time* emerged, $F(1, 30) = 0.15$, $p = 0.70$, $\eta^2 = 0.01$, and the *Time* × *Condition* interaction was not significant, $F(1, 30) = 0.001$, $p = 0.97$, $\eta^2 < 0.001$. Test-retest correlational analyses showed associations for positive ($r = 0.53$, $p = 0.002$) and negative ($r = 0.44$, $p = 0.01$) words recognized over time (see Figure 1 D/E).

Processing Bias—The main effect of *Condition* was significant, $F(1, 30) = 179.17$, $p < 0.001$, $\eta^2 = 0.86$, with adolescents showing a greater positive than negative processing bias. Similar to the free recall effects described earlier, there also was a main effect of *Time,* $F(1, 30) = 12.68$, $p = 0.001$, $\eta^2 = 0.30$. Interestingly, the *Time* × *Condition* interaction was significant, $F(1, 30) = 5.06$, $p = 0.03$, $\eta^2 = 0.14$, likely reflecting within-condition effects, as there was an increase in the positive ($p = 0.003$, $\eta^2 = 0.26$) but not the negative ($p = 0.35$, $\eta^2 = 0.03$) processing bias. Test-retest analyses revealed significant associations for the positive ($r = 0.62$, $p < 0.001$) and negative ($r = 0.57$, $p = 0.001$) processing bias over time.

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Event-Related Potentials

The previously reported ERP results from the initial assessment (Auerbach et al. 2015) were replicated in this larger sample. When examining the P1, the *Time* × *Condition* RMANOVA revealed a main effect of *Condition,* $F(1, 30) = 7.10$, $p = 0.01$, $\eta^2 = 0.19$, which indicated greater overall P1 positivity following positive words compared to negative words (Figure 2). The main effect of *Time,* $F(1, 30) = 0.003$, $p = 0.96$, $\eta^2 < 0.001$, and the *Time* × *Condition* interaction, $F(1, 30) = 0.42$, $p = 0.52$, $\eta^2 = 0.01$, were not significant. In line with our hypothesis, test-retest analyses demonstrated significant associations over time for P1 mean activity following positive ($r = 0.70$, $p < 0.001$) and negative ($r = 0.62$, $p < 0.001$) words (see Figure 3 A/B).

For the early LPP, the *Time* × *Condition* RMANOVA did not yield a main effect of *Condition*, however, there was a trend in the expected direction, $F(1, 30) = 2.92$, $p = 0.10$, $\eta^2 = 0.09$. The main effect for *Time,* $F(1, 30) = 0.06$, $p = 0.81$, $\eta^2 = 0.002$, and the *Time* × *Condition* interaction, $F(1, 30) = 0.02$, $p = 0.89$, $\eta^2 = 0.001$, were not significant. Test-retest analyses revealed associations over time for early LPP activity following positive ($r = 0.83$, $p < 0.001$) and negative ($r = 0.67$, $p < 0.001$) words (see Figure 3 C/D).

In line with our hypothesis, analysis of the late LPP revealed a main effect of *Condition,* $F(1, 30) = 30.68$, $p < 0.001$, $\eta^2 = 0.51$, whereby participants exhibited an enhanced late LPP positivity following positive words compared to negative words (Figure 4). Further, the main effect of *Time,* $F(1, 30) = 0.34$, $p = 0.56$, $\eta^2 = 0.01$, and the *Time* × *Condition* interaction, $F(1, 30) = 0.03$, $p = 0.86$, $\eta^2 = 0.001$, were not significant. The test-retest correlation for positive ($r = 0.59$, $p = 0.001$) and negative ($r = 0.56$, $p = 0.001$) words was significant (see Figure 3 E/F).

Internal Reliability and Correlational Analyses

To test the internal reliability of our ERP indices, we computed the odd-even trial correlations for each component at the baseline and follow-up assessment. For the P1, the odd-even trial correlations were strong (Time 1: $r = .68$, $p < .001$, Time 2: $r = .52$, $p = .003$). Similarly, the internal consistency for the early LPP (Time 1: $r = .80$, $p < .001$, Time 2: $r = .81$, $p < .001$) and late LPP (Time 1: $r = .55$, $p = .001$, Time 2: $r = .75$, $p < .001$) ERPs indicated large effects.

Correlations for baseline and follow-up SRET behavioral and ERP indices are summarized in Table 2. Interestingly, at both the initial and follow-up ERP assessment, greater late LPP positivity following positive words was associated with greater free recall of positive words and a higher positive processing bias score. Conversely, potentiated late LPP positivity in response to negative words was associated with greater recall of negative words across assessments. No other associations emerged between behavioral and ERP indices.

Discussion

Toward the goal of identifying clinically useful biobehavioral markers of depressotypic self-referential processing, the current study sought to test the behavioral and ERP stability of the SRET among healthy, female adolescents over a 3-month period. Extending our findings

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from our prior study (Auerbach et al., 2015) in a larger sample, healthy adolescents endorsed, recalled, and recognized more positive and fewer negative words, and this effect was stable over time. Similarly, healthy youth reported a faster RT when endorsing self-relevant positive words, as opposed to negative words, at both the initial and follow-up assessment. Second, ERP activity to positive and negative words was consistent over time. Namely, healthy youth exhibited potentiated P1 and late LPP positivity to positive versus negative words across assessments. Several findings warrant additional attention.

Similar to past research studying the stability of behavioral markers in children (Goldstein, Hayden, & Klein, 2015), behavioral indices (i.e., endorsement, RT, recall, and recognition, processing bias scores) among adolescents demonstrated stability over time with medium-to-large effect sizes. Additionally, although past research has probed whether ERP responses during the SRET differ among healthy and depressed individuals (Auerbach et al., 2015; Shestyuk & Deldin, 2010) and at-risk youth (Speed et al., in press), no research has tested the stability of the early and late ERP components elicited by the SRET. The current study showed medium-to-large effect sizes when examining the test-retest correlations for the P1, early LPP, and late LPP; namely, there was greater positivity following positive versus negative words across assessments. In addition to the stability of the ERP effects, correlational analyses revealed associations between the late LPP and free recall (as well as positive processing bias). These findings were not unexpected, as the late LPP reflects sustained engagement and encoding processes (Foti et al., 2009; Naumann, Bartussek, Diedrich, & Laufer, 1992). Overall, the stability of the behavioral markers and ERPs obtained during the SRET support its use in probing biobehavioral markers of psychopathology, particularly MDD.

It is important to note several limitations in the current study, which may be addressed in future research. First, to reduce the heterogeneity of our sample, the study included only female adolescents. Although there is no reason to believe that the findings would not extend to male adolescents, future research should address this issue. Additionally, the majority of our study sample was Caucasian, and consequently, research is warranted to test the generalizability of our findings to more diverse samples. Second, originally, the SRET has been used to probe negative self-schema in depressed populations (Derry & Kuiper, 1981; Goldstein et al., 2015). In the current study, healthy adolescents endorsed few negative words as being self-relevant. These low rates of endorsement precluded us from computing ERPs only in response to endorsed adjectives. Additionally, recognition and free recall effects may be influenced by age and intelligence. Third, the current study tested stability over a 3-month period; however, future research would benefit from testing longer periods, particularly as it may relate to stability across developmental periods (e.g., adolescence to adulthood). Fourth, the study was sufficiently powered to test the stability of behavioral and ERP markers. Nonetheless, the small sample size precluded the implementation of a principal component analysis of our ERP effects. Future research also would benefit from testing the stability of these indices in a depressed sample of adolescents. Fifth, the present study provided a necessary first step to test the stability and reliability of ERP and behavioral markers in healthy youth. Moving forward, it will be essential to determine whether these indicators are stable in clinical populations (e.g., depression) both in current and remitted states. Sixth, the inclusion of the same words at the initial and follow-up

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assessment may reduce the novelty of the words during the second ERP assessment. Last, no pubertal information was obtained from our participants, which may have important implications for understanding the development of self-referential processing biases. This issue should be considered in future research.

In summary, prior research has demonstrated differences in behavioral (Connolly, Abramson, & Alloy, 2015; Timbremont & Braet, 2004; Zupan, Hammen, & Jaenicke, 1987) and ERP (Auerbach et al., 2015) effects when using the SRET among healthy and depressed adolescents. The current findings also suggest that these effects remain stable over time in healthy adolescents. A question at large, however, is whether neurophysiological processes associated with depressotypic self-referential processing biases normalize in response to psychotherapeutic and pharmacological treatment. Addressing this critical issue may lead to key clinical insights with respect to designing more targeted treatment for youth with MDD.

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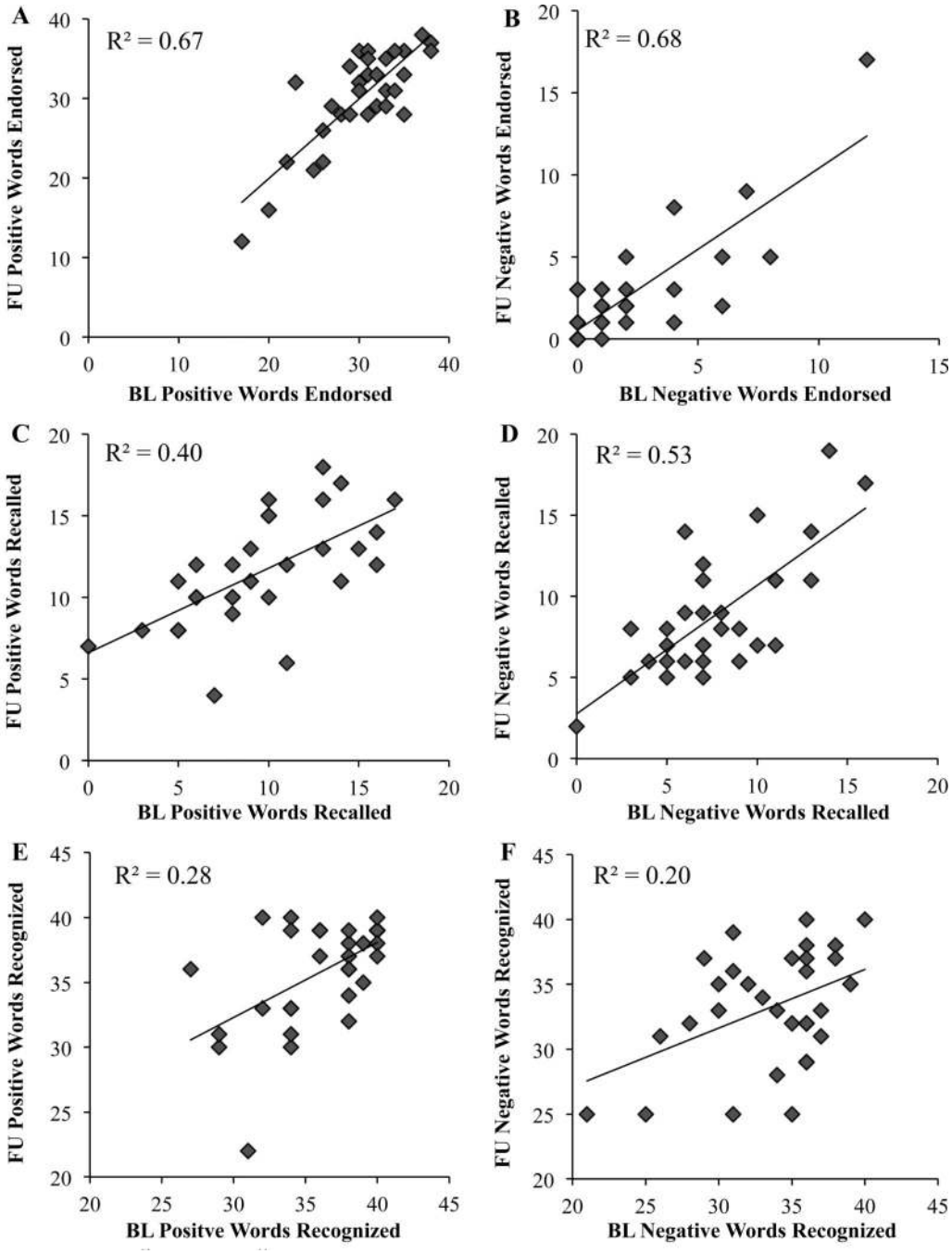

Figure 1.

Test-Retest for Behavioral Indices at the Baseline and Follow-Up Assessment

Note. BL = Baseline; FU = Follow-Up

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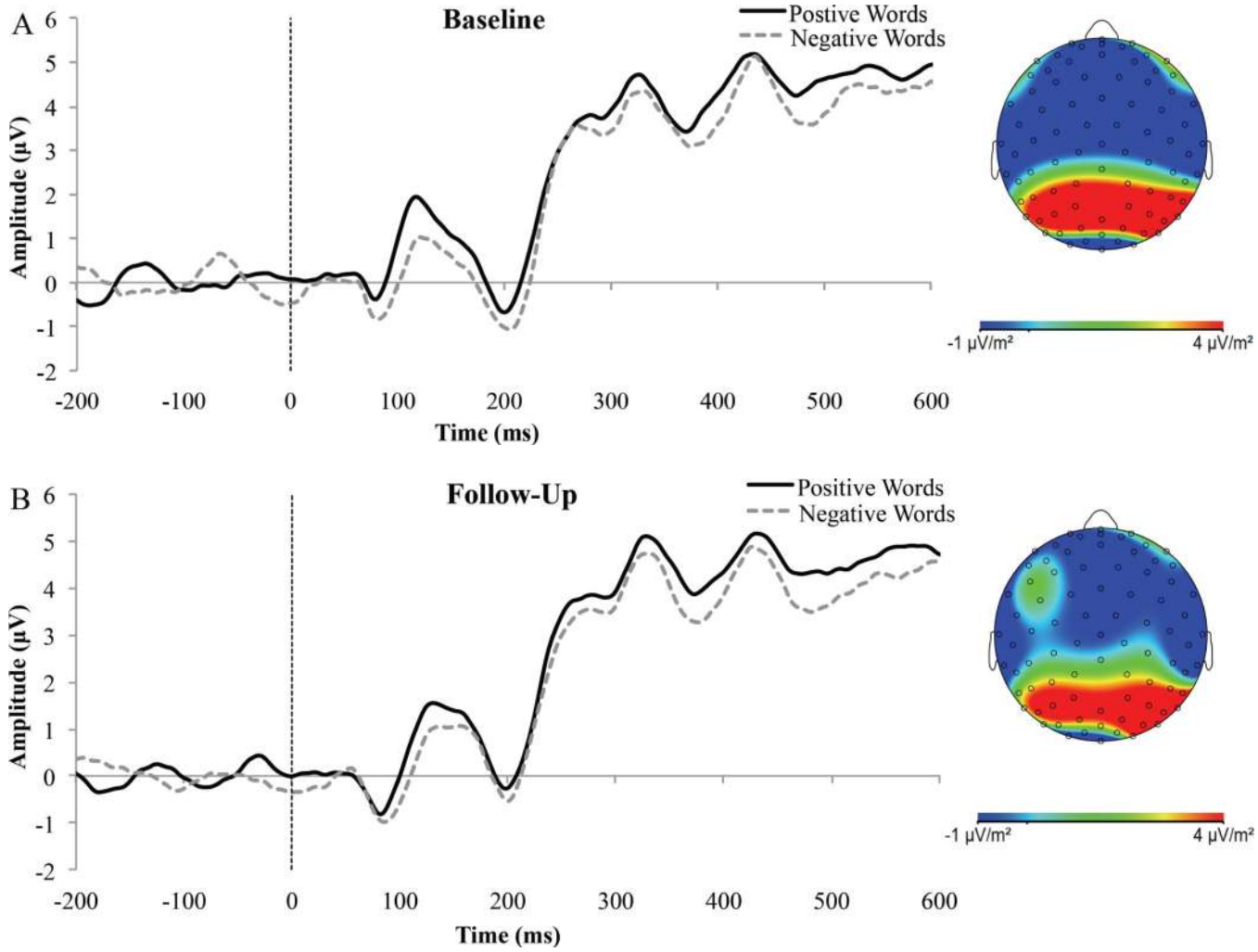

Figure 2.

P1 and Early LPP Responses at the Baseline and Follow-Up Assessment

Note. P1 (108–172 ms post-stimulus) and early LPP (400–600 ms post-stimulus) activity in response to positive and negative words averaged across P1, P2, Pz, POz, PO3, and PO4 for healthy, female adolescents ($n = 31$) during (A) the Initial and (B) Follow-Up Assessment; Scalp topographies reflect the average topography of positive and negative words 108–172 ms post-stimulus.

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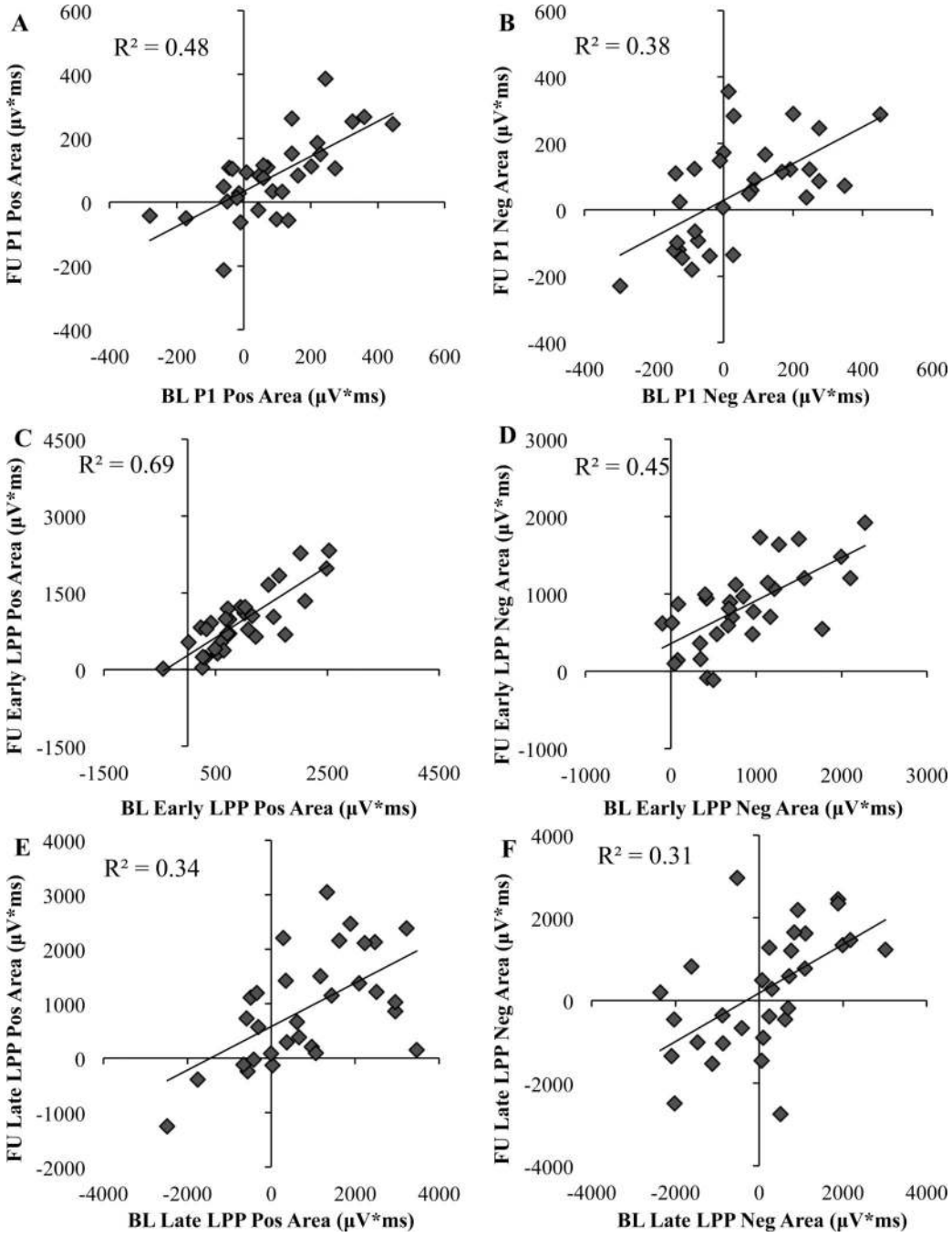

Figure 3.

Test-Retest for ERPs at the Baseline and Follow-Up Assessment

Note. BL = Baseline; FU = Follow-Up; Pos = Positive Words; Neg = Negative Words.

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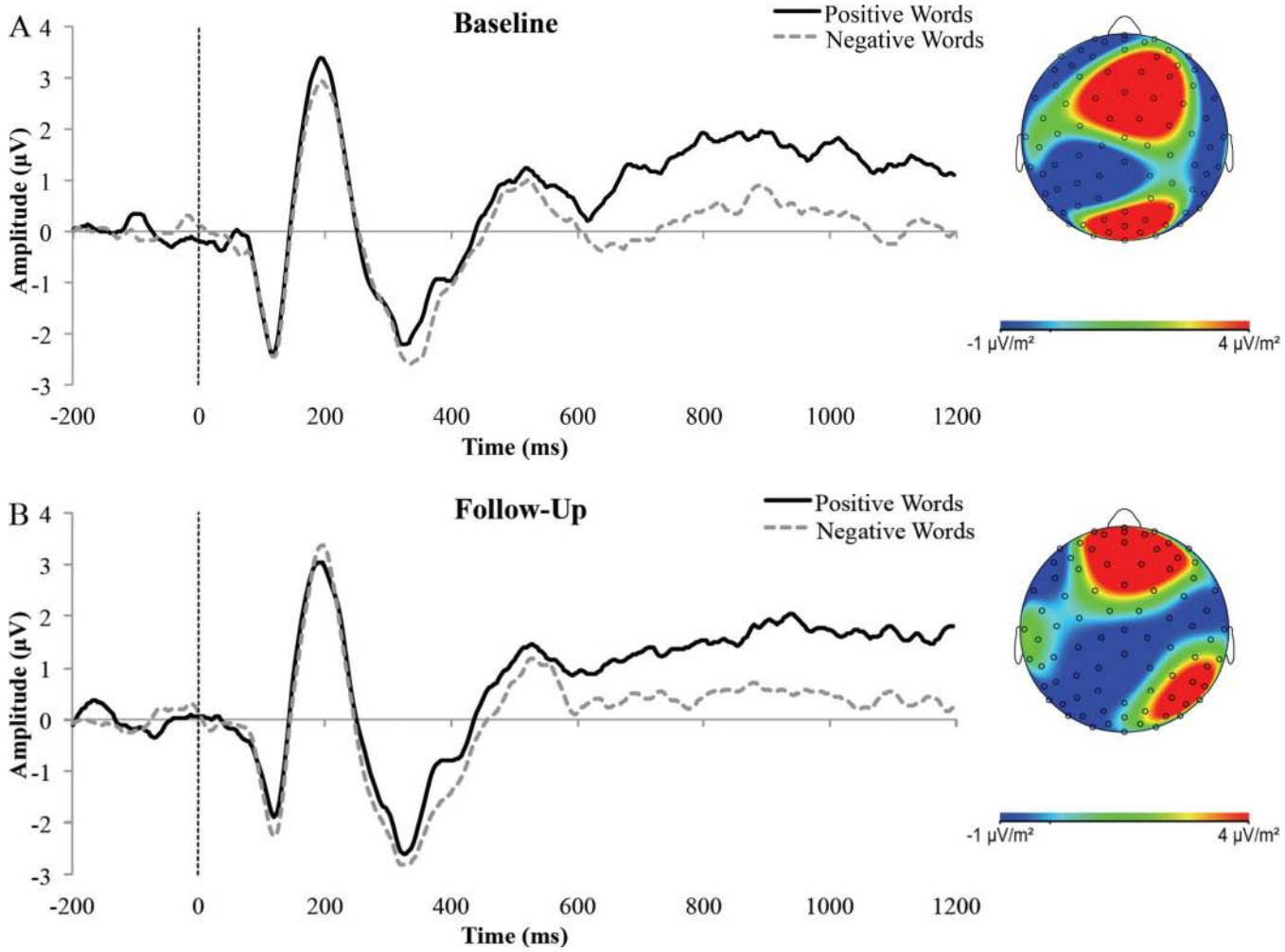

Figure 4.

Late LPP Responses at the Baseline and Follow-Up Assessment

Note. Late LPP (600–1200 ms post-stimulus) activity in response to positive and negative words averaged across Fz, FCz, and Cz for healthy, female adolescents ($n = 31$) during (A) the Initial and (B) Follow-Up Assessment; Scalp topographies reflect the difference between positive and negative words between 600–1200 ms post-stimulus.

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Table 1

Behavioral Data from the Self-Referential Encoding Task

	Initial (*n* = 31)		Follow-Up (*n* = 31)	
Task	**Mean**	**SD**	**Mean**	**SD**
Endorse				
Positive	30.16	5.09	30.10	6.22
Negative	2.19	2.92	2.71	3.48
Reaction Time (ms)				
Positive	518.64	212.01	482.03	221.03
Negative	1221.75	1315.41	1065.18	1930.94
Recall				
Positive	9.52	4.08	11.58	3.38
Negative	7.68	3.48	8.90	3.83
Recognition				
Positive	36.00	3.73	35.77	4.08
Negative	33.45	4.38	33.19	4.48
Processing				
Positive	0.22	0.09	0.27	0.08
Negative	0.03	0.04	0.03	0.04

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Table 2

A. Correlation Among Behavioral Indices and Event-Related Potentials at the Initial (Bottom Diagonal) and Follow-Up (Upper Diagonal) Assessment: Positive Words

	1.	2.	3.	4.	5.	6.	7.	8.
1. Endorse	-	−0.07	−0.10	0.04	0.13	0.11	−0.06	0.10
2. RT	0.22	-	−0.16	−0.45	−0.03	0.21	0.14	−0.19
3. Recall	−0.12	−0.47*	-	0.45*	0.77**	−0.17	−0.30	0.42*
4. Recognition	−0.29	−0.17	0.47**	-	0.33	−0.06	−0.33	0.10
5. Processing	0.12	−0.28	0.87**	0.30	-	−0.02	−0.29	0.46*
6. P1	−0.03	0.27	−0.12	−0.01	−0.19	-	0.09	0.27
7. Early LPP	0.11	−0.10	−0.26	−0.05	−0.12	0.43	-	−0.33
8. Late LPP	−0.08	−0.29	0.44*	0.26	0.42*	−0.15	−0.37*	-

B. Correlation Among Behavioral Indices and Event-Related Potentials at the Initial (Bottom Diagonal) and Follow-Up (Upper Diagonal) Assessment: Negative Words

	1.	2.	3.	4.	5.	6.	7.	8.
1. Endorse	-	−026	0.37*	0.30	0.83**	0.10	−021	0.20
2. RT	−031	-	0.26	0.07	−015	0.19	0.47*	−007
3. Recall	0.45**	−023	-	0.51**	0.55**	0.23	0.13	0.36*
4. Recognition	0.35	−010	0.51**	-	0.43*	−012	−007	0.33
5. Processing	0.95**	−036	0.55**	0.39*	-	−001	−013	0.17
6. P1	0.12	0.15	0.26	0.01	0.06	-	0.17	0.19
7. Early LPP	−027	0.39	−005	−005	−024	0.30	-	−025
8. Late LPP	0.04	−003	0.38*	0.15	0.02	−001	−010	-

Note.

*$p < 0.05$;

**$p < 0.01$;

Participants who did not endorse any negative words as self-relevant were excluded from RT correlations (Baseline excluded $n = 12$; Follow-up excluded $n = 12$).